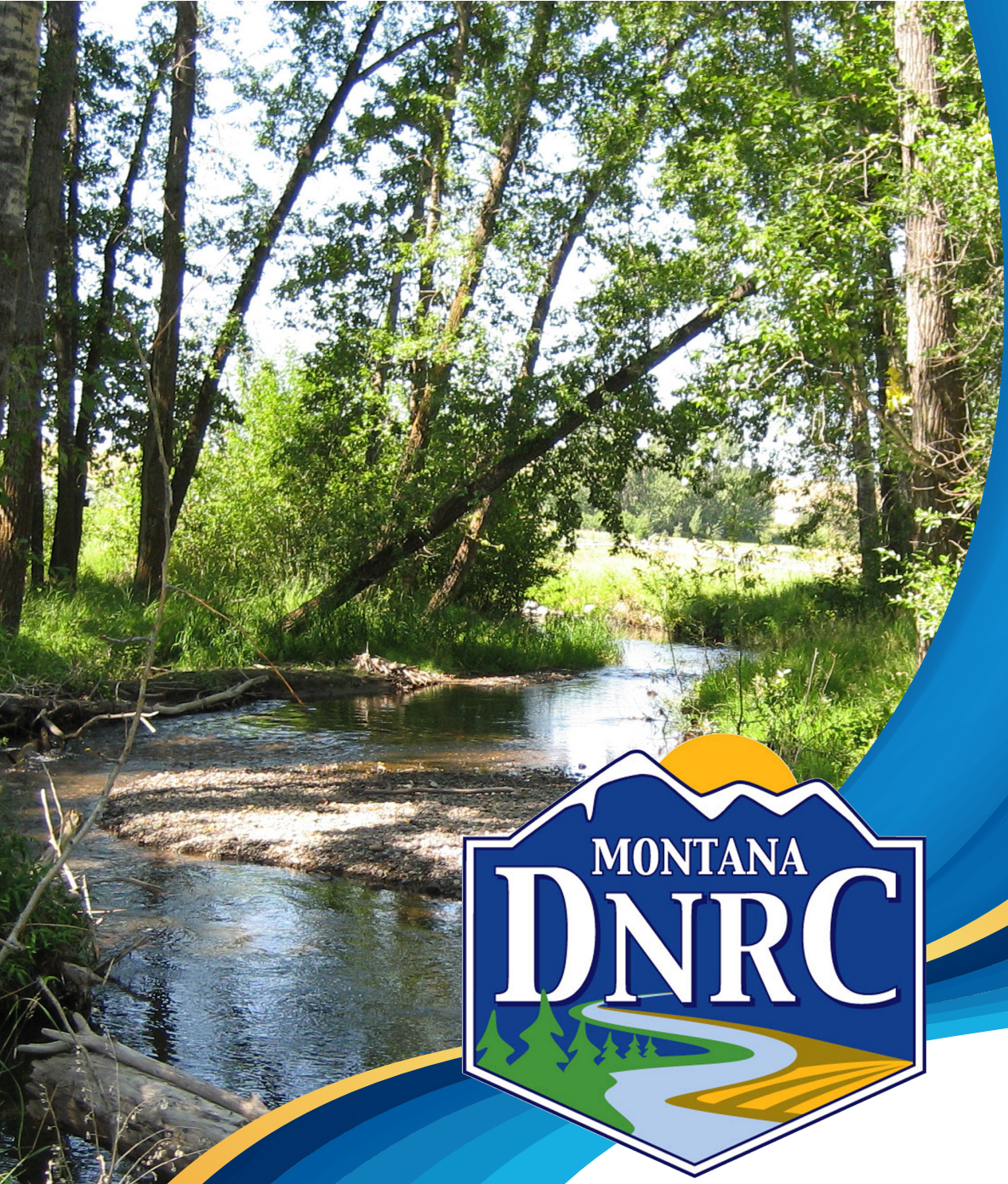

October 2015

BOZEMAN CREEK & TRIBUTARIES FLOODPLAIN STUDY PHASE 2

Hydraulic Analysis and Floodplain Mapping

Contract #: W0-MB-127
MIP Case Number: 13-08-0836S

Michael Baker INTERNATIONAL

FEMA

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Section 1: Introduction and Background

As a part of a Mapping Activity Statement (MAS) contract initiated by the Montana Department of Natural Resources and Conservation (DNRC), Michael Baker International has completed detailed hydraulic and floodplain mapping analyses of Bozeman Creek, its tributaries, and multiple flow splits in the City of Bozeman and Gallatin County. The purpose of this report is to document the hydraulic and floodplain mapping analyses and to provide results for incorporation into the Gallatin County, Montana, and Incorporated Areas Digital Flood Insurance Rate Map (DFIRM) and Flood Insurance Study (FIS) (Reference 1). The data in this report will supersede the information presented in the September 2, 2011, DFIRM and FIS at a later date. Appendix A includes the Certification of Compliance form that confirms the study has been completed using sound and accepted engineering practices and is in compliance with all contract documents.

A list of primary flooding sources included in this hydraulic study is provided in Table 1-1, and map showing these flooding sources is provided in Figure 1-1. It should be noted that these primary flooding sources are not the only flooding sources included in this study. Many flows split from these flooding sources to form secondary flooding sources. These split flows are detailed in Section 3.3 of this report. Also, the study reaches have generally not been extended from the stream lengths published on the effective FIRMs and FIS. The hydraulic analysis was completed using peak discharges for the 10-, 4-, 2-, 1-, and 0.2-percent-annual-chance (10-, 25-, 50-, 100-, and 500-year) flood events. The hydraulic work maps in Appendix B include the floodplain mapping for the 1- and 0.2-percent-annual-chance flood events along with the 0.5-foot floodway mapping where appropriate.

Table 1-1: Flooding Sources Studied

Flooding Source	Upstream Limit	Downstream Limit	Reach Length (Miles)
Bozeman Creek	Approximately 900 feet upstream of Nash Road	Confluence with East Gallatin River	8.9
Figgins Creek	Approximately 1,500 feet upstream of Alder Creek Road	Confluence with Mathew-Bird Creek	1.7
Flat Creek	Approximately 500 feet downstream of Mathew Bird Circle	At Hoffman Drive	1.0
Mathew-Bird Creek	Approximately 3,500 feet upstream of Goldenstein Lane	Confluence with Bozeman Creek	3.9
Mill Ditch Diversion	At diversion from Bozeman Creek	Confluence with East Gallatin River	1.7
Nash Spring Creek	Approximately 3,500 feet upstream of Goldenstein Lane	Confluence with Bozeman Creek	2.7

For this project, multiple contractors were involved in the delivery of the many components that comprise the Technical Support Data Notebook (TSDN). Allied Engineering Services, Inc. (Allied) completed the field surveying tasks for all flooding sources in the project area (Reference 2). The Allied tasks included the

collection of cross-section survey data and hydraulic structure data. The topographic data collection was provided by a joint venture between Photo Science, Inc. and Gaston Engineering & Surveying (Reference 3). Respec Consulting & Services (Respec) completed the hydrologic analyses for the 6 main basins in the Bozeman Creek watershed (HUC 12 100200080905) (References 4 to 9). The topographic, field survey, and hydrologic data were reviewed and approved by FEMA prior to the initiation of the hydraulic and floodplain mapping analyses. Detailed information regarding Allied, Photo Science, Inc., Gaston Engineering & Surveying, and Respec's contributions to the TSDN are included in the appropriate sections of this report.

1.1 Community Description

The City of Bozeman is the county seat of Gallatin County and is the largest community in the county. Gallatin County is located in south central Montana and is bordered by Broadwater, Jefferson, and Madison Counties to the west, Meagher County to the north, Park County, Montana to the east as well as Park and Teton Counties, Wyoming to the east and Fremont County, Idaho to the south. The southern portion of Gallatin County includes a portion of Yellowstone National Park.

Both the City of Bozeman and Gallatin County have experienced rapid population growth in recent years. Table 1-2 summarizes the Census population data (Reference 10).

Table 1-2: Census Population Estimates

Community	2000 Population	2010 Population	% Increase from 2000 to 2010	2014 Population	% Increase from 2010 to 2014
Bozeman	27,509	37,280	35.5%	41,660	11.7%
Gallatin County	67,831	89,513	32.0%	97,308	8.7%

Both communities have been forced to assess the issues that accompany expansive population growth. The Bozeman Creek and Tributaries restudy is timely in that it will define how increases in development have impacted surface water runoff and the flooding sources in the City of Bozeman and Gallatin County. The TSDN will serve as a starting point for community mitigation activities that might include funding capital improvement projects to help alleviate flooding issues or providing extensive public outreach to discuss the hazards of living and working near these streams.

Bozeman Creek

CITY OF BOZEMAN

GALLATIN COUNTY

Mill Ditch

Mathew Bird Creek

Figgins Creek

Flat Creek

Nash Spring Creek

Bozeman Creek

GALLATIN COUNTY

Mathew Bird Creek

Nash Spring Creek

GALLATIN COUNTY

Bozeman Creek

Legend

Main Reaches

- Bozeman Creek
- Figgins Creek
- Flat Creek
- Mathew Bird Creek
- Mill Ditch
- Nash Spring Creek

Figure 1-1: Flooding Source Locations

0 0.5 1 Miles

DATA FRAME PROPERTIES:
Coordinate System: NAD 1983 2011 StatePlane Montana FIPS 2500 Ft Int
Projection: Lambert Conformal Conic
Datum: NAD 1983 2011
Vertical Datum: NAVD 88
Units: Feet

Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100

MONTANA

Gallatin County

Most severe flooding events in the Bozeman Creek watershed (HUC 12 100200080905) have been produced either from high snowmelt, or rain on snow events. Notable flooding within this watershed has occurred numerous times, most recently in May 2011. In the May 25, 2011, edition of the Bozeman Daily Chronicle (Reference 11),multiple pictures show the extensive flooding that occurred along Bozeman Creek. During that flooding event, water spilled out of the banks of Bozeman Creek, finding alternative flowpaths in some locations. Many culverts and bridges, particularly in the downtown area, were overtopped and water flowed freely down roads and caused damage to numerous structures. Per information in a May 26, 2011, Bozeman Daily Chronicle article (Reference 12), Bozeman Creek overtopped Mendenhall Street and Kagy Boulevard causing multiple road and sidewalk closures. The floodwaters threatened numerous commercial buildings in the downtown areas as well.

1.2 Basin Descriptions

The basin descriptions for each of the main flooding sources were taken directly from the Respec Consulting & Services (Respec) Hydrology Reports (References 4 to 9) that were completed in early 2014. In general, the Bozeman Creek watershed (HUC 12 100200080905) encompasses all of the watersheds for the six main flooding sources. The Respec analyses formed the basis of this hydraulic and floodplain mapping investigation and the results are discussed further in Section 2 of this report.

1.2.1 Bozeman Creek

The Bozeman Creek watershed is located within the Bozeman Creek watershed (HUC 12 100200080905) and is a left bank tributary to the East Gallatin River immediately north of Bozeman, MT. Bozeman Creek flows in a northern direction from the Gallatin National Forest towards the City of Bozeman. Bozeman Creek watershed encompasses an area of 49.5 mi^2 with the upper extents located along the divide of the Gallatin Mountain Range. The topography of the watershed ranges from mild and steep mountain slopes in the upper reaches of the watershed to a low sloping valley. The watershed is largely comprised of forested areas in the upper reaches, with the valley floor largely composed of agricultural lands such as farms and grazing pastures before the stream flows through the urbanized City of Bozeman. The soil types found throughout the watershed are predominantly classified within hydrologic soil groups B and C. The Bozeman Creek channel travels from Mystic Lake to its mouth at an average slope of approximately 100 ft/mi (1.95%).

1.2.2 Mathew-Bird Creek

The Mathew-Bird Creek watershed is located within the Bozeman Creek watershed (HUC 12 100200080905). The entire Mathew-Bird watershed encompasses an area of 4.0 mi^2. Mathew-Bird Creek originates in the foothills of the Northern Gallatin Range and transitions to low sloping valley. At the downstream study limit, Mathew-Bird Creek joins Bozeman Creek. Upstream of the upstream study limit, irrigation practices and roads have altered the natural drainage patterns of the upper basin. Mathew-Bird Creek begins to show channel definition at the upstream study limit and flows in a northerly direction through cultivated fields outside the City of Bozeman corporate limits. As Mathew-Bird Creek transitions from an agricultural surrounding to a landscape dominated by residential development, overbank areas remain minimally developed and contain hearty riparian vegetation. Several small check structures exist along the

stream between the proximity of Sundance Drive and Graf Street. Just downstream of Kagy Boulevard, Figgins Creek enters Mathew-Bird Creek. Figgins Creek is a concurrent flood study. Downstream of Figgins Creek, the overbank areas are fully developed and a narrow band of riparian vegetation lines the stream corridor. The remainder of the reach appears altered, with limited overbank storage, and transitions between residential, light industrial, and open-space recreational areas.

1.2.3 Mill Ditch Diversion

The Mill Ditch Diversion watershed is located within the Bozeman Creek and East Gallatin watersheds (HUC 12 100200080904 and 100200080905) with Mill Ditch Diversion being a left bank tributary to the East Gallatin River. Mill Ditch Diversion flows in a northwest direction from its point of diversion with Bozeman Creek. Mill Ditch Diversion watershed encompasses an area of 0.81 mi^2. The topography of the watershed ranges from mild and steep hill slopes in the upper reaches of the watershed to low sloping wetlands. The watershed is largely comprised of undeveloped areas with pockets of development consisting of residential and commercial areas.

1.2.4 Figgins Creek

The Figgins Creek watershed is located within the Bozeman Creek watershed (HUC 12 100200080905) with Figgins Creek being a left bank tributary to Mathew-Bird Creek. Figgins Creek flows in a northern direction form the agricultural lands north of Goldenstein Lane towards the City of Bozeman. Figgins Creek watershed encompasses an area of 1.01 mi^2 with the upper extents located along Goldenstein Lane. The topography of the watershed is classified as a low sloping valley. The watershed is largely comprised of agricultural and developing residential areas with soils classified in hydrologic soil group C.

1.2.5 Flat Creek

The Flat Creek watershed is located within the Bozeman Creek watershed (HUC 12 100200080905). At the downstream study limit, Flat Creek enters a subsurface conduit inlet that travels approximately 1,700 feet before it discharges into Bozeman Creek. Flat Creek flows in a northern direction from its developed headwaters in the City of Bozeman, through Valley View Golf Course and through Kagy Boulevard. Downstream of Kagy Boulevard, Flat Creek flows through a residential area and enters the subsurface conduit inlet. Flat Creek encompasses an area of 0.09 mi2. Flat Creek is spring-fed system and the topography of the watershed is low sloping valley. The watershed is comprised of residential developments and a golf course.

1.2.6 Nash Spring Creek

The Nash Spring Creek watershed is located within the Bozeman Creek watershed (HUC 12 100200080905) with Nash Spring Creek being a left bank tributary to Bozeman Creek. Nash Spring Creek flows in a northern direction from its source spring located just south of Nash Road (approximately two miles upstream of the study limit). Nash Spring Creek encompasses an area of 4.3 mi^2 with the main tributary of Leverich Creek located within the Gallatin National Forest of the Gallatin Mountain Range. Upstream of the confluence with Leverich Creek noted by USGS Quadrangle Maps to be at Red Tail Ranch Road, Nash Spring Creek proper

has a drainage areas less than 0.2 mi^2 while Leverich Creek has an approximate drainage area of 3.6 mi^2. The topography of the watershed ranges from mild and steep mountain slopes in the upper reaches of the watershed to a low sloping valley. The watershed is largely comprised of forested areas in the upper reaches with a valley floor largely composed of residential developments mixed with agricultural lands such as farms and grazing pastures.

1.3 Previous Studies

The flooding sources listed in Table 1-1 were all studied as a part of the currently effective Federal Emergency Management Agency (FEMA) FIS. This DFIRM study was most recently issued as a countywide FIS on September 2, 2011. The eight FIRM panels that will eventually be updated with the information in this report are included in Appendix C. The approximate locations where changes will be made to the Special Flood Hazard Areas (SFHA) are highlighted on the FIRMs. The original hydrologic and hydraulic analysis for the FIS for these flooding sources was performed by the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) for FEMA in 1979. The NRCS analysis was expanded on for portions of Mathew-Bird Creek, Figgins Creek, and Nash Spring Creek in a study performed by Morrison Maierle, Inc. in 1985. The computer modeling program WSP-2 was used for the original model and HEC-2 was used for the 1985 update. The natural and man-made changes that have occurred in the floodplain since 1979 (or 1985) are significant due to the population increases the Bozeman and Gallatin Counties have experienced since 1979 and 1985. Table 1-3 summarizes the Manning's 'n' values, boundary conditions, and number of structures included in the effective hydraulic models for the six main flooding sources. This information provides a baseline so users of this report can compare differences between the effective hydraulic models and the updated hydraulic models.

A section of Bozeman Creek was hydraulically restudied in 2012. This section stretches from Story Street to downstream of Peach Street in the downtown area. The hydraulic analysis was completed by Allied using the computer modeling program HEC-RAS. Surveyed bridges, culverts, and cross sections were taken from the Allied data for incorporation into this hydraulic analysis. The results of the Allied study have not been formally included in the FIRMs and FIS to date and information from that study have been incorporated in this restudy.

Table 1-3: Effective Hydraulic Modeling Information

Flooding Source	Roughness Values		Boundary Conditions	Number of Structures
	Channel	Overbanks		
Bozeman Creek	0.035-0.065	0.045-0.150	East Gallatin River starting water surface elevation	25
Flat Creek	0.028-0.070	0.045-0.300	Mathew-Bird Creek starting water surface elevation*	0
Figgins Creek	0.028-0.070	0.045-0.300	Mathew-Bird Creek starting water surface elevation	8
Mathew-Bird Creek	0.028-0.070	0.045-0.300	Bozeman Creek starting water surface elevation	9
Mill Ditch Diversion	0.028-0.070	0.045-0.300	Bozeman Creek starting water surface elevation	15
Nash Spring Creek	0.028-0.070	0.045-0.300	Bozeman Creek starting water surface elevation	3

*Headlosses through the downstream section were also considered.

Section 2: Hydrologic Analysis

Revised hydrologic analyses for the primary flooding sources in the Bozeman Creek watershed were completed by Respec from January 2014 to April 2014 in order to establish discharges for the 10-, 4-, 2-, 1, and 0.2-percent-annual-chance flood events for use in the hydraulic analysis (References 4 to 9). Each analysis included of several different regression equations, a rainfall runoff model, and the effective discharge rates, as well as a recommendation for the discharges that should be used in the hydraulic model. The watershed workmaps from the hydrology reports are included in Appendix D.

A summary of discharges from the hydrologic reports is presented in Table 2-1. Due to diversions and splits, these discharges are not the final discharges used in the hydraulic model at many locations.

Table 2-1: Discharges Recommended from Hydrologic Analyses

Flooding Source and Location	Peak Discharges (cfs)				
	10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
Bozeman Creek at Nash Road	377	525	647	777	1,120
Bozeman Creek at Goldenstein Road	388	540	666	800	1,150
Bozeman Creek at Private Drive Downstream of Gardner Park Drive	453	632	773	936	1,350
Bozeman Creek upstream of Nash Spring Creek	458	639	788	947	1,370
Bozeman Creek upstream of Mathew-Bird Creek	502	701	865	1,040	1,500

Flooding Source and Location	Peak Discharges (cfs)				
	10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
Bozeman Creek at Olive Street	541	757	935	1,130	1,630
Bozeman Creek at Peach Street	548	768	949	1,140	1,650
Bozeman Creek at mouth	555	777	961	1,160	1,680
Figgins Creek upstream of Cambridge Drive	10	19	27	34	52
Figgins Creek through Alder Creek Drive	15	27	38	48	75
Figgins Creek through Brookdale Drive	23	42	58	72	110
Figgins Creek at Railroad (Formerly CMSP&P)	40	68	94	115	174
Figgins Creek upstream of 3rd Ave	53	89	120	148	226
Figgins Creek through 3rd Ave	86	142	189	229	346
Figgins Creek through Kagy Boulevard	91	149	198	240	360
Figgins Creek at mouth	93	153	203	246	367
Flat Creek at Hoffman Drive	11	17	22	26	38
Mathew-Bird Creek upstream of Goldenstein Lane	19	34	47	58	88
Mathew-Bird Creek through Goldenstein Lane	56	122	186	242	404
Mathew-Bird Creek Near Sundance Drive	62	133	200	260	428
Mathew-Bird Creek Through Graf Street	71	150	224	290	473
Mathew-Bird Creek upstream of Figgins Creek	77	158	234	303	490
Mathew-Bird Creek upstream of Garfield Street	165	282	369	444	737
Mathew-Bird Creek at mouth	183	312	408	486	769
Mill Ditch Diversion at Main Street	35	61	84	105	158
Mill Ditch Diversion upstream of Northern Pacific Railroad	57	97	132	163	240
Mill Ditch Diversion at Northern Pacific Railroad	77	128	171	209	306
Mill Ditch Diversion at Interstate 90	87	146	197	241	355
Mill Ditch Diversion at Confluence with East Gallatin River	92	155	209	256	377
Nash Spring Creek at Goldenstein Lane	62	104	153	207	420

Flooding Source and Location	Peak Discharges (cfs)				
	10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
Nash Spring Creek at Fox Hollow Road	73	122	167	225	457
Nash Spring Creek at Confluence with Bozeman Creek	76	129	173	234	475

Due to the many flow splits, the recommended peak discharges from the hydrologic analyses do not provide a complete representation of the flow changes throughout the watershed. Table 2-2 is a comprehensive summary of the flow changes for each mapped flooding source, as they were determined and applied in the hydraulic model. The table includes the cross section in the hydraulic model where each flow change was applied. Flow diagram maps were created to visually show the flow change locations since the system is very complex and many flooding sources are involved in the hydraulic analyses. For more information on split flows and how they impact peak discharges, see Section 3.3. The flow diagram maps are included in Appendix E.

Table 2-2: Discharges used in Hydraulic Analyses

Flooding Source	Hydraulic Cross Section	Physical Location	Peak Discharges				
			10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
3rd/Kagy Split	1324	At divergence from Figgins Creek	40.37	89.31	122.34	143.96	196.33
Black Avenue Split	2972	At divergence from Flat Creek	14.28	16.68	18.75	25.81	34.99
Bozeman Creek	47979	Upstream limit of detailed study - approximately 900 feet upstream of Nash Road	377	525	647	777	1120
Bozeman Creek	47519	Approximately 400 feet upstream of Nash Road	375.04	516.78	628.43	737.12	995.1
Bozeman Creek	47091	At Nash Road	373.73	468.41	516.84	553.25	604.99
Bozeman Creek	45459	At confluence with Nash Road Split	377	525	647	777	1120
Bozeman Creek	32217	Approximately 500 feet upstream of Goldenstein Lane	377	523.3	625.33	719.59	953.49
Bozeman Creek	31772	At Goldenstein Lane	388	538.3	644.33	742.57	972.17
Bozeman Creek	28687	Approximately 3,000 feet downstream of Goldenstein Lane	453	630.3	751.33	878.57	1172.26
Bozeman Creek	27305	Approximately 3,400 feet downstream of Goldenstein Lane	338.25	422.03	478.14	537.5	678.34
Bozeman Creek	27296	Downstream of divergence of Sourdough Trail Split	338	420.04	474.66	532.23	668.37
Bozeman Creek	20786	Just upstream of confluence with Nash Spring Creek	343	427.04	489.66	543.23	688.37

Flooding Source	Hydraulic Cross Section	Physical Location	Peak Discharges				
			10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
Bozeman Creek	20724	Just downstream of confluence with Nash Spring Creek	387	489.04	566.66	636.23	818.37
Bozeman Creek	18559	Just downstream of confluence with Kagy/Rouse Split	387	497.16	591.62	681.51	968.95
Bozeman Creek	13969	Just downstream of confluence with Rouse Avenue Split	541	757	935	1130	1630
Bozeman Creek	12135	Just downstream of Gallagator Split	530.79	725.82	883.79	1051.94	1485.06
Bozeman Creek	11927	Approximately 100 feet upstream of Mill Ditch Diversion Structure	530.79	723.7	877.49	1038.75	1446.78
Bozeman Creek	11829	At Mill Ditch Diversion Structure	511.63	684.99	836.69	1007.24	1410.99
Bozeman Creek	11561	Approximately 150 feet upstream of Story Street	511.63	684.99	836.69	1007.24	1475.4
Bozeman Creek	10202	At Olive Street	449.5	550.5	685.37	838.68	1272.83
Bozeman Creek	8948	At Mendenhall Street	454.33	561.89	698.43	853.43	1290.98
Bozeman Creek	8566	At Lamme Street	458.43	569.83	706.89	862.95	1301.9
Bozeman Creek	6765	Downstream of confluence with Church Avenue Split	475.69	616.39	760.83	923.8	1377.64
Bozeman Creek	5858	At Aspen Street	482.69	627.39	774.83	943.8	1397.64
Bozeman Creek	4795	Downstream of confluence with Wallace Avenue Split	518.63	695.99	850.69	1027.24	1495.4
Bozeman Creek	3817	At I-90	525.63	704.99	862.69	1047.24	1525.4
Cedar Street Split	1312	At divergence from Mill Ditch Diversion	18.79	52.21	69.26	87.94	136.89
Church Avenue Split	3601	At divergence from Bozeman Creek	62.23	134.59	151.42	168.65	202.67
Church Avenue Split	2436	At Main Street	47.78	105.9	119.42	133.33	160.77
Church Avenue Split	2069	At Mendenhall Street	35.82	81.69	92.19	103.06	124.56
Church Avenue Split	1689	At Lamme Street	27.08	65.34	74.79	83.52	102.19
Church Avenue Split	1306	At Davis Street	23.45	56.77	65.09	72.8	89.26
Church Avenue Split	865	At Fridley Street	17.35	46.66	54.04	60.95	75.86
Figgins Creek	9071	Upstream limit of study - approximately 1,500 feet upstream of Alder Creek Road	10	19	27	34	52
Figgins Creek	7747	Approximately 200 feet upstream of Alder Creek Drive	15	27	38	48	75
Figgins Creek	6766	At Brookdale Drive	23	42	58	72	110

Flooding Source	Hydraulic Cross Section	Physical Location	Peak Discharges				
			10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
Figgins Creek	5882	Approximately 800 feet downstream of Brookdale Drive	40	68	94	115	174
Figgins Creek	4026	Downstream of divergence of Museum Split	34.62	49.06	58.57	64.51	76.69
Figgins Creek	3970	Approximately 600 feet upstream of Overbrook Drive	47.62	70.06	84.57	97.51	128.69
Figgins Creek	2711	Approximately 300 feet downstream of Overbrook Drive	80.62	123.06	153.57	178.51	248.69
Figgins Creek	2198	Downstream of confluence with Museum Split	86	142	189	229	346
Figgins Creek	1862	At 3rd Avenue	45.73	52.79	66.76	85.14	149.77
Figgins Creek	1431	Approximately 400 feet downstream of 3rd Avenue	50.73	59.79	75.76	96.14	163.77
Figgins Creek	514	Downstream of Kagy Boulevard	91	149	198	240	360
Figgins Creek	414	Approximately 300 feet downstream of Kagy Boulevard	50.52	84.36	108.21	148.59	234.91
Figgins Creek	322	Approximately 400 feet downstream of Kagy Boulevard	49.22	76.47	91.96	123.95	187.07
Figgins Creek	280	Approximately 450 feet downstream of Kagy Boulevard	38.94	58.45	66.21	93.48	141.9
Flat Creek	5566	Upstream limit of study - approximately 500 feet downstream of Mathew Bird Circle	11	17	22	26	38
Flat Creek	1808	Downstream of confluence with Golf Course Split	90.63	175.75	248.35	335.7	514.5
Flat Creek	1702	Approximately 300 feet upstream of Kagy Boulevard	90.34	168.14	232.43	308.06	419.69
Flat Creek	1592	Just upstream of Kagy Boulevard	67.42	74.22	81.61	111.88	133.38
Flat Creek	1344	Approximately 100 feet downstream of Kagy Boulevard	59.89	65.74	71.77	90.2	106.45
Flat Creek	1319	Approximately 120 feet downstream of Kagy Boulevard	57.15	62.51	68.08	82.33	96.94
Flat Creek	1191	Downstream of Black Avenue	28.59	29.16	30.59	30.72	32.5
Flat/Kagy Split	697	At divergence from Flat Creek	23.31	101.63	166.83	223.93	361.58

Flooding Source	Hydraulic Cross Section	Physical Location	Peak Discharges				
			10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
Gallagator Split	279	At divergence from Bozeman Creek	10.31	31.28	51.31	78.16	145.19
Garfield Street Split	1459	At divergence from Mathew Bird Creek	15.34	121.32	204.82	277.07	564.68
Garfield Street Split	1371	Just upstream of Black Avenue	14.41	113.07	190.48	257.05	518.34
Garfield Street Split	1212	Just downstream of Black Avenue	10.36	96.3	162.55	218.18	437.9
Golf Course Split	1654	At divergence from Nash Spring Creek	33.94	81.47	135.04	173.66	266.42
Golf Course Split	1419		37.24	94.84	162.37	224.23	369.38
Golf Course Split	1266		37.24	94.99	163.3	229.88	408.77
Golf Course Split	1084		90.53	179.4	262.66	357.3	597.69
Golf Course Split	755		90.63	183.87	273.31	381.08	669.02
Golf Course Split	482		90.63	183.87	273.31	379.81	610.35
Golf Course Split	356		90.63	175.75	248.35	335.7	514.2
I-90 Split	3806	At divergence from Mill Ditch Diversion	0.1	32.87	71	113.14	219.77
Kagy/Rouse Split	1066	At divergence from Golf Course Split	0.1	8.22	25.06	45.47	154.92
Kagy/Rouse Split	556	Approximately 500 feet downstream of Kagy Boulevard	0.1	8.22	25.06	45.38	150.67
Lower Black Split	1266	At divergence from Garfield Street Split	4.15	16.87	28.03	38.97	80.54
Lower Black Split	867		4.15	16.54	24.94	38.97	44.36
Lower Black Split	709		4.15	16.54	24.94	38.97	44.36
Lower Black Split	622		3.43	6.86	8.46	13.12	23.29
Lower Black Split	541		3.46	8.14	10.58	10.58	29.54
Mathew Bird Creek	20778	Upstream limit of study - approximately 3,500 feet upstream of Goldenstein Lane	19	34	47	58	88
Mathew Bird Creek	17343	Just upstream of Goldenstein Lane	56	122	186	242	404
Mathew Bird Creek	15773	Just upstream of Peace Pipe Lane	56	122	186	242	338.45
Mathew Bird Creek	15481	Approximately 300 feet downstream of Peace Pipe Lane	56	110.58	144.57	170.55	213.73
Mathew Bird Creek	15247		56	98.82	116.27	129.51	150.15
Mathew Bird Creek	14801		55.28	88.62	99.83	108.24	120.27
Mathew Bird Creek	14706		55.28	88.62	99.72	107.97	119.6

Flooding Source	Hydraulic Cross Section	Physical Location	Peak Discharges				
			10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
Mathew Bird Creek	14294	Approximately 1,400 feet downstream of Peace Pipe Lane	61.28	99.62	113.72	125.97	143.6
Mathew Bird Creek	14073	At confluence with Rain Roper Split	62	133	200	260	428
Mathew Bird Creek	11096	Approximately 450 feet upstream of Graf Street	71	150	224	290	473
Mathew Bird Creek	10510	Approximately 100 feet downstream of Graf Street	77	158	234	303	490
Mathew Bird Creek	5117	Just upstream of Hoffman Drive	165	282	369	444	737
Mathew Bird Creek	2262	At Garfield Street	150.59	168.93	178.52	186.95	218.66
Mathew Bird Creek	1843	Approximately 500 feet downstream of Garfield Street	168.59	198.93	217.52	228.95	250.66
Mathew Bird Creek	1754		169.29	207.66	233.91	257.34	301.65
Mill Ditch Diversion	9226	At divergence from Bozeman Creek	19.26	40.93	44.8	44.8	74.17
Mill Ditch Diversion	8938	At confluence with Gallagator Split	29.47	72.11	98.41	122.86	219.26
Mill Ditch Diversion	8745		29.47	72.11	98.41	122.86	154.85
Mill Ditch Diversion	5973	Just upstream of Main Street	35	72.11	98.41	122.86	158
Mill Ditch Diversion	4536	Approximately 1,400 feet downstream of Main Street	57	97	132	163	240
Mill Ditch Diversion	3576		57	97	132	161.35	183.82
Mill Ditch Diversion	3534		57	97	132	161.35	176.25
Mill Ditch Diversion	3018	Just upstream of Railroad Crossing	77	136	171	207.35	242.25
Mill Ditch Diversion	2322	Approximately 650 feet downstream of Railroad Crossing	87	154	197	239.35	291.25
Mill Ditch Diversion	1611	Just downstream of confluence with Mill/Railroad Split	87	154	197	241	355
Mill Ditch Diversion	1404	Just upstream of Cedar Street	68.31	101.89	127.84	153.16	218.21
Mill Ditch Diversion	282	Just downstream of confluence with Cedar Street Split	87	154	197	241	355
Mill Ditch Diversion	266	Just upstream of I-90	87.1	121.23	126.1	127.96	135.33
Mill Ditch Diversion	79	Just downstream of I-90	92.1	130.23	138.1	142.96	157.33
Mill Railroad Split	815	At divergence from Mill Ditch Diversion	0.1	0.1	0.1	1.75	63.86
Museum Split	1561	At divergence from Flat Creek	5.48	19.04	35.53	50.59	97.41
Nash Road Split	2373	At divergence from Bozeman Creek	3.37	56.69	130.26	223.85	515.11

Flooding Source	Hydraulic Cross Section	Physical Location	Peak Discharges				
			10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
Nash Spring Creek	14160	Upstream limit of study - approximately 3,500 feet upstream of Goldenstein Lane	62	104	153	207	420
Nash Spring Creek	10574	At Goldenstein Lane	62	104	153	207	420
Nash Spring Creek	10392	Approximately 150 feet downstream of Goldenstein Lane	73	122	167	225	457
Nash Spring Creek	4609	Downstream of confluence with Sourdough Trail Split	157.26	270.6	372.67	493.17	795.38
Nash Spring Creek	4176	Approximately 300 feet downstream of confluence with Sourdough Trail Split	159	273.96	375.34	496.75	800.31
Nash Spring Creek	1436	At divergence of Golf Course Split	156.26	253.54	335.48	440.8	709.55
Nash Spring Creek	1283		125.16	192.58	240.4	323.19	533.99
Nash Spring Creek	1157		125.16	188.41	229.47	300.45	482.74
Nash Spring Creek	1064		121.86	179.21	213.07	272.62	431.03
Nash Spring Creek	994		121.86	179.21	213.02	270.75	420.19
Nash Spring Creek	896		121.86	179.07	212.14	266.97	391.64
Nash Spring Creek	752		96.86	135.21	159.02	196.07	281.61
Nash Spring Creek	669		68.58	94.66	112.78	139.55	202.72
Nash Spring Creek	515		68.58	94.11	110.12	131.77	176.25
Nash Spring Creek	458		68.47	90.18	102.13	115.78	131.39
Peace Pipe Split	2877	At divergence from Mathew Bird Creek	0.1	0.1	0.1	0.1	65.65
Rain Roper Split	1180	At divergence from Mathew Bird Creek	0.1	11.52	41.53	71.55	124.82
Rain Roper Split	1023		0.1	20.63	63.31	102.84	172.69
Rain Roper Split	792		0.82	33.43	85.92	133.07	216.17
Rain Roper Split	525		0.82	33.48	86.27	133.84	217.9
Rain Roper Split	379		0.82	33.48	86.38	134.13	218.95
Rouse Avenue Split	4769	At divergence from Flat Creek	14.28	16.68	18.75	25.81	38.74
Rouse Avenue Split	4727		24.55	28.39	32.28	55.36	74.44
Rouse Avenue Split	3380	Below confluence with Flat Creek	53.14	57.55	62.87	86.08	106.94
Rouse Avenue Split	751	Below confluence with Garfield Street Split	53.14	104.44	174.19	228.76	467.44
Sourdough Trail Split	1765	At divergence from Bozeman Creek	115.1	210.36	276.77	346.44	503.9
Tracy Avenue Split	840	At divergence from Figgins Creek	54.16	94.65	136.89	152.62	225.2
Wallace Avenue Split	4826	At divergence from Church Avenue Split	14.55	28.8	32.1	35.43	42

Flooding Source	Hydraulic Cross Section	Physical Location	Peak Discharges				
			10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
Wallace Avenue Split	3982	At Mendenhall Street	21.68	41.6	46.28	50.95	60.05
Wallace Avenue Split	3607	At Lamme Street	26.32	50.02	55.22	60.96	71.5
Wallace Avenue Split	3238	At Davis Street	29.94	58.59	64.92	71.68	84.44
Wallace Avenue Split	2786	At Fridley Street	36.04	68.7	75.96	83.54	97.86

Section 3: Hydraulic Analysis

3.1 Methodology and Hydraulic Model Setup

Hydraulic modeling was performed using HEC-RAS version 4.1.0 (Reference 13). Cross Sections were cut and terrain data was transferred from GIS using HEC-GeoRAS version 10 (Reference 14). All culverts, bridges, and inline structures were modeled in accordance with the HEC-RAS User's Manual, Version 4.1 (Reference 15). In addition, standards listed in FEMA's Knowledge Sharing Site (KSS) (Reference 16) were followed to ensure the study meets industry standards.

Four model plans were set up for various purposes. The plan titled "Bozeman Flow Calculations" uses discharges from the hydrologic analyses for the primary flooding sources, and optimized lateral weirs to determine the magnitude of each split flow. Section 3.3 of this report contains detailed information on flow split calculations. The plan titled "Bozeman Regulatory" takes discharges from these flow calculations and runs the model (without weirs). The results from this model should be used for regulatory purposes, as well as for determination of water surface elevations for the 10-, 4-, 2-, 1, and 0.2-percent-annual-chance flood events. The third plan is titled "Bozeman Floodway" – floodway encroachment locations and surcharge calculations are contained in this model plan. The final plan is titled "Bozeman Administrative FW Calculations" and is used for calculating and determining the extents of the Administrative Floodways. Detailed information on floodway modeling can be found in Section 3.13 of this report. Appendix B contains the Hydraulic Work Maps.

3.2 Field Survey and Topographic Information

Field survey and topographic information was collected using the methods and procedures outlined in Appendix A (Aerial Mapping and Surveying) of FEMA's Guidelines and Specifications (Reference 17). Since the time the field survey was originally collected, Appendix A has been superseded by FEMA's KSS.

3.2.1 LiDAR Collection

Terrain data was collected on April 18, 2013, for the entire study footprint area in the form of Light Detection and Ranging (LiDAR) points by Photo Science, Inc. (Reference 3). The data was calibrated and checked by Gaston Engineering. The LiDAR deliverables included digital elevation models (DEM) (1-meter resolution),

1-foot contours, and a report documentation among other items. The data exists in the following projection and datum:

		Units
Projection:	Montana State Plane	
Datum:	Horizontal – MT 2500 St Pl NAD83 (2011)	International Feet
	Vertical – NAVD88, Geoid 12A	International Feet

The LiDAR DEM (1-meter resolution) was the primary topographic source for the project and was used to develop the HEC-RAS cross-sections.

3.2.2 Field Survey Collection

Bathymetric data collection was necessary to supplement the LiDAR data since the streams are detailed study reaches which require a higher level of data inputs to achieve better modeling results. Also, detailed hydraulic analyses also require that all structures be included in the modeling unless it can be shown that the structure is not hydraulically significant to the model results. Therefore, field survey was collected.

Ground survey was collected for select riverine cross sections and all hydraulic structures between October 2012 and January 2013 by Allied (Reference 4). Channel cross-sections were taken at approximate maximum 1,000 foot intervals. In total, 500 cross sections and 219 structures were surveyed. Table 3-1 lists the number of cross-sections and structures surveys that were completed for each main study reach. The field survey data was assembled using the following projection and datum:

		Units
Projection:	Montana State Plane	
Datum:	Horizontal – MT 2500 St Pl NAD83 (2011), Epoch 2010	International Feet
	Vertical – NAVD88, Geoid12	US survey feet

Table 3-1: Field Survey Collection Summary

Flooding Source	Number of Hydraulic Structures	Number of Cross Sections
Bozeman Creek	47	138
Flat Creek	22	43
Figgins Creek	25	48
Mathew-Bird Creek	77	154
Mill Ditch Diversion	20	54
Nash Spring Creek	28	63

In addition, photographs of each hydraulic structure were taken to assist with the creation of the hydraulic model cross-section geometries. These photographs are included in Appendix F of this report.

All surveyed hydraulic cross sections and structures were incorporated into the hydraulic model.

3.3 Split Flow Analysis

Due to the limited capacity of the primary flooding sources, there are numerous split flows that leave main channels and become flooding sources unto themselves. Some splits only leave during extreme flood events, but others can be expected with some regularity. Each flow where a significant amount of flow (more than 10 cfs) would leave the main channel was modeled. (Flow may split in other locations, but will likely be either low discharge or less than 0.5 feet deep). Table 3-2 lists each of these flow splits and gives information on how each is expected to form.

Table 3-2: Split Flow Descriptions

Split Flow Name	Splits from	Description	Stream Length (miles)
3rd/Kagy Split	Figgins Creek	Splits from Figgins Creek upstream of the 3rd Avenue Culvert. Heads north along 3rd Avenue, bends east on Kagy Boulevard, and rejoins Figgins Creek	0.2
Black Avenue Split	Flat Creek	Some flow along Flat Creek overtopping the road at Black Avenue splits and continues along Black Avenue. Flow heads northeast and north before joining Garfield Street Split	0.6
Cedar Street Split	Mill Ditch Diversion	Splits from Mill Ditch Diversion upstream of Cedar Street. Flows to the northwest adjacent to Cedar Street, before crossing at a low point along Cedar Street and returning to Mill Ditch Diversion	0.2
Church Avenue Split	Bozeman Creek	Exists Bozeman Creek at Olive Street heading west. Bends north on Church Avenue and continues on Church Avenue before returning to Bozeman Creek	0.6
Flat/Kagy Split	Flat Creek	Splits from Flat Creek upstream of Kagy Boulevard and heads northwest parallel to Kagy before joining Mathew-Bird Creek	0.1
Gallagator Split	Bozeman Creek	Splits from Bozeman Creek upstream of Gallagator Trail and heads northeast parallel to the Gallagator Trail before joining Mill Ditch Diversion	0.1
Garfield Street Split	Mathew-Bird Creek	Some flow along Mathew-Bird Creek overtopping the road at Garfield Street splits and continues along Garfield Street to the east. Bends north at	0.3

Split Flow Name	Splits from	Description	Stream Length (miles)
		Bozeman Avenue, then east on Cleveland Street before joining Rouse Avenue Split	
Golf Course Split	Nash Spring Creek	Flow gradually departs Nash Spring Creek through and goes through the golf course before joining Flat Creek upstream of Kagy Boulevard	0.3
I-90 Split	Mill Ditch Diversion	Flow splits from Mill Ditch Diversion upstream of I-90 and heads northwest parallel to I-90. Crosses under I-90 at L street and spreads out heading north before joining East Gallatin River	0.7
Kagy/Rouse Split	Golf Course Split	Some flow along Golf Course Split overtops Kagy Boulevard and heads north. Some flow joins Rouse Avenue Split to the northwest and some rejoins Bozeman Creek to the northeast	0.1
Lower Black Split	Garfield Street Split	Some flow on Garfield Street Split bends north onto Black Avenue. Some of this flow returns to Mathew Bird Split and some continues to join Rouse Avenue Split	0.2
Mill/Railroad Split	Mill Ditch Diversion	Flow on the left overbank of Mill Ditch Diversion splits and crosses railroad tracks before rejoining Mill Ditch Diversion downstream. This split is not significant for flows with a 1-percent-annual chance recurrence interval or less.	0.2
Museum Split	Figgins Creek	Flow splits from Figgins Creek upstream of the trail embankment, heading north alongside the embankment before crossing it at a low point and returning to Figgins Creek	0.3
Nash Road Split	Bozeman Creek	Flow on the left overbank of Bozeman Creek splits across farmland before crossing Nash Road at a low point and continuing north before rejoining Bozeman Creek	0.4
Peace Pipe Split	Mathew Bird Creek	Flow splits from Mathew Bird Creek to the right along Peace Pipe Drive. It continues along Peace Pipe Drive for approximately 600 feet before finding a low point and moving north through a residential area, before returning to Mathew Bird Creek. This split is not significant for flows with a 1-percent-annual chance recurrence interval or less.	0.5
Rain Roper Split	Mathew Bird Creek	Flow on the right overbank leaves Mathew Bird Creek downstream of Peace Pipe Drive and continues north, parallel to Rain Roper before rejoining Mathew-Bird Creek	0.2

Split Flow Name	Splits from	Description	Stream Length (miles)
Rouse Avenue Split	Flat Creek	Some flow along Flat Creek overtopping the road at Black Avenue splits and continues along Rouse Avenue Flow heads north before joining Bozeman Creek	0.8
Sourdough Trail Split	Bozeman Creek	Flow in the left overbank of the Bozeman Creek splits to the left upstream of a private driveway and heads north before joining Nash Spring Creek	0.3
Tracy Avenue Split	Figgins Creek	Flow in the left overbank of Figgins Creek splits to the north upstream of Hoffman Drive and continues along Tracy Avenue northward before joining Mathew-Bird Creek	0.2
Wallace Avenue Split	Church Avenue Split	Some flow on Church Avenue Split splits to the east on Main Street and bends to the north on Wallace Avenue, heads north and returns to Bozeman Creek	0.9

Understanding the timing of peak flows is imperative in calculating the discharges along each flooding sources. The timing of peak flows varies from flooding source to flooding source. For example, as demonstrated in the hydrologic analyses, the timing of peak flow is not the same for Mathew Bird Creek and Bozeman Creek. The same goes for each of the secondary split flows. The flow diagram in Appendix E is color coded to illustrate the relative time when each flooding source will be experiencing peak discharges. For example, peak flows along Museum Split are caused by flooding events in the Figgins Creek watershed, and will occur at approximately the same time as peak flows are occurring along Figgins Creek.

For most split flows, the flows leaving were calculated using the lateral weir function within HEC-RAS. Lateral weir coefficients were carefully selected based on guidance for values recommended by HEC in the document "Combined 1D and 2D modeling in HEC-RAS". In general, the weir coefficient values in the hydraulic model correlate to the height and shape of the weir and fall into the ranges given in Table 3-3.

Table 3-3: Lateral Weir Coefficients

Description	Weir Coefficient Range
Roadway 3 ft or higher, broad crested weir shape, roadway acts as a weir	1.5 – 2.6
Roadway 1 to 3 ft, broad crested weir shape, roadway acts as a weir but becomes submerged easily	1.0 – 2.0
Natural high ground barrier, 1 to 3 ft high, does not truly act as a weir but water must flow over high ground to get to flow split area	0.5 – 1.0
Non elevated overbank terrain, overland flow escapes	0.2 – 0.5

In addition to modeling the splits using lateral weirs, some reaches received special consideration to ensure that accurate discharge values were calculated and modeled. Some of the special considerations include:

- Black Avenue Split and Rouse Avenue Split – Due to the unique physical circumstances at this flow split location, lateral weirs were not used. Flow along Flat Creek that does not fit in the culvert at Black Avenue overtops the road at a high point. Half the overtopping flow can be expected to head in each direction. Therefore, the flow overtopping the road was evenly divided between these two flooding sources. This is a more reasonable representation of how the flow would split than the use of a lateral weir would be at this location.
- Bozeman Creek – Flow that leaves Bozeman Creek at Goldenstein Lane and the Sourdough Trail Split goes through the large network of splits in the vicinity of Kagy Boulevard before gradually returning, split by split, to Bozeman Creek. In general, conservative assumptions were made as to when the flow returns to Bozeman Creek in this area. For example, when flow enters Bozeman Creek from Rouse Avenue Split at Cross Section 13969, all flow that left Bozeman Creek at Goldenstein Lane or via Sourdough Trail Split is assumed to have returned. Also, a significant portion of flow along Mathew Bird Creek will enter Bozeman Creek at this location. Therefore, the flow at this location is equal to the flow from the hydrology report "Bozeman Creek at Olive Street", even though Olive Street is some distance downstream of this point.
- Church Avenue Split – As flow goes north along Church Avenue, it gradually splits to both the east (towards Wallace Avenue split) and the west (towards Bozeman Creek) along the crossing east-west roads. These flow transfers were modeled and calculated simultaneously using lateral weirs on both sides of Church Avenue Split.
- Flat Creek at confluence with Golf Course Split – Flow that joins Flat Creek from Golf Course Split greatly overwhelms any flow coming from the upper reaches of Flat Creek. Golf Course Split will have its greatest peak discharges during Bozeman Creek flooding events, which are unlikely to occur simultaneously with Flat Creek flooding events. Therefore, flow that originates in the Flat Creek watershed is assumed to be zero when the Golf Course Split is at its peak.
- Flat Creek at Hoffman Drive – The effective map shows Flat Creek ending at Hoffman Drive as a result of an inlet to the City's storm sewer system. However, a review of the sewer system revealed that the inlet and pipe is not adequately sized to be able to handle all the flows along Flat Creek. (The storm sewer system has a 21" diameter pipe; insufficient to handle the flows given the great increase of discharge on Flat Creek caused by flows delivered from Bozeman Creek via Sourdough Trail Split, Nash Spring Split, and Golf Course Split). However, downstream of Hoffman Drive, the 1-percent annual chance flood event is less than 1 foot in average depth, so is mapped as X-shaded.
- Garfield Street Split – Peak flows on Garfield Street Split occur during flooding originating in the Mathew Bird Creek watershed. Because the flood peaks at a different time, flow on Black Avenue Split will be minimal during flooding on Garfield Street Split. Therefore, flow from Black Avenue Split is not added on to the peak flows on Garfield Street Split.
- Lower Black Split – Peak flows on Lower Black Split occur during flooding originating in the Mathew Bird Creek watershed.

- Mathew-Bird Creek at Kagy Boulevard – Mathew Bird Creek accepts flow that originates from splits ultimately fed by Bozeman Creek in the Flat/Kagy Split. However, peak flows on Bozeman Creek are unlikely to be significant at the same time as peak flows are occurring on flow that originates in the Mathew-Bird Creek watershed. Peak flows that originate in the Mathew Bird watershed dominate at all cross sections.
- Mathew Bird Creek at Figgins Creek and Tracy Avenue Split – Flow from Figgins Creek will enter Mathew Bird Creek both at the confluence with Figgins Creek and at the confluence with Tracy Avenue Split. Given the uncertainty in the flow split, Mathew Bird Creek is modeled conservatively to assume that all flow from Figgins Creek enters Mathew Bird Creek at the confluence with Figgins Creek.
- Mill Ditch Diversion at diversion structure – Lateral structure calculations reveal that approximately 45 cfs will split from Bozeman Creek in the vicinity of the Mill Ditch Diversion structure during the 1-percent-annual chance flooding event. This is significantly lower than the 340 cfs on Mill Ditch Diversion presented in the effective study. It appears that the effective study is in error. The right overbank of Bozeman Creek in this area is relatively high, which doesn't allow much flow to overtop into Mill Ditch Diversion. The structure itself has a relatively small opening (3' x 2.5'), which can only pass a limited amount of flow. Additionally, given the relatively flat slope of Mill Ditch Diversion in this area, backwater limits the amount of flow that splits. All of this taken into account, 45 cfs in Mill Ditch Diversion at this location is reasonable.
- Mill Ditch Diversion at diversion structure – The 2-percent-annual-chance and 1-percent-annual chance are the same at this location. It is reasonable that these discharges would be similar given the size of the diversion structure and the fact that it is largely limited by backwater.
- Mill Ditch Diversion at South Church Avenue – During the 0.2%-annual-chance event, flow at this location splits back across the Gallagator Trail to Bozeman Creek. This is caused by an undersized culvert at South Church Avenue. This demonstrates that even if the Mill Ditch Diversion structure size was increased, flow along Mill Ditch Diversion would still be limited by this structure.
- Mill Ditch Diversion – In the Mill Ditch Diversion hydrologic analysis report, it clearly states that the greater of two discharges should be used – flow that originates in the Mill Diversion Ditch watershed, or flow that splits from Bozeman Creek. For the reach identified in the hydrologic report as "at Main Street", the discharges originating from the Mill Ditch Diversion dominate for the 10-year and 500-year event, while the flows splitting from Bozeman Creek dominate for the 25-, 50-, and 100-year event. For the reach identified in the hydrologic report as "upstream of Northern Pacific Railroad" (and downstream), the flow that originates in the Mill Ditch Diversion watershed dominates for all recurrence intervals.
- Mill/Railroad Split – According to the lateral weir calculations, discharges to Mill/Railroad Split will be less than 2 cfs during the 1-percent-annual chance flood event. This is not a significant amount of flow. Therefore, Mill/Railroad Split is considered to be a split during the 0.2-percent-annual chance event only, and is mapped as Zone X shaded.
- Nash Spring Creek at Goldenstein Lane – Some flow splits from Bozeman Creek toward Nash Spring Creek at Goldenstein Lane. However, flow peaks on Bozeman Creek and Nash Spring Creek do

not occur at the same time. Peak flows on Nash Spring Creek between Goldenstein Lane and the confluence with Sourdough Trail Split are caused by floods originating in the Nash Spring Creek watershed.

- Nash Spring Creek downstream of Sourdough Trail Split - Peak discharges are influenced by the combined flow that originates in the Nash Spring Creek watershed, and the flow from Sourdough Trail Split (which originates from Bozeman Creek). The maximum peak discharges on Nash Spring Creek downstream of Sourdough Trail Split are attained during the maximum flow on Bozeman Creek. According to data interpolated from the hydrologic analysis, while Bozeman Creek is peaking, flows originating on Nash Spring Creek are at between 58% (for the 10yr event) and 27% (for the 500 year event) of their maximums. The peak Sourdough Trail Split flow and this percentage of the Nash Spring Creek flow are added together to calculate total peak flows in this area.
- Rouse Avenue Split – The upper reaches of Rouse Avenue Split are fed by flows from Flat Creek (flows that originate in the Bozeman Creek watershed). However, peak flows downstream of the confluence with Garfield Street Split are dominated by flows from Garfield Street Split, which originates in the Mathew Bird Creek watershed.

This network of split flows drastically changes the magnitude of peak discharges for all of the flooding sources. Therefore, the discharge values from the hydrologic analyses were highly modified to account for for the impacts of the flow splits. Table 2-2 contains the correct flooding discharges as modified by the hydraulic split calculations. The flow diagram that illustrates these splits is provided in Appendix E.

3.4 Profile Baseline

The centerlines for the main six flooding sources and the many split reaches were used to define the Profile Baselines and river stationing as the stream distance in feet above the confluence with the respective receiving streams. For example, the stream centerline of Bozeman Creek is referenced in feet above its confluence with the East Gallatin River. The stream stationing for all modeled split flow reaches also reference the stream distance in feet above its respective receiving stream. Table 3-4 lists all modeled streams and their stationing references. Summaries of key features along the flooding sources are presented in Table 3-5 to Table 3-30.

Table 3-4: Summary of Station References

Flooding Source	Station Reference
3rd Avenue – East Kagy Boulevard Split	Feet above confluence with Figgins Creek
Black Avenue Split	Feet above confluence with Garfield Street Split
Bozeman Creek	Feet above confluence with East Gallatin River
Cedar Creek Split	Feet above confluence with Mill Ditch Diversion

Flooding Source	Station Reference
Church Avenue Split	Feet above confluence with Bozeman Creek
East Kagy Boulevard - Rouse Avenue	Feet above confluence with Bozeman Creek
Figgins Creek	Feet above confluence with Mathew-Bird Creek
Flat Creek	Feet above confluence with Rouse Avenue Split
Flat Creek – East Kagy Boulevard Split	Feet above confluence with Mathew-Bird Creek
Gallagator Split	Feet above confluence with Mill Ditch Diversion
Garfield Street Split	Feet above confluence with Rouse Avenue Split
Golf Course Split	Feet above confluence with Flat Creek
Interstate 90 Split	Feet above confluence with East Gallatin River
Lower Black Avenue Split	Feet above confluence with Rouse Avenue Split
Mathew-Bird Creek	Feet above confluence with Bozeman Creek
Mill Ditch Diversion	Feet above confluence with East Gallatin River
Mill Ditch Diversion – Railroad Split	Feet above confluence with Mill Ditch Diversion
Museum Split	Feet above confluence with Figgins Creek
Nash Road Split	Feet above confluence with Bozeman Creek
Nash Spring Creek	Feet above confluence with Bozeman Creek
Rain Roper Split	Feet above confluence with Mathew-Bird Creek
Rouse Avenue Split	Feet above confluence with Bozeman Creek
Sourdough Trail Split	Feet above confluence with Nash Spring Creek
Tracy Avenue Split	Feet above confluence with Mathew-Bird Creek
Wallace Avenue Split	Feet above confluence with Bozeman Creek

Table 3-5: Summary of Key Features along the Profile Baseline of 3rd Avenue–East Kagy Boulevard Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Convergence with Figgins Creek	Downstream study limit; confluence with Figgins Creek	144	1	11
1324	Divergence from Figgins Creek	Upstream study limit; furthest upstream cross section; discharge received from Figgins Creek, calculated via Figgins Creek LS 1912	144	1	11

Table 3-6: Summary of Key Features along the Profile Baseline of Black Avenue Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Garfield Street Split	Downstream study limit; confluence with Garfield Street Split	25	1	10
2972	Divergence from Flat Creek	Upstream study limit; furthest upstream cross section; discharge received from Flat Creek, discharge manually adjusted to be half of the flow from Flat Creek that overtops Black Avenue Culvert (the other half flows to Rouse Avenue Split). Peak flow along Black Avenue Split originates in the Bozeman Creek watershed.	25	1	11

Table 3-7: Summary of Key Features along the Profile Baseline of Bozeman Creek

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map Number
0	Confluence with East Gallatin River	Downstream study limit; confluence with East Gallatin River	1047	5	1
46	Griffin Drive	Stream Crossing #1 – Single span bridge with a span length of 16’	1047	5	1
1387	Warehouse Road	Stream Crossing #2 – Single span bridge with a span length of 60’	1047	5	1

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map Number
3372	Gold Avenue	Stream Crossing #3 – Single span bridge with a span length of 44’	1047	5	2
3650	Interstate 90	Stream Crossing #4 – 8.5’x10’ horizontal elliptical concrete culvert, 288 feet long; 9.7’x10.7’ horizontal elliptical concrete culvert, 288 feet long; 40’x10’ concrete box culvert, 288 feet long	1047	5	2
3817	Flow Change Location	Flow change location from Hydrology report - "Bozeman Creek at Mouth". Flow is not exactly the same as hydrology report because flow that departed to Gallagator Split and Mill Ditch Diversion has not returned.	1047	5	2
4023	Flow Change Location	Last cross section before flow change location	1027	5	2
4280	Railroad Bridge	Stream Crossing #5 – Double span bridge with a full length of 45’, and 1’ wide pier	1027	5	2
4780	Warehouse Road	Stream Crossing #6 – Single span bridge with a span length of 42’	1027	5	2
4795	Flow Change Location	Discharge from Wallace Avenue Split received via Junction “WallaceBozeman”	1027	5	2
5170	Flow Change Location	Last cross section before discharge from Wallace Avenue Split is received	944	4	2
5518	Tamarack Street	Stream Crossing #7 – Single span bridge with a span length of 24’	944	4	4
5633	Wood Footbridge	Stream Crossing #8 – Triple span bridge with a full length of 48’, 2-1’ wide piers	944	4	4
5858	Flow Change Location	Flow change location from Hydrology report - "Bozeman Creek at Peach Street". Flow is not exactly the same as hydrology report because flow that departed to Gallagator Split, Mill Ditch Diversion, and Wallace Avenue Split has not returned.	944	4	4
6297	Flow Change Location	Last cross section before flow change location	924	4	4
6735	Peach Street	Stream Crossing #9 – Single span bridge with an approximate span length of 12’	924	4	4
6765	Flow Change Location	Flow enters from Church Avenue Split via Junction "ChurchBozeman"	924	4	4
6824	Flow Change Location	Last cross section before discharge form Church Avenue Split is received	863	3	4

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map Number
7424	North Rouse Avenue	Stream Crossing #10 – Single span bridge with a span length of 19’	863	3	4
7518	Private Drive	Stream Crossing #11 – Single span bridge with a span length of 20’	863	3	4
8566	Flow Change Location	Discharge returns from Church Avenue Split via Lamme Street (Church Avenue LS 1773)	863	3	6
8590	Lamme Street	Stream Crossing #12 - Single span bridge with an approximate span length of 12’	853	3	6
8627	Flow Change Location	Last cross section before 10 cfs returns from Church Avenue Split via Lamme Street (Church Avenue LS 1773)	853	3	6
8735	City Hall Pedestrian Crossing	Stream Crossing #13 - Single span bridge with an approximate span length of 28’	853	3	6
8948	Flow Change Location	Discharge returns from Church Avenue Split via Mendenhall Street (Church Avenue LS 2176)	853	3	6
8970	Mendenhall Street	Stream Crossing #14 - Single span bridge with a span length of 12’	839	3	6
9009	Flow Change Location	Last cross section before 14 cfs returns form Church Avenue Split via Mendenhall Street	839	3	6
9170	Main Street North Alley	Stream Crossing #15 – Single span bridge with an approximate span length of 12’	839	3	6
9216	Pedestrian Bridge	Stream Crossing #16 - Single span bridge with an approximate span length of 19’	839	3	6
9370	Main Street	Stream Crossing #17 - Upstream end is a single span bridge with an approximate span length of 13’ and downstream end is a single span arch bridge with a span length of 14’	839	3	6
9755	Babcock Street	Stream Crossing #18 - Upstream end is a single span bridge with a span length of 16’ and downstream end is a single span bridge with a span length of 12’	839	3	8
10100	Olive-Rouse	Stream Crossing #19 - Upstream end is a single span bridge with an approximate span length of 12’ and downstream end is a single span bridge with a span length of 23’	839	3	8
10202	Flow Change Location	Discharge departs towards Church Avenue Split via LS 10304	839	3	8

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map Number
10582	Flow Change Location	Last cross section before 168 cfs leaves the stream towards Church Avenue Split via LS 10304	1007	3	8
10965	Bogert Park Pedestrian Bridge	Stream Crossing #20 - Single span bridge with an approximate span length of 39'	1007	3	8
11396	Storey Street	Stream Crossing #21 - Single span bridge with an approximate span length of 12'	1007	3	8
11561	Flow Change Location	500 year flow enters from Mill Ditch Diversion via Mill Ditch Diversion LS 8937	1007	3	8
11805	Mill Diversion Structure	Stream Crossing #22 – Modeled as a single span "bridge" with a span of 24'	1007	3	9
11829	Flow Change Location	Discharge departs towards Mill Ditch Diversion via the Mill Ditch Diversion structure (LS 11860)	1007	3	9
11927	Flow Change Location	Discharge departs towards Mill Ditch Diversion upstream of the Mill Ditch Diversion structure (LS 12087)	1039	3	9
12088	Flow Change Location	Last cross section before discharge departs towards Mill Ditch Diversion upstream of the Mill Ditch Diversion structure (LS 12087)	1052	3	9
12110	Gallagator Bridge	Stream Crossing #23 – 4 span bridge with a full span length of 44', 3-1' wide piers	1052	3	9
12135	Flow Change Location	Discharge departs towards Gallagator Split via LS 12265	1052	3	9
12267	Flow Change Location	Last cross section before 78 cfs leaves the stream towards Gallagator Split via LS 12265	1130	3	9
12273	Footbridge	Stream Crossing #24 – Single span bridge with a span length of 34.5'	1130	3	9
12980	South Church Avenue	Stream Crossing #25 - Single span bridge with a span length of 16'	1130	3	9
13528	South Church Avenue	Stream Crossing #26 –single span arch bridge with a span length of 16'	1130	3	9
13688	Footbridge at 905 South Church Avenue	Stream Crossing #27 - Single span wood bridge with a span length of 21'	1130	3	9
13952	Ice Pond Road	Stream Crossing #28 - Single span bridge with a span length of 34'	1130	3	9
13969	Flow Change Location	Discharge enters from Rouse Avenue Split. All flow that has split off of Bozeman Creek upstream of this location is assumed to have returned by	1130	3	9

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map Number
		this point. Also, the great majority of flow from Mathew Bird Creek will have joined Bozeman Creek by this point. Therefore, flow is from hydrology report - "Bozeman Creek at Olive Street"			
14205	Flow Change Location	Last cross section before discharge from Rouse Avenue Split enters channel	682	3	9
15560	Private Drive at 1203 South Church Avenue	Stream Crossing #29 - Single span bridge with a span length of 22’	682	3	10
15696	Private Drive at 1301 South Church Avenue	Stream Crossing #30 - Single span bridge with a span length of 43’	682	3	10
15845	Footbridge at 1307 South Church Avenue	Stream Crossing #31 - Single span bridge with an approximate span length of 30’	682	3	10
16690	Private Drive	Stream Crossing #32 - Single span bridge with a span length of 27’	682	3	10
17320	Private Drive at 1417 South Church Avenue	Stream Crossing #33 - Single span bridge with a span length of 31’	682	3	10
17613	Bridge at 1629 South Church Avenue	Stream Crossing #34 - Single span wood bridge with a span length of 26’	682	3	11
17725	Bridge at 1629 South Church Avenue	Stream Crossing #35 - Single span wood bridge with a span length of 60.5’	682	3	11
18559	Flow Change Location	Discharge enters from Kagy/Rouse Split via Junction "KagyRouse"	682	3	11
18765	Flow Change Location	Last cross section before Flow enters from Kagy/Rouse Split via Junction "KagyRouse"	636	2	11
18776	Bridge at 1815 Sourdough Road	Stream Crossing #36 - Single span wood bridge with a span length of 28’	636	2	11
19036	Bridge at 1815 Sourdough Road	Stream Crossing #37 - Single span wood bridge with a span length of 19’	636	2	11
19377	Footbridge	Stream Crossing #38 - Single span wood bridge with a span length of 28.5’	636	2	11
20525	Kagy Boulevard	Stream Crossing #39 - Single span bridge with a span length of 52’	636	2	22
20724	Flow Change Location	Discharge change location from hydrology report - "Bozeman Creek Upstream of Mathew Bird Creek". Flow is not exactly the same as hydrology report because flow that departed to Nash Spring Creek at	636	2	22

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map Number
		Goldenstein Lane via LS 32425 and Sourdough Trail Split has not returned.			
20786	Flow Change Location	Discharge change location from hydrology report - "Bozeman Creek Upstream of Nash Spring Creek". Flow is not exactly the same as hydrology report because flow that departed to via LS 32425 and Sourdough Trail Split has not returned.	543	2	22
21303	Flow Change Location	Last cross section before flow change location	532	2	22
21305	Footbridge	Stream Crossing #40 - Single span wood bridge with a span length of 31’	532	2	22
21761	Footbridge at 2855 Sourdough	Stream Crossing #41 – Single span wood bridge with a span length of 24’	532	2	22
22752	Footbridge	Stream Crossing #42 - Single span wood bridge with a span length of 24’	532	2	22
22956	Footbridge	Stream Crossing #43 - Single span wood bridge with a span length of 23.5’	532	2	22
23272	Bradley Road	Stream Crossing #44 - Single span bridge with a span length of 20’	532	2	23
23544	Private Drive	Stream Crossing #45 - Single span bridge with a span length of 24.5’	532	2	23
23949	Footbridge	Stream Crossing #46 - Single span wood bridge with a span length of 36’	532	2	23
24561	Footbridge at 3375 Sourdough	Stream Crossing #47 - Single span wood bridge with a span length of 32’	532	2	23
24971	Footbridge	Stream Crossing #48 - Single span wood bridge with a span length of 25.5’	532	2	23
25694	Footbridge at 3455 Sourdough	Stream Crossing #49 - Single span wood bridge with a span length of 29’	532	2	23
26017	Footbridge 3519 Sourdough	Stream Crossing #50 - Single span wood bridge with a span length of 26.5’	532	2	23
27280	Private Drive at 3599 Sourdough	Stream Crossing #51 - Single span bridge with an approximate span length of 29’	532	2	24
27296	Flow Change Location	Discharge departs towards Sourdough Trail Split via LS 27683	532	2	24
27305	Flow Change Location	Discharge departs towards Sourdough Trail Split via LS 27683	538	2	24

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map Number
27684	Flow Change Location	Last cross section before discharge departs towards Sourdough Trail Split via LS 27683	879	2	24
28037	Footbridge	Stream Crossing #52 - Single span metal arch bridge with a span length of 45’	879	2	24
28683	Footbridge	Stream Crossing #53 - Single span metal arch bridge with a span length of 45’	879	2	24
28687	Flow Change Location	Discharge change location from hydrology report - "Bozeman Creek at Private Drive Downstream of Gardner Park Drive". Flow is not exactly the same as hydrology report because flow that departed via LS 32425 has not returned.	879	2	24
28923	Flow Change Location	Last cross section before flow change location	743	2	25
31730	Goldenstein Road	Stream Crossing #54 - Single span bridge with a span length of 66’	743	2	26
31772	Flow Change Location	Discharge change location from hydrology report - "Bozeman Creek at Goldenstein Road"	743	2	26
32217	Flow Change Location	Discharge departs toward Nash Spring Creek via LS 32425	720	2	26
32438	Flow Change Location	Last cross section before discharge departs toward Nash Spring Creek via LS 32425	777	2	26
32445	Footbridge at 146 Hitching Post Road	Stream Crossing #55 - Single span wood arch bridge with a span length of 28’	777	2	26
32697	Footbridge	Stream Crossing #56 - Single span wood bridge with a span length of 31.5’	777	2	26
33998	Footbridge	Stream Crossing #57 - Single span wood bridge with a span length of 30’	777	2	26
41950	Footbridge	Stream Crossing #58 - Single span wood bridge with a span length of 26.5’	777	2	28
43129	Footbridge	Stream Crossing #59 - Single span wood bridge with a span length of 26’	777	2	29
45459	Flow Change Location	Discharge returns from Nash Road Split via Junction "NashRdSplit"	777	2	30
45788	Flow Change Location	Last cross section before discharge returns from Nash Road Split via Junction "NashRdSplit"	553	1	31

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map Number
47063	Nash Road	Stream Crossing #60 – Single barrel 11.67'x7.75' horizontal elliptical concrete culvert; 40 feet long	553	1	31
47091	Flow Change Location	Discharge departs toward Nash Road Split via LS 47978	553	1	31
47519	Flow Change Location	Discharge departs toward Nash Road Split via LS 47978	737	1	31
47979	Upstream Study Reach	Limit of detailed study; furthest upstream surveyed cross section; discharge from Hydrology report - "Bozeman Creek at Nash Road"	777	1	31

Table 3-8: Summary of Key Features along the Profile Baseline of Cedar Street Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Mill Ditch Diversion	Downstream reach limits; confluence with Mill Ditch Diverson	88	1	5
1312	Divergence from Mill Ditch Diversion	Discharge splits from Mill Ditch Diversion, calculated via Mill Ditch Diversion LS 1610; furthest upstream cross section	88	1	5

Table 3-9: Summary of Key Features along the Profile Baseline of Church Avenue Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Bozeman Creek	Downstream reach limits; confluence with Bozeman Creek	61	1	4
865	Split Flow Location	Discharge departs along Fridley Street towards Wallace Avenue Split via LS 969	61	1	6

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
970	Split Flow Location	Last cross section before discharge departs along Fridley Street towards Wallace Avenue Split via LS 969	73	1	6
1306	Split Flow Location	Discharge departs along Davis Street towards Wallace Avenue Split via LS 1420	73	1	6
1421	Split Flow Location	Last cross section before discharge departs along Davis Street towards Wallace Avenue Split via LS 1420	84	1	6
1689	Split Flow Location	Discharge departs along Lamme Street towards Bozeman Creek via LS 1773 and towards Wallace Avenue Split via LS 1772	84	1	6
1774	Split Flow Location	Last cross section before discharge departs along Lamme Street towards Bozeman Creek via LS 1773 and towards Wallace Avenue Split via LS 1772	103	1	6
2069	Split Flow Location	Discharge departs along Mendenhall Street towards Bozeman Creek via LS 2176 and towards Wallace Avenue Split via LS 2175	103	1	6
2177	Split Flow Location	Last cross section before discharge departs along Mendenhall Street towards Bozeman Creek via LS 2176 and towards Wallace Avenue Split via LS 2175	133	1	6
2436	Split Flow Location	Discharge departs along Main Street toward Wallace Avenue Split via LS 2594	133	1	6
2595	Split Flow Location	Last cross section before discharge departs along Main Street toward Wallace Avenue Split via LS 2594	169	1	6
3601	Divergence from Bozeman Creek	Discharge splits from Bozeman Creek, calculated via Bozeman Creek LS 10304; furthest upstream cross section	169	1	8

Table 3-10: Summary of Key Features along the Profile Baseline of Figgins Creek

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Mathew-Bird Creek	Downstream reach limits; confluence with Mathew-Bird Creek	93	3	11
137	Private Drive	Stream Crossing #1 – Single barrel 2.8' corrugated metal culvert, 39 feet long	93	3	11
267	Private Drive	Stream Crossing #2 – Single span bridge with a span length of 7.5'	93	3	11
280	Split Flow Location	Discharge departs toward Tracy Avenue Split via LS 394	93	3	11
322	Split Flow Location	Discharge departs toward Tracy Avenue Split via LS 394	124	3	11
395	Flow Change Location	Last cross section before discharge departs toward Tracy Avenue Split via LS 394	149	3	11
402	Private Drive	Stream Crossing #3 – Single span bridge with a span length of 11'	149	3	11
414	Flow Change Location	Discharge change location from hydrology report - "Figgins Creek at Mouth". Also, flow departs toward Tracy Avenue Split via LS 513	149	3	11
514	Flow Change Location	Discharge returns from 3rd Avenue/Kagy Boulevard Split	240	3	11
596	Flow Change Location	Last cross section before discharge returns from 3rd Avenue/Kagy Boulevard Split	96	2	11
692	Kagy Boulevard	Stream Crossing #4 – Single barrel 2.5'x1.8' horizontal elliptical concrete Culvert, 230 feet long	96	2	11
883	Footbridge at 1901 Tracy	Stream Crossing #5 - Single span wood bridge with a span length of 17.5'	96	2	11
941	Footbridge at 1907 Tracy	Stream Crossing #6 - Single span wood bridge with a span length of 11'	96	2	11
1427	Footbridge at 2017 Tracy	Stream Crossing #7 - Single span wood bridge with a span length of 16'	96	2	11
1431	Flow Change Location	Flow change location from hydrology report - "Figgins Creek through Kagy Boulevard". Flow is not the same as hydrology report because flow has departed to3rd/Kagy Split has not yet returned.	96	2	11
1611	Flow Change Location	Last cross section before flow change location.	85	2	11

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
1812	3rd Avenue	Stream Crossing #8 – Single barrel 3'x2.2' horizontal elliptical concrete Culvert, 84 feet long	85	2	11
1862	Split Flow Location	Flow departs towards 3rd Avenue/Kagy Boulevard Split via LS 1912	85	2	11
1962	Flow Change Location	Last cross section before flow departs towards 3rd Avenue/Kagy Boulevard Split via LS 1912	229	2	11
2198	Flow Change Location	Flow returns from Museum Split via Junction "Museum"	229	2	11
2530	Flow Change Location	Last Cross section before flow returns from Museum Split via Junction "Museum"	179	1	12
2694	Footbridge	Stream Crossing #9 - Single span bridge with a span length of 13'	179	1	12
2711	Flow Change Location	Flow change location from hydrology report – "Figgins Creek through 3rd Ave". Flow is not the same as hydrology report because flow that has departed to Museum Split has not returned	179	1	12
2715	Footbridge	Stream Crossing #10 - Single span bridge with a span length of 10'	98	1	12
2719	Flow Change Location	Last cross section before flow change location	98	1	12
3012	Overbrook Drive	Stream Crossing #11 – Double barrel 4'x2.4' corrugated arch metal culvert, 45 feet long	98	1	12
3342	Overbrook Drive	Stream Crossing #12 – Single barrel 3.8'x2.8' horizontal elliptical concrete culvert, 43 feet long; Single barrel 4.2'x2.9' horizontal elliptical concrete culvert, 43 feet long	98	1	12
3522	Trail	Stream Crossing #13 – Single barrel 2'x1.5' horizontal elliptical concrete culvert, 108 feet long	98	1	12
3687	Footbridge	Stream Crossing #14 - Single span bridge with a span length of 12'	98	1	12
3967	Footbridge	Stream Crossing #15 - Single span bridge with a span length of 10'	98	1	12
3970	Flow Change Location	Flow change location from hydrology report – "Figgins Creek upstream of 3rd Ave". Flow is not the same as hydrology report because flow that has departed toward Museum Split has not yet returned.	98	1	12

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
3980	Flow Change Location	Last cross section before flow change location	65	1	12
4002	Trail	Stream Crossing #16 – Single barrel 3.1' concrete culvert, 44 feet long	65	1	12
4026	Flow Change Location	Flow departs towards Museum Split via LS 4139	65	1	12
4263	Flow Change Location	Last cross section before flow departs towards Museum Split via LS 4139	115	1	12
5012	Trail	Stream Crossing #17 – Single barrel 3.4'x1.25' horizontal elliptical concrete culvert, 10 feet long	115	1	13
5872	Trail	Stream Crossing #18 – Single barrel 3.5'x2.2' horizontal elliptical concrete culvert, 16 feet long	115	1	13
5882	Flow Change Location	Flow change location from hydrology report - "Figgins Creek at Railroad (Formerly CMSP&P)"	115	1	13
6112	Flow Change Location	Last cross section before flow change location from hydrology report - "Figgins Creek at Railroad (Formerly CMSP&P)"	72	1	13
6702	Brookdale Drive	Stream Crossing #19 – Triple barrel 4.9'x3' corrugated metal arch culvert, 120 feet long	72	1	13
6766	Flow Change Location	Flow change location from hydrology report - "Figgins Creek through Brookdale Drive"	72	1	13
6882	Flow Change Location	Last cross section before flow change location from hydrology report - "Figgins Creek through Brookdale Drive"	48	1	13
7487	Inline Structure	Stream Crossing #20 – Inline Structure	48	1	14
7552	Alder Creek Road	Stream Crossing #21 – Double barrel 4.9'x3' corrugated metal arch culvert, 102 feet long	48	1	14
7737	Trail	Stream Crossing #22 – Single barrel 2.1' concrete culvert, 19 feet long	48	1	14
7747	Flow Change Location	Flow change location from hydrology report - "Figgins Creek through Alder Creek Drive"	48	1	14
7832	Flow Change Location	Last cross section before flow change location from hydrology report - "Figgins Creek through Alder Creek Drive"	34	1	14
9071	Upstream Study Reach	Detailed study limit; furthest upstream cross section; discharge from Hydrology report - "Figgins Creek upstream of Cambridge Drive"	34	1	14

Table 3-11: Summary of Key Features along the Profile Baseline of Flat Creek

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Rouse Avenue Split	Downstream reach limits; confluence with Rouse Avenue Split	31	2	15
867	Footbridge	Stream Crossing #1 - Single span bridge with a span length of 8.5’	31	2	15
940	Footbridge	Stream Crossing #2 - Single span bridge with a span length of 10’	31	2	15
953	Footbridge	Stream Crossing #3 - Single span bridge with a span length of 6’	31	2	15
1191	Flow Change Location	Flow exits towards Black Avenue Split and Rouse Avenue Split. Discharge manually adjusted in model - of flow on Flat Creek that overtops culvert at Black Avenue, half is routed toward Black Avenue Split, and half is routed toward Rouse Avenue Split.	31	2	15
1225	Black Avenue	Stream Crossing #4 - Single barrel 2.6’x1.6’ horizontal elliptical concrete culvert, 58 feet long	82	2	15
1252	Flow Change Location	Last cross section before flow change location	82	2	15
1310	Private Drive	Stream Crossing #5 - Single barrel 2.4’x2.9’ horizontal elliptical concrete culvert, 19.5 feet long	82	2	15
1319	Flow Change Location	Flow exits towards Rouse Avenue Spill via LS 1410	82	2	15
1344	Flow Change Location	Flow exits towards Rouse Avenue Spill via LS 1410	90	2	15
1411	Flow Change Location	Last cross section before flow exits towards Rouse Avenue Spill via LS 1410	112	2	15
1415	Kagy Boulevard	Stream Crossing #6 - Single barrel 4.5’x2.4’ horizontal elliptical concrete culvert, 175 feet long	112	2	15
1592	Flow Change Location	Flow exits towards Flat/Kagy Split via LS 1790	112	2	15
1702	Flow Change Location	Flow exits towards Flat/Kagy Split via LS 1790	308	2	15

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
1791	Flow Change Location	Last cross section before flow exits towards Flat/Kagy Split via LS 1790	336	2	15
1800	Trail	Stream Crossing #7 - Single barrel 2’ corrugated metal culvert, 16 feet long	336	2	15
1808	Flow Change Location	Flow enters from Golf Course Split via Junction "GolfCourse"	336	2	15
1890	Flow Change Location	Last cross section before flow enters from Golf Course Split via Junction "GolfCourse"	26	1	15
1892	Inline Structure	Stream Crossing #8 - Weir	26	1	15
2467	Golf Crossing	Stream Crossing #9 - Single barrel 2’x1.5’ horizontal elliptical concrete culvert, 5 feet long	26	1	16
2835	Golf Crossing	Stream Crossing #10 - Single span bridge with a span length of 6’	26	1	16
3265	Golf Crossing	Stream Crossing #11 - Single span bridge with a span length of 8’	26	1	16
3640	Golf Crossing	Stream Crossing #12 - Single barrel 3’ concrete culvert, 19 feet long	26	1	16
3735	Golf Crossing	Stream Crossing #13 - Single barrel 2’ corrugated metal culvert, 20 feet long	26	1	16
3940	Fence Crossing	Stream Crossing #14 - Single span bridge with a span length of 27.3’	26	1	16
4115	Culvert Crossing	Stream Crossing #15 - Single barrel 2.5’ corrugated metal culvert, 330 feet long	26	1	16
4465	Pond Outlet Structure	Stream Crossing #16 - Single barrel 1’ concrete culvert, 18 feet long	26	1	17
4815	Lake Inlet	Stream Crossing #17 - Single barrel 1.25’ corrugated metal culvert, 20 feet long	26	1	17
5015	Golf Crossing	Stream Crossing #18 - Single barrel 1.25’ corrugated metal culvert, 20 feet long	26	1	17
5370	Golf Crossing	Stream Crossing #19 - Single barrel 1’ corrugated metal culvert, 20 feet long	26	1	17
5433	Footbridge	Stream Crossing #20 - Single span bridge with a span length of 8.5’	26	1	17

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
5555	Golf Crossing	Stream Crossing #21 - Single barrel 1.5' corrugated metal culvert, 12 feet long	26	1	17
5566	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge from hydrology report - "Flat Creek at Hoffman Drive"	26	1	17

Table 3-12: Summary of Key Features along the Profile Baseline of Flat Creek – Kagy Boulevard Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Mathew-Bird Creek	Downstream study limit; confluence with Mathew Bird Creek	224	1	11
697	Divergence from Flat Creek	Upstream study limit; furthest upstream cross section; Discharge splits from Flat Creek, calculated via Flat Creek LS 1790	224	1	11

Table 3-13: Summary of Key Features along the Profile Baseline of Gallagator Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Mill Ditch Diversion	Downstream study limit; confluence with Mill Ditch Diversion	78	1	9
279	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge splits from Bozeman Creek, calculated via Bozeman Creek LS 12265	78	1	9

Table 3-14: Summary of Key Features along the Profile Baseline of Garfield Street Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Rouse Avenue Split	Downstream study limit; confluence with Rouse Avenue Split	218	1	9
1212	Flow Change Location	Discharge enters from Black Avenue Split. Because the timing of peaks between Black Avenue Split and Garfield Street Split is different, this does not impact the discharge on Garfield Street Split. Also, discharge exits towards Lower Black Split via LS 1370.	218	1	10
1371	Flow Change Location	Discharge exits towards Mathew-Bird Creek via LS 1458.	257	1	10
1459	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge splits from Mathew-Bird Creek. Discharge manually set in model to be equal to the amount of flow on Mathew-Bird Creek that does not fit in the culvert at Garfield Street.	277	1	10

Table 3-15: Summary of Key Features along the Profile Baseline of Golf Course Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Flat Creek	Downstream study limit; confluence with Flat Creek	336	1	15
356	Flow Change Location	Flow exits towards Kagy/Rouse Split via LS 754	336	1	15
482	Flow Change Location	Flow exits towards Kagy/Rouse Split via LS 754	380	1	15

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
755	Flow Change Location	Flow enters from Nash Spring Creek, calculated via Nash Spring Creek LS 623	381	1	15
943	Flow Change Location	Last cross section before flow enters from Nash Spring Creek via Nash Spring Creek LS 623	357	1	22
1084	Flow Change Location	Flow enters from Nash Spring Creek, calculated via Nash Spring Creek LS 890	357	1	22
1266	Flow Change Location	Flow enters from Nash Spring Creek, calculated via Nash Spring Creek LS 1053	230	1	22
1419	Flow Change Location	Flow enters from Nash Spring Creek, calculated via Nash Spring Creek LS 1266	224	1	22
1564	Flow Change Location	Last cross section before flow enters from Nash Spring Creek via Nash Spring Creek LS 1266	174	1	22
1654	Flow Change Location	Discharge splits from Nash Spring Creek, calculated via Nash Spring Creek LS 1590	174	1	22

Table 3-16: Summary of Key Features along the Profile Baseline of Interstate 90 Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with East Gallatin River	Downstream reach limit; confluence with East Gallatin River	113	1	2
3806	Upstream study limit	Furthest upstream cross section; discharge splits from Mill Ditch Diversion, calculated via Mill Ditch Diversion LS 281	113	1	5

Table 3-17: Summary of Key Features along the Profile Baseline of Kagy Boulevard – Rouse Ave. Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Bozeman Creek	Downstream study reach; confluence with Bozeman Creek	45	1	15
556	Flow Change Location	Flow exits towards Rouse Avenue Split via LS 664	45	1	15
723	Flow Change Location	Last cross section before flow exits towards Rouse Avenue Split via LS 664	45	1	15
1066	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge splits from Golf Course Split, calculated via Golf Course Split LS 754	45	1	15

Table 3-18: Summary of Key Features along the Profile Baseline of Lower Black Avenue Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Downstream Study Limit	Downstream study limit; confluence with Rouse Avenue Split	10	1	9
541	Flow Change Location	Flow exits towards Mathew Bird Creek via LS 919	10	1	9
622	Flow Change Location	Flow exits towards Mathew Bird Creek via LS 919	13	1	9
709	Flow Change Location	Flow exits towards Mathew Bird Creek via LS 919	39	1	9
867	Flow Change Location	Flow exits towards Mathew Bird Creek via LS 919	39	1	9
1266	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge splits from Garfield Split, calculated via Garfield Split LS 1370	39	1	10

Table 3-19: Summary of Key Features along the Profile Baseline of Mathew Bird Creek

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Bozeman Creek	Downstream study limit; confluence with Bozeman Creek	257	2	9
392	Gallagator Trail	Stream Crossing #1 - Double span bridge with a full length of 25.114', with piers	257	2	9
752	Trail Crossing	Stream Crossing #2 - Single span bridge with a span length of 27'	257	2	9
1152	Footbridge	Stream Crossing #3 - Single span bridge with a span length of 8'	257	2	9
1242	Footbridge	Stream Crossing #4 - Single span bridge with a span length of 16'	257	2	9
1429	Footbridge	Stream Crossing #5 - Single span bridge with a span length of 12'	257	2	9
1472	Footbridge	Stream Crossing #6 - Single span bridge with a span length of 17.7'	257	2	9
1692	Footbridge	Stream Crossing #7 - Single span bridge with a span length of 12.6'	257	2	9
1754	Flow Change Location	Flow enters from Lower Black Split, calculated via Lower Black Split LS 919	257	2	9
1833	Flow Change Location	Last cross section before flow enters from Lower Black Split, calculated via Lower Black Split LS 919	229	2	9
1837	Footbridge	Stream Crossing #8 - Single span bridge with an approximate span length of 25'	229	2	9
1843	Flow Change Location	Flow change location from hydrology report - "Mathew-Bird Creek at mouth". Flow is not the same as hydrology report because flow that exited on Garfield Street Split does not return.	229	2	10
2032	Flow Change Location	Last cross section before flow change location from hydrology report - "Mathew-Bird Creek at mouth". Flow is not the same as hydrology report because flow that exited on Garfield Street Split does not return.	187	2	10
2225	Footbridge	Stream Crossing #9 - 4 span bridge with a full length of 56', 2-1' piers and 2-1.2' piers	187	2	10
2262	Flow Change Location	Flow exits toward Garfield Street Split. Discharge manually set in model to be equal to the amount of flow on Mathew-Bird Creek that fits in the culvert	187	2	10

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
		at Garfield Street (overtopping flow is routed into Garfield Street Split). Also, flow enters from Garfield Street Split via Garfield Street Split LS 1458			
2372	Garfield Street	Stream Crossing #10 – Single barrel 5.5'x3.5' corrugated metal arch culvert, 155 feet long	444	2	10
2418	Flow Change Location	Last cross section before flow change location	444	2	10
2452	Footbridge	Stream Crossing #11 - Single span bridge with a span length of 15'	444	2	10
2509	Footbridge	Stream Crossing #12 - Single span bridge with a span length of 9'	444	2	10
3102	Footbridge	Stream Crossing #13 - Single span bridge with a span length of 40'	444	2	10
4102	Mason Street	Stream Crossing #14 - Single barrel 4.9'x3' horizontal elliptical concrete culvert, 80 feet long	444	2	10
5087	Hoffman Drive	Stream Crossing #15 – Single barrel 4.9'x3' corrugated metal arch culvert, 63 feet long	444	2	11
5117	Flow Change Location	Flow change location from hydrology report - "Mathew Bird Creek upstream of Garfield Street"	444	2	11
5144	Flow Change Location	Last cross section before flow change location from hydrology report - "Mathew Bird Creek upstream of Garfield Street"	303	2	11
5497	Kagy Boulevard	Stream Crossing #16 – Single barrel 4.5'x2.4' corrugated metal arch culvert, 155 feet long	303	2	11
6067	Footbridge	Stream Crossing #17 - Single span bridge with a span length of 8'	303	2	11
6153	Footbridge	Stream Crossing #18 - Single span bridge with a span length of 10'	303	2	11
6249	Footbridge at 2007 Spring Creek Drive	Stream Crossing #19 - Single span bridge with a span length of 18'	303	2	11
6422	Footbridge at 2104 Spring Creek Drive	Stream Crossing #20 - Single span bridge with a span length of 12.7'	303	2	11
6475	Footbridge at 2212 Spring Creek Drive	Stream Crossing #21 - Single span bridge with a span length of 12'	303	2	11
6554	Footbridge at 2404 Spring Creek Drive	Stream Crossing #22 - Single span bridge with a span length of 13'	303	2	11

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
6642	Footbridge	Stream Crossing #23 - Single span bridge with a span length of 13’	303	2	11
6777	Footbridge	Stream Crossing #24 - Single span bridge with a span length of 16’	303	2	11
6902	Footbridge	Stream Crossing #25 - Single span bridge with a span length of 10.9’	303	2	11
7020	Footbridge	Stream Crossing #26 - Single span bridge with a span length of 17.25’	303	2	16
7451	Footbridge	Stream Crossing #27 - Single span bridge with a span length of 16’	303	2	16
7510	Footbridge	Stream Crossing #28 - Single span bridge with a span length of 14’	303	2	16
7533	Inline Structure	Stream Crossing #29 - Weir	303	2	16
7632	Crossing	Stream Crossing #30 – Single barrel 3’ corrugated metal culvert, 16 feet long	303	2	16
7822	Footbridge	Stream Crossing #31 - Single span bridge with a span length of 18’	303	2	16
7907	Private Drive	Stream Crossing #32 – Single barrel 4.2’x3’ concrete box culvert, 23 feet long	303	2	16
8015	Footbridge	Stream Crossing #33 - Single span bridge with a span length of 14.2’	303	2	16
8030	Inline Structure	Stream Crossing #34 - Weir	303	2	16
8169	Footbridge	Stream Crossing #35 - Single span bridge with a span length of 14’	303	2	16
8320	Footbridge	Stream Crossing #36 - Single span bridge with a span length of 16’	303	2	16
8425	Footbridge	Stream Crossing #37 - Single span bridge with a span length of 14’	303	2	16
8504	Footbridge	Stream Crossing #38 - Single span bridge with a span length of 14.5’	303	2	16
8722	Trail Crossing	Stream Crossing #39 - Single span bridge with a span length of 14’	303	2	16
8839	Footbridge	Stream Crossing #40 - Single span bridge with an upstream span length of 18.2’ and downstream span length of 18.5’	303	2	16

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
10497	Trail Crossing	Stream Crossing #41 - Single barrel 3' corrugated metal culvert, 18 feet long	303	2	17
10510	Flow Change Location	Flow change location from hydrology report - "Mathew-Bird Creek upstream of Figgins Creek"	303	2	17
10558	Flow Change Location	Last cross section upstream of flow change location from hydrology report - "Mathew-Bird Creek upstream of Figgins Creek"	290	2	17
10642	Graf Street	Stream Crossing #42 – Triple barrel 4.9'x2.9' corrugated metal arch culvert, 105 feet long	290	2	17
11087	Footbridge	Stream Crossing #43 - Single span bridge with a span length of 14'	290	2	17
11096	Flow Change Location	Flow change location from hydrology report - "Mathew-Bird Creek through Graf Street"	290	2	17
11139	Flow Change Location	Last cross section upstream of flow change location from hydrology report - "Mathew-Bird Creek through Graf Street"	260	2	17
11201	Footbridge	Stream Crossing #44 - Single span bridge with a span length of 14'	260	2	17
11232	Shed over Mathew-Bird Creek	Stream Crossing #45 - Single span bridge with a span length of 17.5'	260	2	17
11707	Footbridge	Stream Crossing #46 - Single span bridge with a span length of 25'	260	2	17
11954	Footbridge	Stream Crossing #47 - Single span bridge with a span length of 18'	260	2	17
12014	Footbridge	Stream Crossing #48 - Single span bridge with a span length of 20'	260	2	17
12073	Footbridge	Stream Crossing #49 - Single span bridge with a span length of 16'	260	2	17
12133	Footbridge	Stream Crossing #50 - Single span bridge with a span length of 13'	260	2	17
12182	Footbridge	Stream Crossing #51 - Single span bridge with a span length of 11'	260	2	17
12415	Footbridge	Stream Crossing #52 - Single span bridge with a span length of 15'	260	2	18
12567	Footbridge	Stream Crossing #53 - Single span bridge with a span length of 15'	260	2	18

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
12922	Footbridge	Stream Crossing #54 - Single span bridge with a span length of 20’	260	2	18
13077	Footbridge 3316 Sundance Drive	Stream Crossing #55 - Single span bridge with a span length of 19’	260	2	18
13199	Footbridge 3318 Sundance Drive	Stream Crossing #56 - Single span bridge with a span length of 21’	260	2	18
13374	Footbridge 3318 Sundance Drive	Stream Crossing #57 - Single span bridge with a span length of 12’	260	2	18
13574	Footbridge	Stream Crossing #58 - Single span bridge with a span length of 15’	260	2	18
13857	Footbridge	Stream Crossing #59 - Single span bridge with a span length of 13.5’	260	2	18
14018	Footbridge	Stream Crossing #60 - Single span bridge with a span length of 11’	260	2	18
14073	Flow Change Location	Flow returns from Rain Roper Split and Peace Pipe Split via Junction "RainRoper"	260	2	18
14287	Flow Change Location	Last cross section before flow returns from Rain Roper Split via Junction "RainRoper"	126	1	18
14290	Footbridge	Stream Crossing #61 - Single span bridge with a span length of 9’	126	1	18
14294	Flow Change Location	Flow change location from hydrology report - "Mathew-Bird Creek near Sundance Drive". Flow is not the same as hydrology report because flow that exited on Rain Roper Split and Peace Pipe Split has not yet returned.	126	1	18
14409	Flow Change Location	Last cross section upstream of flow change location from hydrology report - "Mathew Bird Creek near Sundance Drive". Flow is not the same as hydrology report because flow that exited on Rain Roper Split has not yet returned.	108	1	18
14639	Footbridge at 330 Sundance Drive	Stream Crossing #62 - Single span bridge with a span length of 16’	108	1	18
14702	Trail Crossing	Stream Crossing #63 - Single span bridge with a span length of 21’	108	1	18
14706	Flow Change Location	Flow exits towards Rain Roper Split via LS 15712	108	1	18

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
14801	Flow Change Location	Flow exits towards Rain Roper Split via LS 15712	108	1	19
15247	Flow Change Location	Flow exits towards Rain Roper Split via LS 15712	130	1	19
15481	Flow Change Location	Flow exits towards Rain Roper Split via LS 15712	171	1	19
15713	Flow Change Location	Last cross section upstream of flow exits towards Rain Roper Split via LS 15712	242	1	19
15742	Peace Pipe Drive	Stream Crossing #64 - Double barrel 6.1'x3.8' horizontal elliptical concrete culvert, 50 feet long	242	1	19
15773	Flow Change Location	Flow exits towards Peace Pipe Split via LS 15821	242	1	19
16082	Field Crossing	Stream Crossing #65 - Triple span bridge with a full length of 35', 2-0.5' wide piers	242	1	19
16358	Footbridge	Stream Crossing #66 - Single span bridge with a span length of 20'	242	1	19
16793	Footbridge	Stream Crossing #67 - Single span bridge with a span length of 15'	242	1	19
17132	Footbridge	Stream Crossing #68 - Single span bridge with a span length of 22'	242	1	20
17322	Goldenstein Lane	Stream Crossing #69 - Single barrel 2.8'x1.8' horizontal elliptical concrete culvert, 52 feet long	242	1	20
17343	Flow Change Location	Flow change location from hydrology report - "Mathew-Bird Creek through Goldenstein Lane"	242	1	20
17477	Flow Change Location	Cross section upstream of flow change location from hydrology report - "Mathew-Bird Creek through Goldenstein Lane"	58	1	20
18332	Crossing	Stream Crossing #70 – Single barrel 2' corrugated metal culvert, 20 feet long	58	1	20
18714	Crossing	Stream Crossing #71 – Single barrel 2' corrugated metal culvert, 10 feet long	58	1	20
19312	Crossing	Stream Crossing #72 – Single barrel 2' corrugated metal culvert, 30 feet long	58	1	20
19627	Crossing	Stream Crossing #73 – Single barrel 1.5' concrete culvert, 24 feet long	58	1	20

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
20022	Crossing	Stream Crossing #74 – Single barrel 2' concrete pipe culvert, 22 feet long	58	1	21
20778	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge from hydrology report - "Mathew-Bird Creek upstream of Goldenstein Lane"	58	1	21

Table 3-20: Summary of Key Features along the Profile Baseline of Mill Ditch Diversion

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with East Gallatin River	Downstream study limit; confluence with East Gallatin River	143	4	5
36	Bohart Road	Stream Crossing #1 – Single barrel 4' corrugated metal culvert, 45 feet long	143	4	5
79	Flow Change Location	Flow change from the hydrology report - "Mill Ditch Diversion at confluence with East Gallatin River". Flow is not the same as hydrology report because flow that exited on I-90 split does not return.	143	4	5
166	Interstate 90	Stream Crossing #2 – Single barrel 4' concrete culvert, 172 feet long	128	4	5
266	Flow Change Location	Flow exits towards I-90 Split via LS 281	128	4	5
282	Flow Change Location	Flow returns from Cedar Street Split via Junction "MillCedar"	241	4	5
671	Flow Change Location	Cross section upstream of flow returns from Cedar Street Split via Junction "MillCedar"	153	3	5
1376	Cedar Street	Stream Crossing #3 - Single barrel 4.25'x2.6' horizontal elliptical concrete culvert, 40 feet long	153	3	5
1404	Flow Change Location	Flow exits towards Cedar Street Split via LS 1614	153	3	5
1611	Flow Change Location	Flow returns from Mill/Railroad Split via Junction "MillRail"	241	3	5

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
1629	Flow Change Location	Cross section upstream of flow returns from Mill/Railroad Split via Junction "MillRail"	239	2	5
2322	Flow Change Location	Flow change from the hydrology report - "Mill Ditch Diversion at Interstate 90". Flow is not the same as hydrology report because flow that exited on Mill/Railroad Split has not yet returned.	239	2	5
2706	Flow Change Location	Cross section upstream of flow change from the hydrology report - "Mill Ditch Diversion at Interstate 90". Flow is not the same as hydrology report because flow that exited on Mill/Railroad Split has not yet returned.	207	2	5
2976	Railroad Crossing	Stream Crossing #4 - Single span bridge with a span length of 14’	207	2	7
3018	Flow Change Location	Flow change from the hydrology report - "Mill Ditch Diversion at Northern Pacific Railroad". Flow is not the same as hydrology report because flow that exited on Mill/Railroad Split has not yet returned.	207	2	7
3058	Flow Change Location	Cross section upstream of flow change from the hydrology report - "Mill Ditch Diversion at Northern Pacific Railroad". Flow is not the same as hydrology report because flow that exited on Mill/Railroad Split has not yet returned.	161	2	7
3511	Railroad Crossing	Stream Crossing #5 – Single barrel 10’x4’ concrete box culvert, 77 feet long	161	2	7
3534	Flow Change Location	Flow exits toward Mill/Railroad Split via LS 3597	161	2	7
3576	Flow Change Location	Flow exits toward Mill/Railroad Split via LS 3597	161	2	7
3598	Flow Change Location	Cross section upstream of flow exits toward Mill/Railroad Split via LS 3597	163	2	7
3631	Access Road	Stream Crossing #6 – Single barrel 4’ concrete culvert, 172 feet long	163	2	7
4511	Simpkins Parking Lot Access	Stream Crossing #7 – Single barrel 3.4’ concrete culvert, 43 feet long	163	2	7
4536	Flow Change Location	Flow change from the hydrology report - "Mill Ditch Diversion upstream of Northern Pacific Railroad"	163	2	7
4818	Flow Change Location	Cross section upstream of flow change from the hydrology report - "Mill Ditch Diversion upstream of Northern Pacific Railroad"	123	2	7

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
5286	Railroad Crossing	Stream Crossing #8 – Single barrel 3.9' concrete culvert, 43 feet long	123	2	7
5546	Village Downtown Boulevard	Stream Crossing #9 – Single barrel 12'x3.25' concrete box culvert, 97 feet long	123	2	7
5760	Bozeman Town Pump Culvert	Stream Crossing #10 – Single barrel 12'x4' concrete box culvert, 223.7 feet long	123	2	7
5916	Main Street	Stream Crossing #11 – Single barrel 10.667'x5.24' corrugated metal arch culvert, 925 feet long	123	2	7
5973	Flow Change Location	10 year and 500 year flows taken from the hydrology report - "Mill Ditch Diversion at Main Street". 25, 50, and 100 year flows are still controlled by flows from Gallagator Split and Mill Ditch Diversion Structure.	123	2	8
6336	Inline Structure	Stream Crossing #12 - Weir	123	2	8
6501	Footbridge	Stream Crossing #13 - Single span bridge with a span length of 34'	123	2	8
6608	Inline Structure	Stream Crossing #14 - Weir	123	2	8
6921	Footbridge	Stream Crossing #15 - Single span bridge with a span length of 55'	123	2	8
8466	Trail Crossing	Stream Crossing #16 - Single barrel 5.8'x3.2' horizontal elliptical concrete culvert, 12 feet long	123	2	8
8701	South Church Avenue	Stream Crossing #17 - Double barrel 3.5' concrete culvert, 75 feet long	123	2	8
8745	Flow Change Location	Flow exits toward Bozeman Creek via LS 8937	123	2	9
8938	Flow Change Location	Flow enters from Gallagator Split	123	2	9
9018	Flow Change Location	Cross section upstream of flow entering from Gallagator Split	45	1	9
9036	Gallagator Trail	Stream Crossing #18 - Double barrel 3.5' corrugated metal culvert, 30 feet long	45	1	9
9226	Upstream Study Reach	Downstream study limit; furthest upstream cross section; discharge splits from Bozeman Creek, calculated via Bozeman Creek LS 11860 and 12087	45	1	9

Table 3-21: Summary of Key Features along the Profile Baseline of Mill Ditch Diversion – Railroad Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Mill Ditch Diversion	Downstream study limit; confluence with Mill Ditch Diversion	2	1	5
815	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge splits from Mill Ditch Diversion, calculated via Mill Ditch Diversion LS 3597	2	1	5

Table 3-22: Summary of Key Features along the Profile Baseline of Museum Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Figgins Creek	Downstream study limits; confluence with Figgins Creek	51	1	12
1560	Divergence from Figgins Creek	Upstream study limits; furthest upstream cross section; discharge splits from Figgins creek, calculated via Figgins LS 4139	51	1	12

Table 3-23: Summary of Key Features along the Profile Baseline of Nash Spring Creek

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Bozeman Creek	Downstream study limit; confluence with Bozeman Creek	116	2	22
93	Footbridge at 546 Kagy Boulevard	Stream Crossing #1 - Single span bridge with a span length of 21’	116	2	22
339	Footbridge at 544 Kagy Boulevard	Stream Crossing #2 - Single span bridge with a span length of 8’	116	2	22

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
450	Footbridge with Gazebo at 542 Kagy Boulevard	Stream Crossing #3 - Single span bridge with a span length of 9’	116	2	22
458	Flow Change Location	Flow exits towards Golf Course Split via LS 623	116	2	22
515	Flow Change Location	Flow exits towards Golf Course Split via LS 623	132	2	22
624	Flow Change Location	Cross section upstream of flow exiting towards Golf Course Split via LS 623	140	2	22
647	Golf Crossing	Stream Crossing #4 - Single barrel 3’ corrugated metal culvert, 0.44 feet long	140	2	22
669	Flow Change Location	Flow exits towards Golf Course Split via LS 890	140	2	22
752	Flow Change Location	Flow exits towards Golf Course Split via LS 890	196	2	22
891	Flow Change Location	Cross section upstream of flow exiting towards Golf Course Split via LS 890	267	2	22
894	Footbridge	Stream Crossing #5 - Single span bridge with a span length of 20’	267	2	22
896	Flow Change Location	Flow exits towards Golf Course Split via LS 1053	267	2	22
994	Flow Change Location	Flow exits towards Golf Course Split via LS 1053	271	2	22
1054	Flow Change Location	Cross section upstream of flow exiting towards Golf Course Split via LS 1053	273	2	22
1059	Golf Crossing	Stream Crossing #6 - Double barrel 3’ corrugated metal culvert, 8.5 feet long	273	2	22
1064	Flow Change Location	Flow exits towards Golf Course Split via LS 1266	273	2	22

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
1157	Flow Change Location	Flow exits towards Golf Course Split via LS 1266	300	2	22
1267	Flow Change Location	Cross section upstream of flow exiting towards Golf Course Split via LS 1266	323	2	22
1275	Golf Crossing	Stream Crossing #7 - Double barrel 2.5' corrugated metal culvert, 13 feet long	323	2	22
1283	Flow Change Location	Flow exits towards Golf Course Split via LS 1590	323	2	22
1436	Flow Change Location	Flow exits towards Golf Course Split via LS 1590	441	2	22
1591	Flow Change Location	Cross section upstream of flow exiting towards Golf Course Split via LS 1590	497	2	22
1597	Golf Crossing	Stream Crossing #8 - Single span bridge with a span length of 25'	497	2	22
2205	Golf Crossing	Stream Crossing #9 - Single span bridge with an upstream span length of 31.62' and a downstream span length of 31.42'	497	2	23
2291	Footbridge	Stream Crossing #10 - Single span bridge with a span length of 21.384'	497	2	23
2514	Footbridge	Stream Crossing #11 - Single span bridge with a span length of 16.5'	497	2	23
2645	Footbridge	Stream Crossing #12 - Single span bridge with a span length of 16.915'	497	2	23
2845	Footbridge	Stream Crossing #13 - Single span bridge with a span length of 18'	497	2	23
3115	Golf Crossing	Stream Crossing #14 - Single span bridge with a span length of 28.075'	497	2	23

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
3394	Footbridge	Stream Crossing #15 - Single span bridge with a span length of 14.1’	497	2	23
3453	Footbridge	Stream Crossing #16 - Single span bridge with a span length of 7.967’	497	2	23
3731	Inline Structure	Stream Crossing #17 - Weir	497	2	23
3772	Golf Crossing	Stream Crossing #18 - Single span bridge with a span length of 17.619’	497	2	23
3949	Footbridge	Stream Crossing #19 - Single span bridge with a span length of 16’	497	2	23
4167	Golf Crossing	Stream Crossing #20 - Double barrel 2.5’ corrugated metal culvert, 13 feet long	497	2	23
4176	Flow Change Location	Flow change location from hydrology report - "Nash Spring Creek at confluence with Bozeman Creek". Flows do not equal hydrology report because of addition of flows from Sourdough Trail Split	497	2	23
4415	Flow Change Location	Cross section upstream of RS 4176 flow change location	493	2	23
4609	Flow Change Location	Flow enters from Sourdough Trail Split. Maximum peak discharges on Nash Spring Creek downstream of this point are attained during maximum flow on Bozeman Creek. According to data interpolated from the hydrologic analysis, while Bozeman Creek is peaking, flows originating on Nash Spring Creek are at between 58% (for the 10yr event) and 27% (for the 500 year event) of their maximums. The peak Sourdough Trail Split flow and this percentage of the Nash Spring Creek flow are added together to calculate total peak flows in this area.	493	2	23
4996	Flow Change Location	Cross section upstream of flow entering from Sourdough Trail Split	225	1	23

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
5552	Trail Crossing	Stream Crossing #21 - Single barrel 3.4' corrugated metal culvert, 25 feet long	225	1	24
6302	Footbridge	Stream Crossing #22 - Single span bridge with a span length of 16.5'	225	1	24
6997	Footbridge	Stream Crossing #23 - Single span bridge with a span length of 25'	225	1	24
7262	Footbridge	Stream Crossing #24 - Single span bridge with a span length of 18.2'	225	1	24
7735	Trail Crossing	Stream Crossing #25 - Single barrel 2.7' corrugated metal culvert, 21 feet long	225	1	24
10388	Footbridge	Stream Crossing #26 - Single span bridge with a span length of 18.5'	225	1	26
10392	Flow Change Location	Flow change location from hydrology report - "Nash Spring Creek at Fox Hollow Road"	225	1	26
10455	Flow Change Location	Cross section upstream of flow change location from hydrology report - "Nash Spring Creek at Fox Hollow Road"	207	1	26
10547	Goldstein Lane	Stream Crossing #27 - Single barrel 4' corrugated metal culvert, 48 feet long	207	1	26
10574	Flow Change Location	Flow enters from Bozeman Creek via Bozeman Creek LS 32425. However, peak flows are not coincident, and peak flows that originate from Nash Spring Creek still dominate in this area.	207	1	26
14087	Inline Structure	Stream Crossing #28 - Weir	207	1	27
14160	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge from hydrology report - "Nash Spring Creek at Goldenstein Lane"	207	1	27

Table 3-24: Summary of Key Features along the Profile Baseline of Nash Road Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Bozeman Creek	Downstream study limit; confluence with Bozeman Creek	224	1	30
2373	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge splits from Bozeman Creek via Bozeman Creek LS 47978	224	1	31

Table 3-25: Summary of Key Features along the Profile Baseline of Peace Pipe Road Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Mathew-Bird Creek	Downstream study limit; confluence with Mathew-Bird Creek	0.1	1	18
2877	Upstream Study Reach	Upstream limit of study; furthest upstream cross section; discharge splits from Mathew-Bird Creek via Mathew-Bird Creek LS 15821	0.1	1	19

Table 3-26: Summary of Key Features along the Profile Baseline of Rain-Roper Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Mathew-Bird Creek	Downstream study limit; confluence with Mathew-Bird Creek	134	1	18
379	Flow Change Location	Discharge splits from Mathew-Bird Creek via Mathew-Bird Creek LS 15821	134	1	18
525	Flow Change Location	Discharge enters from Mathew-Bird Creek via Mathew-Bird Creek LS 15712	134	1	19
792	Flow Change Location	Discharge enters from Mathew-Bird Creek via Mathew-Bird Creek LS 15712	133	1	19

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
1023	Flow Change Location	Discharge enters from Mathew-Bird Creek via Mathew-Bird Creek LS 15712	103	1	19
1180	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge splits from Mathew-Bird Creek via Mathew-Bird Creek LS 15712	72	1	19

Table 3-27: Summary of Key Features along the Profile Baseline of Rouse Avenue Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Bozeman Creek	Downstream study limit; confluence with Bozeman Creek	229	3	9
751	Flow Change Location	Flow enters from Garfield Street Split via Junction "GarfieldRouse". Also, flow enters from Lower Black Split (manually entered in model)	229	3	9
1005	Flow Change Location	Cross section upstream of flow entering from Garfield Street Split via Junction "GarfieldRouse" and flow entering from Lower Black Split (manually entered in model)	86	2	9
3380	Flow Change Location	Flow enters from Flat Creek via Junction "FlatRouse"	86	1	10
3545	Flow Change Location	Cross section upstream of flow entering from Flat Creek via Junction "FlatRouse"	55	1	15
4727	Flow Change Location	Flow enters from Flat Creek via Flat Creek LS 1410	55	1	15
4769	Upstream Study Reach	Upstream limit of study; furthest upstream cross section; discharge manually adjusted to be half of the flow from Flat Creek that overtops Black Avenue Culvert (the other half flows to Black Avenue Split)	26	1	15

Table 3-28: Summary of Key Features along the Profile Baseline of Sourdough Trail Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Nash Spring Creek	Downstream study limit; confluence with Nash Spring Creek	346	1	23
1765	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge splits from Bozeman Creek via Bozeman Creek LS 27683	346	1	24

Table 3-29: Summary of Key Features along the Profile Baseline of Tracy Avenue Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Mathew-Bird Creek	Downstream study limit; confluence with Mathew Bird Creek	153	1	10
840	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge splits from Figgins Creek via Figgins Creek LS 513 and LS 394	153	1	11

Table 3-30: Summary of Key Features along the Profile Baseline of Wallace Avenue Split

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
0	Confluence with Bozeman Creek	Downstream limit of study; confluence with Bozeman Creek	84	1	3
2786	Flow Change Location	Flow enters from Church Avenue Split via Fridley Street, calculated with Church Avenue Split LS 969	84	1	6
2878	Flow Change Location	Cross section upstream of flow entering from Church Avenue Split via Fridley Street, calculated with Church Avenue Split LS 969	72	1	6

River Station (ft)	Feature	Description	1-percent-annual-chance discharge (cfs)	Model Reach Number	Work Map ID
3238	Flow Change Location	Flow enters from Church Avenue Split via Davis Street, calculated with Church Avenue Split LS 1420	72	1	6
3319	Flow Change Location	Cross section upstream of flow entering from Church Avenue Split via Davis Street, calculated with Church Avenue Split LS 1420	61	1	6
3607	Flow Change Location	Flow enters from Church Avenue Split via Lamme Street, calculated with Church Avenue Split LS 1772	61	1	6
3715	Flow Change Location	Cross section upstream of flow entering from Church Avenue Split via Lamme Street, calculated with Church Avenue Split LS 1772	51	1	6
3982	Flow Change Location	Flow enters from Church Avenue Split via Mendenhall Street, calculated with Church Avenue Split LS 2175	51	1	6
4095	Flow Change Location	Cross section upstream of flow entering from Church Avenue Split via Mendenhall Street, calculated with Church Avenue Split LS 2175	35	1	6
4826	Upstream Study Reach	Upstream study limit; furthest upstream cross section; discharge splits from Church Avenue Split via Church Avenue Split LS2594	35	1	6

3.5 Boundary Conditions

The reach boundary conditions were set using normal depth water surface elevations for all the primary flooding sources in this study. The slope was calculated based on the slope of the channel in the vicinity of the most downstream cross section. For the split flow flooding sources, boundary condition was set either using a junction or known water surface elevation (if the timing of the peak is the same for the split as for the receiving flooding source), or using normal depth (if the timing of the peak of the split is not the same as the receiving flooding source. For some flooding sources, water surface elevations at the downstream end of the reach will be controlled by backwater from the receiving flooding source. Table 3-31 summarizes the boundary conditions used in the analysis.

Table 3-31: Boundary Conditions

Flooding Source	Boundary Condition
3rd/Kagy Split	Junction with Figgins Creek (Junction: 3rdKagy)
Black Avenue Split	Normal Depth S = 0.012
Bozeman Creek	Normal Depth S = 0.010
Cedar Street Split	Junction with Mill Ditch Diversion (Junction: MillCedar)
Church Avenue Split	Junction with Bozeman Creek (Junction: ChurchBozema)
Figgins Creek	Normal Depth S = 0.014
Flat Creek	Junction with Rouse Avenue Split (Junction: FlatRouse)
Flat/Kagy Split	Normal Depth S = 0.100
Gallagator Split	Junction with Mill Ditch Diversion (Junction: Gallagator)
Garfield Street Split	Junction with Rouse Avenue Split (Junctions: GarfieldRous)
Golf Course Split	Junction with Flat Creek (Junction: GolfCourse)
I-90 Split	Normal Depth S = 0.002
Kagy/Rouse Split	Junction with Bozeman Creek (Junction: KagyRouse)
Lower Black Split	Known Water Surface Elevation (Equal to WSEL on Rouse Avenue Split)
Mathew Bird Creek	Normal Depth S = 0.014
Mill Ditch Diversion	Normal Depth S = 0.010
Mill/Railroad Split	Junction with Mill Ditch Diversion (Junction: MillRail)
Museum Split	Junction with Figgins Creek (Junction: Museum)
Nash Spring Creek	Normal Depth S = 0.010
Nash Road Split	Junction with Bozeman Creek (Junction: NashRdSplit
Peace Pipe Split	Junction with Mathew Bird Creek (Junction: RainRoper)
Rain Roper Split	Junction with Mathew Bird Creek (Junction: RainRoper)
Rouse Avenue Split	Normal Depth S = 0.010
Sourdough Trail Split	Junction with Nash Spring Creek (Junction: SourdoughTr)
Tracy Avenue Split	Normal Depth S = 0.005
Wallace Avenue Split	Junction with Bozeman Creek (Junction: WallaceBoze)

3.6 Manning's Roughness Coefficients

Manning's roughness coefficients (Manning's 'n' values) were determined based on aerial imagery and photographs provided by the Allied Engineering Surveyors.

For channel areas, Manning's 'n' values were set to 0.045 for most cross sections. This is indicative of a clean, winding channel with some weeds and stones. At other cross sections, Manning's 'n' values were higher, indicative of timber or brush in the channel. For flooding sources that run along roadways, Manning's 'n' values were set to 0.016, indicative of rough asphalt.

Manning's 'n' values for overbank areas were more variable, to account for different land uses and vegetation growth. At some cross sections, overbank Manning's 'n' values were as low as 0.040, indicative of grassy yard or pasture areas, or cultivated areas with field crops. At other cross sections, Manning's 'n' values were set higher, indicative of brush, trees, and undergrowth. At some cross sections, Manning's 'n' values were elevated somewhat higher than the vegetation would indicate to account for other obstructions in the floodplain, such as buildings, garages, or sheds. Table 3-32 provides a summary of the range of Manning's 'n' values used.

Table 3-32: Manning's 'n' Values used in Hydraulic Model

Land Use and Description	Range of Manning's 'n' Values
Channel – Winding with some weeds and stones	0.045
Channel – Winding with more weeds, brush, or trees	0.050 – 0.080
Channel – Street flow on asphalt	0.016
Overbanks – grassy areas	0.040 – 0.060
Overbanks – farmed/cultivated areas	0.040 – 0.060
Overbanks – brush, trees, other obstructions	0.060 – 0.080
Overbanks – low density development	0.045 – 0.080

3.7 Development of Cross Sectional Geometries

Cross sectional geometries were established based on the geometry of both the 2013 LiDAR and the 2012-2013 field survey. Cross sectional geometries were first taken from the LiDAR using HEC-GeoRAS, version 10 (Reference 14). At locations where cross section survey was collected, the survey data was superimposed on the cross section at the appropriate location using manual methods.

At cross section locations along the primary flooding sources where survey data not collected, bathymetric cross section geometry was interpolated between adjacent surveyed cross sections.

For cross sections on the secondary or split flow flooding sources, cross sectional geometries were determined using the LiDAR terrain data only. Given that these flooding sources did not contain water when the LiDAR was collected, bathymetric or survey data would not improve the modeling geometries. Therefore, survey was not collected or used in the model for these flooding sources.

Cross section locations were set using established engineering practice and guidance provided in the HEC-RAS Hydraulic Reference Manual. Several cross sections were modified using the skew adjustment in HEC-RAS. All total, there are 1,047 cross sections in the hydraulic model, across approximately 28 miles of detailed study. This averages out to approximately one cross section every 140 feet.

Contraction and expansion coefficients were set as recommended in the HEC-RAS Hydraulic Reference Manual – 0.3 and 0.5 in cross sections adjacent to hydraulic structures, and 0.1 and 0.3 in cross sections that are not adjacent to hydraulic structures. There are a handful of other cross sections that are not adjacent to hydraulic structures where higher expansion and contraction coefficients are used. These are indicative of rapid contraction or expansion caused by natural land features or man-made embankments.

Photographs of select cross sections (adjacent to hydraulic structures) can be viewed in Appendix F. The cross section numbering is based on the HEC-RAS river stations and not the river station the cross section was assigned when the field survey was collected. The "Surveyed Structure Stationing Key" table in Appendix F provides a cross walk between the HEC-RAS river stations and the survey data. In addition, a "Structures without Photographs" table was included in Appendix F to list the structures that do not have photographs to help identify them. Cross section geometries can be viewed in Appendix G.

3.8 Hydraulic Structures

Hydraulic structures were modeled in HEC-RAS using established engineering practice and guidance provided in the HEC-RAS Hydraulic Reference Manual. A total of 223 structures were surveyed and are modeled in the hydraulic model, all along the primary flooding sources. A summary of these structures is provided in Table 3-33 through Table 3-38.

Structure geometries were taken from the collected survey data. The photographs, sketches, and spatial data in GIS were all used to most reasonably and accurately model the geometry of each individual hydraulic structure.

Low flow and high flow structure modeling approaches were all determined in accordance with guidance provided in the HEC-RAS Hydraulic Reference Manual. Due to practical spacing limitations, not all hydraulic structures have the standard 4-cross section contraction and expansion placements recommended in the Hydraulic Reference Manual. However, for many structures, cross section 1 and cross section 4 of the recommended approach are not necessary – for example, in the instance of small footbridges that overtop easily, distinct contraction and expansion reaches do not exist in the traditional way. In these areas, the cross section associated with the next upstream or downstream structure is sufficient as a stand-in for the traditional cross section 1 or 4.

Photographs of most hydraulic structures can be viewed in Appendix F. Structure and cross section geometries can be viewed in Appendix G.

Table 3-33: Summary of Modeled Hydraulic Structures along Bozeman Creek

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Griffin Drive	46	Bridge	16				
Warehouse Road	1387	Bridge	60				
Gold Avenue	3372	Bridge	44				
Interstate 90	3650	Culvert		288	Concrete	Horizontal Ellipse & Box	8.5'x 10' (1), 9.7'x10.7' (1), 40'x10' (1 Box)
Railroad Bridge	4280	Bridge	45				
Warehouse Road	4780	Bridge	42				
Tamarack Street	5518	Bridge	24				
Wood Footbridge	5633	Bridge	48				
Peach Street	6735	Bridge	12				
North Rouse Avenue	7424	Bridge	19				
Private Drive	7518	Bridge	20				
Lamme Street	8590	Bridge	12				
City Hall Pedestrian Crossing	8735	Bridge	28				
Mendenhall Street	8970	Bridge	12				
Main Street North Alley	9170	Bridge	12				
Pedestrian Bridge	9216	Bridge	19				
Main Street	9370	Bridge	14				
Babcock Street	9755	Bridge	16				
Olive-Rouse	10100	Bridge	23				
Bogert Park Pedestrian Bridge	10965	Bridge	39				
Storey Street	11396	Bridge	12				
Mill Diversion Structure	11805	Bridge	44				
Gallagator Bridge	12110	Bridge	44				
Footbridge	12273	Bridge	34.5				
South Church Avenue	12980	Bridge	16				
South Church Avenue	13528	Bridge	17				
Footbridge at 905 South Church Avenue	13688	Bridge	21				

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Ice Pond Road	13952	Bridge	34				
Private Drive at 1203 South Church Avenue	15560	Bridge	22				
Private Drive at 1301 South Church Avenue	15696	Bridge	43				
Footbridge at 1307 South Church Avenue	15845	Bridge	30				
Private Drive	16690	Bridge	27				
Private Drive at 1417 South Church Avenue	17320	Bridge	31				
Bridge at 1629 South Church Avenue	17613	Bridge	26				
Bridge at 1629 South Church Avenue	17725	Bridge	60.5				
Bridge at 1815 Sourdough	18776	Bridge	28				
Bridge at 1815 Sourdough	19036	Bridge	19				
Footbridge	19377	Bridge	28.5				
Kagy Boulevard	20525	Bridge	52				
Footbridge	21305	Bridge	31				
Footbridge	22752	Bridge	24				
Footbridge	22956	Bridge	23.5				
Bradley Road	23272	Bridge	20				
Private Drive	23544	Bridge	24.5				
Footbridge	23949	Bridge	36				
Footbridge at 3375 Sourdough	24561	Bridge	32				
Footbridge	24971	Bridge	25.5				
Footbridge at 3455 Sourdough	25694	Bridge	29				
Footbridge at 3519 Sourdough	26017	Bridge	26.5				
Private Drive at 3599 Sourdough	27280	Bridge	30				
Footbridge	28037	Bridge	45				
Footbridge	28683	Bridge	45				

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Goldenstein Road	31730	Bridge	66				
Footbridge at 146 Hitching Post Road	32445	Bridge	28				
Footbridge	32697	Bridge	31.5				
Footbridge	33998	Bridge	30				
Footbridge	41950	Bridge	26.5				
Footbridge	43129	Bridge	26				
Nash Road	47063	Culvert		40	Concrete	Horizontal Ellipse	11.67'x7.75' (1)

Table 3-34: Summary of Modeled Hydraulic Structures along Figgins Creek

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Private Drive	137	Culvert		39	Metal	Circular	2.8' (1)
Private Drive	267	Bridge	7.5				
Private Drive	402	Bridge	11				
Kagy Boulevard	692	Culvert		230	Concrete	Horizontal Ellipse	2.5'x1.8' (1)
Footbridge at 1901 Tracy Avenue	883	Bridge	17.5		Wood		
Footbridge at 1907 Tracy Avenue	941	Bridge	11				
Footbridge at 2017 Tracy Avenue	1427	Bridge	16				
3rd Avenue	1812	Culvert		84	Concrete	Horizontal Ellipse	3'x2.2' (1)
Footbridge	2684	Bridge	13				
Footbridge	2715	Bridge	10				
Overbrook Drive	3012	Culvert		45	Metal	Arch	4'x2.4' (1)
Overbrook Drive	3342	Culvert		43	Concrete	Horizontal Ellipse	3.8'x2.8' (1), 4.2'x2.9' (1)
Trail	3522	Culvert		108	Concrete	Horizontal Ellipse	2'x1.5' (1)

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Footbridge	3687	Bridge	12				
Footbridge	3967	Bridge	10				
Trail	4002	Culvert		44	Concrete	Circular	3.1' (1)
Trail	5012	Culvert		10	Concrete	Horizontal Ellipse	3.4'x1.25' (1)
Trail	5872	Culvert		16	Concrete	Horizontal Ellipse	3.5'x2.2' (1)
Brookdale Drive	6702	Culvert		120	Metal	Arch	4.9'x3' (3)
Inline Structure	7487	Weir					
Alder Creek Road	7552	Culvert		102	Metal	Arch	4.9'x3' (2)
Trail	7737	Culvert		19	Concrete	Circular	2.1' (1)

Table 3-35: Summary of Modeled Hydraulic Structures along Flat Creek

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Footbridge	867	Bridge	8.5				
Footbridge	940	Bridge	10				
Footbridge	953	Bridge	6				
Black Avenue	1225	Culvert		58	Concrete	Horizontal Ellipse	2.6'x1.6' (1)
Private Drive	1310	Culvert		19.5	Concrete	Horizontal Ellipse	2.4'x2.9' (1)
Kagy Boulevard	1415	Culvert		175	Concrete	Horizontal Ellipse	4.5'x2.4' (1)
Trail	1800	Culvert		16	Metal	Circular	2' (1)
Inline Structure	1892	Weir					
Golf Crossing	2467	Culvert		5	Concrete	Horizontal Ellipse	2'x1.5' (1)
Golf Crossing	2835	Bridge	6				
Golf Crossing	3265	Bridge	8				
Golf Crossing	3640	Culvert		19	Concrete	Circular	3' (1)
Golf Crossing	3735	Culvert		20	Metal	Circular	2' (1)
Fence Crossing	3940	Bridge	27.3				
Culvert Crossing	4115	Culvert		330	Metal	Circular	2.5' (1)
Pond Outlet Structure	4465	Culvert		18	Concrete	Circular	1' (1)

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Pond Inlet	4815	Culvert		20	Metal	Circular	1.25' (1)
Golf Crossing	5015	Culvert		20	Metal	Circular	1.25' (1)
Golf Crossing	5370	Culvert		20	Metal	Circular	1' (1)
Footbridge	5433	Bridge	8.5				
Golf Crossing	5555	Culvert		12	Metal	Circular	1.5' (1)

Table 3-36: Summary of Modeled Hydraulic Structures along Mathew-Bird Creek

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Gallagator Trail	392	Bridge	25.114				
Trail Crossing	752	Bridge	27				
Footbridge	1152	Bridge	8				
Footbridge	1242	Bridge	16				
Footbridge	1429	Bridge	12				
Footbridge	1472	Bridge	17.7				
Footbridge	1692	Bridge	12.6				
Footbridge	1837	Bridge	25				
Footbridge	2225	Bridge	56				
Garfield Street	2372	Culvert		155	Metal	Arch	5.5'x3.5" (1)
Footbridge	2245	Bridge	15				
Footbridge	2509	Bridge	9				
Footbridge	3102	Bridge	40				
Mason Street	4102	Culvert		80	Concrete	Horizontal Ellipse	4.9'x3' (1)
Hoffman Drive	5087	Culvert		63	Metal	Arch	4.9'x3' (1)
Kagy Boulevard	5497	Culvert		155	Metal	Arch	4.5'x2.4' (1)
Footbridge	6067	Bridge	8				
Footbridge	6153	Bridge	10				
Footbridge at 2007 Spring Creek Drive	6249	Bridge	18				
Footbridge at 2104 Spring Creek Drive	6422	Bridge	12.7				
Footbridge at 2212 Spring Creek Drive	6475	Bridge	12				
Footbridge at 2404 Spring Creek Drive	6554	Bridge	13				

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Footbridge	6642	Bridge	13				
Footbridge	6777	Bridge	16				
Footbridge	6902	Bridge	10.9				
Footbridge	7020	Bridge	17.25				
Footbridge	7451	Bridge	16				
Footbridge	7510	Bridge	14				
Inline Structure	7533	Weir					
Crossing	7632	Culvert		16	Metal	Circular	3" (1)
Footbridge	7822	Bridge	18				
Private Drive	7907	Culvert		23	Concrete	Box	4.2'x3' (1)
Footbridge	8015	Bridge	14.2				
Inline Structure	8030	Weir					
Footbridge	8169	Bridge	14				
Footbridge	8320	Bridge	16				
Footbridge	8425	Bridge	14				
Footbridge	8504	Bridge	14.5				
Trail Crossing	8722	Bridge	14				
Footbridge	8839	Bridge	18.5				
Trail Crossing	10497	Culvert		18	Metal	Circular	3' (1)
Graff Street	10642	Culvert		105	Metal	Arch	4.9'x2.9' (3)
Footbridge	11087	Bridge	14				
Footbridge	11201	Bridge	14				
Shed over Mathew-Bird Creek	11232	Bridge	17.5				
Footbridge	11707	Bridge	25				
Footbridge	11954	Bridge	18				
Footbridge	12014	Bridge	20				
Footbridge	12073	Bridge	16				
Footbridge	12133	Bridge	13				
Footbridge	12182	Bridge	11				
Footbridge	12415	Bridge	15				
Footbridge	12567	Bridge	15				
Footbridge	12922	Bridge	20				
Footbridge at 3316 Sundance Drive	13077	Bridge	19				
Footbridge at 3318 Sundance Drive	13199	Bridge	21				
Footbridge at 3318 Sundance Drive	13374	Bridge	12				

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Footbridge	13574	Bridge	15				
Footbridge	13857	Bridge	13.5				
Footbridge	14018	Bridge	11				
Footbridge	14290	Bridge	9				
Footbridge at 330 Sundance Drive	14639	Bridge	16				
Trail Crossing	14639	Bridge	21				
Peace Pipe Drive	15742	Culvert		50	Concrete	Horizontal Ellipse	6.1'x3.8' (2)
Field Crossing	16082	Bridge	35				
Footbridge	16358	Bridge	20				
Footbridge	16793	Bridge	15				
Footbridge	17132	Bridge	22				
Goldenstein Lane	17322	Culvert		52	Concrete	Horizontal Ellipse	2.8'x1.8' (1)
Crossing	18332	Culvert		20	Metal	Circular	2' (1)
Crossing	18714	Culvert		10	Metal	Circular	2' (1)
Crossing	19312	Culvert		30	Metal	Circular	2' (1)
Crossing	19627	Culvert		24	Concrete	Circular	1.5' (1)
Crossing	20022	Culvert		22	Concrete	Circular	2' (1)

Table 3-37: Summary of Modeled Hydraulic Structures along Mill Ditch Diversion

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Bohart Road	36	Culvert		45	Metal	Circular	4' (1)
Interstate 90	166	Culvert		172	Concrete	Circular	4' (1)
Cedar Street	1372	Culvert		40	Concrete	Horizontal Ellipse	4.25'x2.6' (1)
Railroad Crossing	2976	Bridge	14				
Railroad Crossing	3511	Culvert		77	Concrete	Box	10'x4' (1)
Access Road	3631	Culvert		172	Concrete	Circular	4' (1)
Simpkins Parking Lot Access	4511	Culvert		43	Concrete	Circular	3.4' (1)
Railroad Crossing	5286	Culvert		43	Concrete	Circular	3.9' (1)
Village Downtown Boulevard	5546	Culvert		97	Concrete	Box	12'x3.25' (1)
Bozeman Town Pump Culvert	5760	Culvert		223.7	Concrete	Box	12'x4' (1)
Main Street	5916	Culvert		925	Metal	Arch	10.667'x5.24' (1)

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Inline Structure	6336	Weir					
Inline Structure	6608	Weir					
Footbridge	6921	Bridge	34				
Trail Crossing	8466	Culvert		12	Concrete	Horizontal Ellipse	5.8'x3.2' (1)
South Church Avenue	8701	Culvert		75	Concrete	Circular	3.5' (2)
Gallagator Trail	9036	Culvert		30	Metal	Circular	3.5' (2)

Table 3-38: Summary of Modeled Hydraulic Structures along Nash Spring Creek

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Footbridge at 546 Kagy Boulevard	93	Bridge	20				
Footbridge at 544 Kagy Boulevard	339	Bridge	8				
Footbridge with Gazebo at 542 Kagy Boulevard	450	Bridge	9				
Golf Crossing	647	Culvert		0.44	Metal	Circular	3' (2)
Footbridge	894	Bridge	20				
Golf Crossing	1059	Culvert		8.5	Metal	Circular	3' (2)
Golf Crossing	1275	Culvert		13	Metal	Circular	2.5' (2)
Golf Crossing	1597	Bridge	25				
Golf Crossing	2205	Bridge	31.52				
Footbridge	2291	Bridge	21.384				
Footbridge	2514	Bridge	16.5				
Footbridge	2645	Bridge	16.915				
Footbridge	2845	Bridge	18				
Golf Crossing	3115	Bridge	28.075				
Footbridge	3394	Bridge	14.1				
Footbridge	3453	Bridge	7.967				
Inline Structure	3731	Weir					
Golf Crossing	3772	Bridge	17.619				
Footbridge	3949	Bridge	16				
Golf Crossing	4167	Culvert		13	Metal	Circular	2.5' (2)
Trail Crossing	5552	Culvert		25	Metal	Circular	3.4' (1)
Footbridge	6302	Bridge	16.5				
Footbridge	6997	Bridge	25				
Footbridge	7262	Bridge	18.2				

Location	River Station	Type	Approx. Total Bridge Span (ft)	Culvert Length (ft)	Culvert Type	Culvert Shape	Culvert Size (# of Barrels)
Trail Crossing	7735	Culvert		21	Metal	Circular	2.7' (1)
Footbridge	10388	Bridge	18.5				
Goldenstein Lane	10547	Bridge	48				
Inline Structure	14087	Weir					

3.9 Non-Conveyance/Blocked Obstruction Areas

Ineffective areas and blocked obstructions were used in the model to restrict flows to areas of cross sections capable of actively conveying flow. Ineffective flow areas were used to model several different hydraulic scenarios:

- In the vicinity of hydraulic structures, ineffective areas are used in areas that would not actively convey flow due to being blocked by the abutments or the approach to the structure itself. These ineffective areas were placed in accordance with structure modeling guidance provided in the HEC-RAS Hydraulic Reference Manual.
- For hydraulically disconnected regions, ineffective areas were added to the model to account for the fact that flow would not be actively conveyed in these areas.
- In overbank areas where flow during flooding events would be minor or insignificant, ineffective areas were used to ensure that accurate hydraulic calculations were taking place in the active, more significant flowpaths. This type of area tended to be a location where flow would not significantly penetrate, such as locations where flow to the lower overbank areas would be mostly blocked by high ground or an embankment near to the bank station.
- Areas of backwater were modeled as ineffective flow.
- Areas where the flow would be predominately lateral to the primary direction of flow were modeled as ineffective flow areas. One example of this would be at a cross section where a lateral incoming ditch was picked up along the cross section from the terrain data. These areas of lateral flow would not convey flow effectively in the primary flow direction during a flooding event.
- Areas near buildings (or in the hydraulic "shadow" of buildings) were occasionally modeled as ineffective areas. This is done to account for areas of flow that would not be active to do the blockage caused by nearby buildings.

Blocked obstructions were also used in the model. These blocked obstructions primarily served two main purposes:

- Buildings in a cross section were occasionally modeled as blocked obstructions. Not all buildings were modeled this way – in areas where the profile of the building was narrow compared to the overall width of the cross section, blocked obstructions were not used and the Manning's 'n' value

was adjusted upward to account for areas of low-density development. However, in areas of higher density development, particularly in the downtown Bozeman area, blocked obstructions were used.

- Blocked obstructions were also used to block off the "normal" elevation of lakes, ponds, and other localized depressions.

All ineffective areas and blocked obstructions were placed in accordance with sound engineering judgment and guidance from the HEC-RAS Hydraulic Reference Manual. In total, 540 cross sections contain either ineffective flow, blocked obstructions, or both. A summary of cross sections with ineffective areas or blocked obstruction, along with reason for the placement of ineffective or blocked areas, is contained in the table titled "Explanation of Ineffective and Blocked Flows" in Appendix H.

3.10 Letter of Map Revision and Existing Study Data Incorporation

One Letter of Map Revision (LOMR) was incorporated into this hydraulic analysis and floodplain mapping effort: LOMR 15-08-0124P. This LOMR is on Mill Ditch Diversion at Bozeman Town Pump #1, upstream of Village Downtown Boulevard. This LOMR becomes effective on October 23, 2015. Because this hydraulic analysis fully incorporates the LOMR, the LOMR will not need to be re-issued after a Physical Map Revision (PMR) project incorporates this analysis.

A hydraulic analysis was performed by Allied Engineering Services, Inc. (Allied) for a section of Bozeman Creek in the downtown area, from Story Street to Peach Street. Geometric data from the Allied study including surveyed bridges, culverts, and cross sections were taken from the Allied study and were used in this hydraulic model. Several updates were made to the Allied data, including:

- Cross sections were extended left and right to encompass the entire floodplain
- Manning's 'n' values were adjusted to be consistent with this study
- Ineffective areas and blocked obstructions were adjusted and added
- Floodway modeling was performed

The Allied study has not been incorporated in the FIRMs and FIS. Because the Allied study is incorporated into this study, it will not need to be independently incorporated in the future.

3.11 Multiple/Worst Case Scenario Analysis

Reviews of the effective FIRM panels, survey data, and terrain data showed that there are no FEMA accredited levees in the study area.

There were two landforms that were considered to be non-levee embankments. Non-levee embankments are structures that cannot be accredited in accordance to the Code of Federal Regulations, Title 44, Chapter 1, Section 59.1 (44 CFR Section 59.1). These two non-levee embankments are:

- Along the right overbank of Museum Split, between Cross Section 1069 and Cross Section 314. The non-levee embankment is a trail that runs parallel to Museum Split. If the trail embankment were to

fail at any point along this reach, the flow in Museum Split would immediately spread out into a broad, unconfined area and split eastward towards Figgins Creek. According to normal depth calculations, depths in this area would be significantly less than one foot deep. Therefore, this area is mapped as a Zone X Shaded area.

- Along the left overbank of Lower Black Avenue Split, between Cross Section 541 and Cross Section 59. The non-levee embankment is a berm that runs parallel to Lower Black Avenue Split and the lower reach of Rouse Avenue Split. If the berm fails at any location along this reach, the flow in Lower Black Avenue would immediately spread out into a broad, unconfined area and split northward toward Bozeman Creek and Mathew Bird Creek. According to normal depth calculations, depths in this area would be significantly less than one foot deep. Therefore, this area is mapped as Zone X Shaded.

3.12 Model Calibration

Calibration of the hydraulic models could not be performed because of a lack of gage data and high water mark information in the study area. There are also no known historic peak discharges to use for comparison. The only verification of the model results can be assessed by community anecdotal information.

3.13 Floodway Analysis

Two types of floodway analysis were performed: Standard floodway analysis using the equal conveyance reduction method, and Administrative floodway analysis, using a technique developed specifically for the unique split flow characteristics of some flooding sources found in this study.

Floodways for all flooding sources with 1-percent-annual chance depths of greater than one foot were all determined using the equal conveyance reduction method. Per state of Montana guidelines, the maximum allowable surcharge at any given cross section is 0.50 feet. The floodway encroachment stations were revised until this requirement was met.

There are several notes to remember about the equal conveyance reduction floodways:

- The encroachment stations are set using the HEC-RAS hydraulic modeling program, encroaching on the overbanks on each side of the channel by reducing the conveyance equally on both sides until the target surcharge (0.50 feet) is met.
- When HEC-RAS sets the encroachment stations after the first floodway modeling run, there are frequently surcharges greater than the maximum allowable at many cross sections. The target surcharge is lowered on a cross section-by-cross section basis until the maximum allowable surcharge is not exceeded at any cross section.
- It is generally not possible for the surcharge to be exactly 0.50 feet at all locations. The surcharge is brought as close to the maximum allowable height at each cross section without going over.
- Negative surcharges are occasionally calculated in HEC-RAS. Efforts were made to change the encroachment stationing to remove the negative surcharges. However, some negative surcharges

remain. All remaining negative surcharges are no more than -0.04 feet in magnitude (i.e., they can be rounded to zero).

- At some areas where cross sections are close together, the equal conveyance reduction method produces a floodway that is unreasonable due to inconsistent floodway widths between cross sections. The floodway is smoothed by manually moving encroachment stations in the model.
- Because the encroachments are not allowed into the channels of flooding sources, floodways sometimes appear to be unbalanced. However, this is appropriate: if the channel is on the far left side of the floodplain, for example, the left side cannot be further encroached and all encroaching is done on the right side of the floodplain.
- In the vicinity of split flows, the target surcharge was set to zero feet. This was necessary to ensure that the flow distribution is maintained. Encroachment should not be allowed in these split areas because they may impact the flow distribution, and cause significant increases on far downstream on a split.

The second type of floodways created are Administrative Floodways, which were placed at the head of shallow flooding splits. The shallow flooding splits naturally reduce discharges on the main reach. Therefore, the the purpose of the Administrative Floodways is to protect the split flow distributions. The approach in designating these floodway areas was agreed upon by the Montana DNRC and FEMA Region VIII.

To create the administrative floodways, two approaches were used: first, all flows in that would naturally split were kept in the main reach for the encroached floodway run, for the entire duration of the split flow. This was the preferred alternative, because it does not rely on the split flow to keep surcharges below the allowable limit. However, this approach did not work for any of the splits – forcing the split flow back into the main reach caused unacceptable increases in the main reach.

Therefore, a second approach for designating administrative floodways was executed. This approach involved designating some of the upstream ends of the shallow flow splits as Administrative Floodways in order to protect the split flow distribution.

Modeling calculations for the Administrative Floodway were performed in the model plan titled “Bozeman Administrative FW Calculations”. It is important to note that this model plan should not be used for determining water surface elevations or any other purpose: it was exclusively used to determine the extents of the Administrative Floodways.

To determine the extents of the Administative Floodways, blocked obstructions were used the model. A pre-determined height of blockage of the channel was set for each of the shallow flow splits. The blockage was set as follows:

- 1 foot high for shallow flooding splits along roads with no nearby intersections
- 2 feet high for shallow flooding splits along roads with nearby intersections
- 5 feet high for shallow flooding splits in broad, unconfined areas.

These heights were selected based on what a reasonable expectation for likely potential changes to the floodplain could be. For example, along roads with no nearby intersections, likely potential changes to the flowpath could include road realignment, widening, repaving, or have speedbumps installed. None of these changes are likely to make a difference of more than one vertical foot on the flowpath. Therefore, adding a blocked obstruction of 1 foot in height would most likely encompass all future changes to the flowpath.

The blocked obstruction of pre-determined height was moved along the cross sections of split flow paths until the obstruction no longer impacted the most upstream cross section of the split. The location of the blocked obstruction defines the Administrative Floodways. We can be reasonably confident that no future changes to the flowpaths downstream of the limit of Administrative Floodway would impact the flow distribution of the split.

A detailed list of the eight administrative floodways is provided in Table 3-39. These Administrative Floodways should be administered in the same fashion as the standard floodways: no encroachments should be permitted unless it can be shown that the project would not cause increases (including on the main reaches), or unless a CLOMR is approved.

Table 3-39: Administrative Floodways

Flooding Source	Blockage Depth used in calculations (ft)	Downstream limit of Floodway (Cross Section Number)
3rd/Kagy Split	2	901
Black Avenue Split	1	2545
Church Avenue Split	2	2919
Garfield Street Split	2	974
I-90 Split	5	2033
Lower Black Avenue Split	1	1164
Rouse Avenue Split	1	4452
Tracy Avenue Split	2	572

3.14 cHECk-RAS

The cHECk-RAS computer program was used as a tool to find possible errors in the HEC-RAS hydraulic model. All errors found by cHECk-RAS have either been resolved or reviewed to confirm that the modeling is correct. The full cHECk-RAS output set, along with notes and "responses", can be found in Appendix I.

Section 4: Floodplain Mapping

FEMA's KSS and many of FEMA's technical guidance documents were consulted to ensure the mapping meets mandatory requirements necessary to map the results of this study on Gallatin County's FIRM panels in the future. To create this data set so that it can be incorporated into the Gallatin County DFIRM, the following guidance documents were used: Data Capture Standards Technical Reference (Reference 18),

FlRM Panel Technical Reference (Reference 19), Mapping Base Flood Elevations on Flood Insurance Rate Maps (Reference 20); Metadata (Reference 21); Physical Map Revision (PMR) (Reference 22); Flood Insurance Rate Map (FIRM) Database (Reference 23); and, Flood Insurance Rate Map (FIRM) Graphics (Reference 24).

In this section of the report, four different sets of maps are presented to help illustrate the updates to the SFHAs in the study and how these changes impact the community. These maps are discussed in length in Sections 4.1, 4.3, 4.4 and 4.5. For all four sets of maps, the layout and numbering scheme match so that report users can easily compare the information shown on the different work maps.

4.1 Floodplain Work Maps

Floodplain mapping was performed using results from the hydraulic analysis and the 2013 PhotoScience LiDAR. The workmaps are included in Appendix B, and they show the locations of the 1- and 0.2-percent-annual-chance flood event floodplain delineations along with the floodway delineations. Water surface elevation data, as well as floodway extents, were extracted from HEC-RAS using GeoRAS, version 10. GeoRAS was also used to produce rough floodplain delineations. These rough delineations were manually smoothed and adjusted to ensure reasonable floodplain delineations and to account for hydraulic features such as backwater or islands.

At some hydraulic cross sections, mapped floodplain and floodway topwidths may not exactly match modeled floodplain and floodway topwidths. A table titled "Map-Model Topwidth Agreement Check" has been included in Appendix H to identify these locations and to call out other conditions that cause the mapping to vary from the model output. These apparent discrepancies have multiple causes, depending on the cross section. Some of the reasons for apparent map-model discrepancy include:

- Differences caused by the fact that elevations derived for the model from the survey data are different from the LiDAR that was used for floodplain mapping
- All small islands are removed from the mapping – this is a standard FEMA practice to account for uncertainty around the islands, and because many islands are not visible at the FIRM scale
- Hydraulically disconnected areas, which occasionally impact the model topwidth, are not mapped
- Mapping at a cross section can be influenced by another flooding source
- Differences can be caused by rapid expansion or contraction of the floodplain width in the model – i.e. – one cross section depicts flow wide across the entire low valley of the floodplain, and the next cross section depicts all flow contained in the channel. However, in reality, all flow would not immediately be directed to the channel. In these instances, engineering judgment was used to create a realistic floodplain.

Flooding sources that maintained 1-percent-annual chance flooding depths of less than 1.0 foot for significantly long reaches were mapped as X-shaded flooding Zones. Flooding sources with average depths of less than 1.0 foot include 3rd/Kagy Split, Black Avenue Split, Church Avenue Split, Garfield Street Split, the lower portion of I-90 Split, the upper portion of Lower Black Split, Mill/Railroad Split, Rouse Avenue Split,

Tracy Avenue Split, and Wallace Avenue Split. Table 4-1 highlights the flooding sources that are susceptible to shallow flooding only, along with the average flow depth.

Table 4-1: Shallow Flooding Sources

Flooding Source	Average Depth (ft)
3rd/Kagy Split	0.5
Black Avenue Split	0.3
Church Avenue Split	0.4
Flat Creek (Downstream of XS 403)	0.5
Garfield Street Split	0.5
I-90 Split (Downstream of XS 2719)	0.4
Lower Black Avenue Split (Upstream of XS 306)	0.4
Rouse Avenue Split	0.4
Tracy Avenue Split	0.5
Wallace Avenue Split	0.3

Flowpaths that diverge from these shallow flooding areas were also delineated, primarily along streets in the downtown area, alongside Bozeman Creek, Church Avenue Split, and Wallace Avenue Split. Many of these flowpaths were not modeled. These flowpaths primarily diverge from other shallow flooding areas and would be constrained to relatively low discharges. It is reasonable to assume in each case that average flow depths below 1.0 foot would be maintained; therefore, further modeling was not necessary. These flowpaths were delineated either until they converged with a modeled flowpath, or were terminated at locations that were deemed to have sub-surface storm sewer systems with adequate capacity to carry the flow.

In addition to these shallow flooding sources, two other flooding sources are also mapped as Zone X shaded hazards: Peace Pipe Split and Mill/Railroad Split. These two flooding sources are mapped as Zone X shaded flooding sources because the flow splits will not be significant during the 1%-annual-chance event, but they will occur during the 0.2%-annual-chance event.

4.2 Effective Tie-In Locations

There are only three streams and four locations where it is necessary to tie-in the revised study data to effective SFHAs. These areas are summarized in Table 4-2 which also lists the effective SFHAs the restudies will be tied into along with the tie-in streams' water surface elevations. The upstream limit of Bozeman Creek ties-in to an effective Zone A so the actual water surface elevations are not listed in the table. Also, the 4-percent-annual-chance water surface elevations were not included in the table because the effective studies do not have published values for that flood frequency. Table 4-2 also identifies the Hydraulic Work Map where the effective tie-in locations can be found.

Table 4-2: Water Surface Elevations for Effective Profile Tie-Ins for Restudied Streams

Flooding Source	Effective Tie-In Flooding Source	Work Map ID	Flood Frequency				
			10%-Annual-Chance Peak Discharge Water Surface Elevation (ft)	4%-Annual-Chance Peak Discharge Water Surface Elevation (ft)	2%-Annual-Chance Peak Discharge Water Surface Elevation (ft)	1%-Annual-Chance Peak Discharge Water Surface Elevation (ft)	0.2%-Annual-Chance Peak Discharge Water Surface Elevation (ft)
Downstream End of Bozeman Creek	East Gallatin River	1	4,715.5	NA	4,715.9	4,716.1	4,716.7
Upstream End of Bozeman Creek	Effective Zone A	31	NA	NA	NA	NA	NA
Downstream end of Interstate 90 Split	East Gallatin River	1	4,726.4	NA	4,727.7	4,727.7	4,728.3
Mill Ditch Diversion	East Gallatin River	5	4,746.9	NA	4,747.7	4,748.1	4,748.5

4.3 Changes Since Last FIRM Mapping – 1-Percent-Annual-Chance Flood Event Comparison

The Changes Since Last FIRM (CSLF) dataset highlights locations where this restudy has resulted in changes to the 1-percent-annual-chance flood event when compared to the effective 1-percent-annual-chance flood event on the 2011 FIRM. This dataset can quickly show communities areas that were added or removed from the SFHA and is a useful tool for outreach or mitigation activities. The CSLF work maps are included in Appendix J. FEMA's Guidance for Flood Risk Analysis and Mapping: Changes Since Last FIRM (Reference 25) document was used to help create this product.

4.4 Changes Since Last FIRM Mapping – Floodway Comparison

In addition to the CSLF work maps that show changes in the 1-percent-annual-chance flood event, a separate set of work maps was created to show the changes in floodway delineations between the new and effective studies. The CSLF – Floodway Comparison maps are located in Appendix K.

4.5 Letters of Map Change Analysis

To help prepare Bozeman and Gallatin County for the future FIRM and FIS updates, the DNRC has evaluated all Letters of Map Change (LOMC) which includes Letters of Map Amendment (LOMA), Letters of Map Revision based on Fill (LOMR-F), and Letters of Map Revision Floodway (LOMR-FW) to see if the LOMCs are located on potential PMR FIRM panels (Appendix C). Table 4-3 lists the cases for Bozeman, and Table 4-4 lists the Gallatin County cases that were included in Gallatin County and Bozeman's Revalidation letters (07-08-0704V-300027 and 07-08-0704V-300028, respectively) along with LOMCs that have been processed since the Gallatin Countywide DFIRM project's effective date of September 2, 2011. These cases will be included in the Summary of Map Actions (SOMAs) letters for Bozeman and Gallatin County when the PMR is processed. The location maps are included in Appendix L and the locations of the LOMCs are shown on the maps with a star and the corresponding case number. The Letters of Map Revision discussed in Section 3.10 of this report are not included in this section. The LOMCs are available for download from FEMA's Map Service Center website http://msc.fema.gov/.

Table 4-3: Bozeman LOMC Cases

LOMC Case Number	Determination Date	Identifier	FIRM Panel
03-08-0339A	May 21, 2003	Mathew-Bird Creek - South Meadow Minor Subdivison, Portion of Lots 2 and 3	30031C0819D
04-08-0106A	December 19, 2003	Figgins Creek - 2000 South Third Avenue; Lot 3, Block 4, Thompson's Addition No. 3	30031C0816D
05-08-0660A	September 22, 2005	Figgins Creek - 409 Overbrook Drive; Overbrook at Westridge	30031C0816D
09-08-0194A	April 21, 2009	Bozeman Creek - 425 East Aspen Street; Tract A, Block 117, Northern Pacific Addition	30031C0809D
11-08-1121A*	October 18, 2011	Bozeman Creek - 3095 Sourdough Road; Lot 9, Block/Section A, Meadowlark	30031C0819D
12-08-0339A	April 5, 2012	Mathew-Bird Creek - 1615 South Black Avenue, #109; Lot 109, Minor No. 38 (Woodbrook Townhouses, 2)	30031C0816D
12-08-0402A	March 2, 2012	Figgins Creek - 3229 Hidden Springs Lane; Lot 2, Block 12, Alder Creek, Phase 2	30031C0818D
12-08-0464A	May 8, 2012	Figgins Creek - 3111 Summerset Drive; Lot 2, Block 9, Alder Creek, Phase 2	30031C0818D
12-08-0482A	May 1, 2012	Figgins Creek - 2407 Westridge Drive; Lot 14, Block 9, Figgins Addition, Phase 4	30031C0818D
12-08-0710A	August 14, 2012	Bozeman Creek - 717 North Church Avenue; Lots 8-12, Block 118, Northern Pacific Addition	30031C0817D
12-08-0722A	August 30, 2012	Bozeman Creek - 619 North Church Avenue ; Lots 7-12, Block 119, Northern Pacific Addition	30031C0817D
12-08-1008A	October 2, 2012	Figgins Creek - 3273 Hidden Springs Lane; Lot 5, Block 12, Alder Creek, Phase 2	30031C0818D
13-08-0165A	January 10, 2013	Bozeman Creek - 402 Bonner Lane; Lot 15, Ice Pond Townhouses P.U.D.	30031C0816D

LOMC Case Number	Determination Date	Identifier	FIRM Panel
13-08-0418A	February 21, 2013	Bozeman Creek - 301 East Olive Street; Guy's Addition	30031C0816D
13-08-0523A	March 19, 2013	Bozeman Creek - 307 East Olive Street; Lots 1-2, Guy's Addition	30031C0816D
13-08-0553A	June 20, 2013	Mill Ditch Diversion - 202 North Broadway Avenue; Lot 14, Block 41, Northern Pacific Addition	30031C0817D
13-08-0728A	June 11, 2013	Bozeman Creek - 803 South Church Avenue; Portion of Section 18, Bozeman Creek Annexation	30031C0817D
13-08-0769A	May 23, 2013	Bozeman Creek - 425 East Lincoln Street; Portion of Section 18, Lot 2	30031C0817D
13-08-1144A	September 12, 2013	Mathew-Bird Creek - 102 Silverwood Drive; Lot 18A, Amended Portion of Woodridge Addition	30031C0818D
13-08-1237A	September 26, 2013	Mill Ditch Diversion - 102 North Broadway; Portion of Section 7, Lot 1	30031C0817D
13-08-1380A	November 5, 2013	Bozeman Creek – 2185 Kagy Garden Court; Portion of Section 18, Township 2 South, Range 6 East, Lot 1, Minor Sub 464	30031C0817D
14-08-0037A	October 24, 2013	Bozeman Creek - 425 Ice Pond Road; Portion of Section 18, Township 2 South, Range 6 East	30031C0817D
14-08-0359A	May 29, 2014	Bozeman Creek - 123 South Rouse Avenue; Portion of Section 7, Lot 2	30031C0816D
14-08-0642A	April 22, 2014	Figgins Creek - 2409 Westridge Drive; Lot 13, Block 9, Figgins Addition, 4th Phase	30031C0818D
14-08-1130A	July 17, 2014	Figgins Creek - 3217 Hidden Springs Lane; Lot 1, Block 12, Alder Creek Subdivision, Phase 2	30031C0818D
15-08-0764A	April 9, 2015	Bozeman Creek - 3173 Sourdough Road	30031C0818D
15-08-1033A	June 5, 2015	Figgins Creek - 3117 Summerset Drive; Lot 3, Block 9, Alder Creek Subdivision, Phase 2	30031C0818D

*Case supersedes 03-08-0252A on the City of Bozeman Revalidation letter (07-08-0704V-300028).

Table 4-4: Gallatin County LOMC Cases

LOMC Case Number	Determination Date	Identifier	FIRM Panel
02-08-151A	June 7, 2002	Bozeman Creek – 2855 Sourdough Road; COS 2072, Lot 1, Portion of Section 19, T2S, R6E, M.P.M.	30031C0816D
12-08-0060A*	December 15, 2011	Bozeman Creek - 3045 Sourdough Road; Lots 1-4, Block/Section A, Meadowlark	30031C0819D
12-08-0061A**	December 15, 2011	Bozeman Creek - 3075 Sourdough Road; Lots 6-7 & 12-13, Block/Section A, Meadowlark	30031C0819D
13-08-0410A	March 12, 2013	Bozeman Creek - 3485, 3519 Sourdough Road; Lot 14-15, Bulen's	30031C0819D

*Case supersedes 98-08-108A on the City of Bozeman Revalidation letter (07-08-0704V-300028).
**Case supersedes 92-08-011G on the City of Bozeman Revalidation letter (07-08-0704V-300028).

4.6 Floodplain Boundary Standard Audit

The Floodplain Boundary Standard (FBS) audit is a process originally introduced in FEMA's Procedure Memorandum (PM 38) (Reference 26) to "provide reliable and defendable" flood hazard mapping to incorporate into the FIRM. The FBS audit verifies that the floodplain delineations are accurate by comparing the water surface elevations generated by hydraulic modeling to the best available terrain data. For this study, the water surface elevations were created using the best available terrain data so the self-certification process went smoothly. However, it was necessary to denote many audit points as "exceptions" since they violated acceptable compliance tolerances for practical reasons. Examples of exceptions to an audit point being out of tolerance are confluence, tributary or backwater areas, and around hydraulic structures. The FBS self-certification forms are included with the QA/QC documentation for this study.

4.7 Flood Depth Grids

Flood depth grids were created for the 1- and 0.2-percent-annual chance flood events to show the difference in inundation depths for the flood frequencies. The flood depth grids are tools communities can use to illustrate different action that can be taken to reduce flood risk. FEMA's Guidance for Flood Risk Analysis and Mapping: Flood Depth and Analysis Grids (Reference 27) was followed to create the flood depth grids. The flood depth grids are included in the digital datasets that accompany this report.

Section 5: Flood Insurance Study

FEMA's KSS (Reference 16), Technical Reference: FIS Report (Reference 28), and Guidance for Flood Risk Analysis and Mapping: Flood Insurance Study Report (Reference 29) were followed to create the products in this section of the report. The 2011 FIS for Gallatin County was created prior to the release of FEMA's new format guidance, and it is assumed that a future PMR project to incorporate this analysis in the

Gallatin County FIS and DFIRM will be produced using the newest specifications. The FIS components included in Sections 5.1, 5.2, and 5.3 were created using FEMA's latest format specifications.

5.1 FIS Text

The relevant FIS tables have been populated with data from this study and will supersede the information in the 2011 FIS when a PMR project is sponsored. The FIS information is in Appendix M.

5.2 Floodway Data Tables

The Floodway Data Tables are in Appendix N of this report. Footnotes have been added where appropriate to denote cross sections where special considerations cause differences between the information reported in the Floodway Data Tables, the HEC-RAS model, or the Hydraulic Work Maps.

5.3 Water Surface Elevation Profiles

Profiles have not been provided for split flow reaches with depths less than 1 foot and those reaches will be mapped Shaded Zone X. The split flows that will not have a profile include: Mill Railroad Split, Peace Pipe Road Split, and Wallace Avenue Split.

In addition, flooding sources with partially mapped profiles due to the necessity of having administrative floodways and/or depths of less than 1 foot include the following:

- 3rd/Kagy Split (Administrative FW U/S of XS 901)
- Black Avenue Split (Administrative FW U/S of XS 2545)
- Church Avenue Split (Administrative FW U/S of XS 2919)
- Garfield Street Split (Administrative FW U/S of XS 974)
- I-90 Split (Administrative FW U/S of XS 2033, deeper than 1 foot U/S of 2782)
- Lower Black Split (Administrative FW U/S of XS 622, deeper than 1 foot D/S of XS 541)
- Rouse Avenue Split (Administrative FW U/S of 4452, deeper than 1 foot D/S of XS 596)
- Tracy Avenue Split (Administrative FW U/S of XS 572)

The water surface elevation profiles depict the 10-, 4-, 2-, 1-, and 0.2-percent annual chance flood events and are included in Appendix O of this report.

Section 6: References

1. Federal Emergency Management Agency, Flood Insurance Study, Gallatin County Montana and Incorporated Areas, September 2, 2011.

2. Allied Engineering Services, Inc., Field Survey Summary Report, Bozeman Creek and Tributaries Floodplain Restudy, Bozeman, MT, January 18, 2013.

3. Photo Science Geospatial Solutions, Bozeman Creek, MT, LiDAR FOCUS, May 16, 2013.

4. Respec Consulting & Services, Bozeman Creek Hydrologic Analysis – Bozeman Creek and Tributaries Digital Flood Insurance Rate Map Restudy Project, April 2014.

5. Respec Consulting & Services, Figgins Creek Hydrologic Analysis – Bozeman Creek and Tributaries Digital Flood Insurance Rate Map Restudy Project, March 2014.

6. Respec Consulting & Services, Flat Creek Hydrologic Analysis – Bozeman Creek and Tributaries Digital Flood Insurance Rate Map Restudy Project, January 2014.

7. Respec Consulting & Services, Mathew-Bird Creek Hydrologic Analysis – Bozeman Creek and Tributaries Digital Flood Insurance Rate Map Restudy Project, March 2014.

8. Respec Consulting & Services, Mill Ditch Diversion Hydrologic Analysis – Bozeman Creek and Tributaries Digital Flood Insurance Rate Map Restudy Project, April 2014.

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