Big Hole River Approximate Level Floodplain Study

Hydraulic Analysis and Floodplain Mapping

August 15, 2014

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Table of contents

Chapter		Pages
1.	**Introduction**	**1**
1.1.	Background Information	1
1.2.	Basin Description	2
1.3.	Big Hole River Approximate Flood Study	3
2.	**Past Studies**	**5**
2.1.	SCS Flood Plain Management Study	5
2.2.	FEMA Flood Insurance Study	6
2.3.	Flood Inundation Potential Mapping and Channel Migration Zone Delineation	7
3.	**Hydrologic Analyses**	**9**
4.	**Hydraulic Analysis**	**14**
4.1.	Hydraulic Analysis Overview and Procedures	14
4.2.	Topographic Data Acquisition	17
4.3.	Profile Baseline	17
4.4.	Boundary Conditions	22
4.5.	Development of Cross Sectional Geometries	22
4.6.	Bank Station Assignments	22
4.7.	Hydraulic Structures	23
4.8.	Roughness Coefficients	23
4.9.	Areas of Non-Conveyance	24
4.10.	Model Calibration	24
4.11.	cHECk-RAS	24
5.	**Floodplain Mapping**	**25**
5.1.	Zone Descriptions	25
5.2.	Tie-In to Effective Mapping	26
6.	**Unique Modeling and Mapping Scenarios**	**27**
6.1.	Diverted and Split Flows	27
6.2.	Conflicting Data Sources	33
6.3.	West Reach Tie-in to SCS Study	34
6.4.	Urbanized Areas	38
7.	**Summary**	**41**
8.	**References**	**42**

Appendices

Appendix A.	**Floodplain Maps**	**A**
Appendix B.	**cHECk-RAS**	**B**
Appendix C.	**Top Width Checks**	**C**
Appendix D.	**Profiles**	**D**
Appendix E.	**Floodplain Data Tables**	**E**
Appendix F.	**Topographic Data Report**	**F**
Appendix G.	**FEMA Effective Data**	**G**
Appendix H.	**Big Hole Rating Curves**	**H**

Tables

Table 1. Big Hole River Floodplain Study reach descriptions. 3
Table 2. Results and flow change locations of the 1986 SCS Flood Plain Management Study 6
Table 3. Results and flow change locations of the 1986 FEMA FIS 6
Table 4. Results and flow change locations of the 2005 Flood Inundation Potential Mapping Study 7
Table 5. Utilized Discharges and Hydrologic Methods for the Big Hole River 10
Table 6. Summary of discharges for the East Reach of the Big Hole River 12
Table 7. Summary of discharges for the West Reach of the Big Hole River 13
Table 8. Summary of HEC-RAS models and associated plans utilized for the present study 15
Table 9. Summary of key features along the profile baseline of the East Reach 18
Table 10. Summary of key features along the profile baseline for the North Section of the West Reach 19
Table 11. Summary of key features along the profile baseline for the Middle Section of the West Reach 20
Table 12. Summary of key features along the profile baseline for the South Section of the West Reach 21
Table 13. Summary of overflow discharges of the East Reach 30
Table 14. Comparison of WSELs affected by the application of diverted flows 31
Table 15. Summary of overflow models of the East Reach 32
Table 16. Summary of split discharges of the West Reach at Wisdom Split 33
Table 17. Comparison of WSEL and top width at West Reach tie-in to SCS Study 34

Figures

Figure 1. Overview of approximate study limits 4
Figure 2. Recommended 1-percent annual discharge for each location 11
Figure 3. Sections of the analyzed West Reach 16
Figure 4. Difference in floodplains below the most upstream overflow of the East Reach 28
Figure 5. Difference in floodplains below the most downstream overflow of the East Reach 29
Figure 6. West Reach downstream tie-in utilizing SCS WSEL for boundary condition. 36
Figure 7. West Reach downstream tie-in utilizing normal depth for boundary condition 37
Figure 8. Originally delineated floodplains at the Town of Wisdom 39
Figure 9. Updated 100-year floodplain at the Town of Wisdom 40

1. Introduction

In cooperation with the Montana Department of Natural Resources and Conservation (DNRC), the Montana Department of Environmental Quality (DEQ), Anaconda-Deer Lodge County, Beaverhead County, Butte-Silver Bow County, Madison County, the Big Hole River Watershed Committee (BHWC), and Future West, Atkins and RESPEC have been contracted to perform an approximate level floodplain analysis for 117 miles of the Big Hole River. The entities mentioned above have provided financial support for this project as well as acting as a Technical Advisory Committee (TAC) for work products. This approximate level floodplain analysis is the final phase of a two phase effort to better understand the flood hazard and refine the flood hazard boundary along the Big Hole River.

1.1. Background Information

At the time of this study, Butte-Silver Bow and Anaconda-Deer Lodge Counties are the only counties to have effective FEMA maps along the Big Hole River. The Big Hole River from the confluence with the Jefferson River at Twin Bridges to the Butte-Silver Bow Co. boundary is within Madison and Beaverhead Co. and is therefore unmapped by the Federal Emergency Management Agency (FEMA). Once the Big Hole River meets the Butte-Silver Bow Co. boundary just south of Melrose, the river serves as the divide between Beaverhead and Butte-Silver Bow Co. Beaverhead Co. is located on the west side of the river and is unmapped. The east side of the Big Hole River is located in Butte-Silver Bow Co. and is effectively mapped with a mix of detailed and approximate studies. From the Butte-Silver Bow southern boundary, the east side of the Big Hole River is mapped as a detailed area (Zone AE) with a floodway. The detailed area extends upstream approximately 0.5 mi through the town of Melrose. From the upstream limits of the detailed floodplain, the Butte-Silver Bow portion of the river is mapped as an approximate zone (Zone A) until meeting the Anaconda-Deer Lodge Co. boundary about 8.5 miles upstream of Wise River. From this location, the Big Hole River is located within Beaverhead and Anaconda-Deer Lodge and is unmapped throughout its remaining reaches.

As previously mentioned, the Big Hole River for much of its entire length has either never been mapped for flood hazard or has been mapped as an Approximate A Zone under the National Flood Insurance Program (NFIP) managed by the FEMA. Flood hazard designations of this type commonly originated in the 1970s from Flood Hazard Boundary Maps which often lack technical basis for their flood hazard delineations. Montana is presently experiencing increasing developmental pressures in rural settings. Local governments that participate in the NFIP are tasked to provide regulatory framework for areas designated with a flood hazard in compliance with minimum standards set forth by the NFIP. The most difficult hazard areas to regulate development are the Approximate A Zones where little or no technical information is available to support those activities. The basis for regulation then comes in the form of “best available data”. Generally, communities then place the burden of developing technical information on the individual. This leads to inconsistencies of data throughout a reach of questionable integrity due to a lack of standards.

Present day technology has expedited hydrologic and hydraulic modeling and the associated mapping processes to develop detailed flood study information. The majority of cost often exists in the large scale collection of high resolution topographic data that adequately captures the topographic features that influence the flow regime and allows for hydraulic modeling and flood hazard mapping. For rural areas, the large costs associated with collecting high resolution topographic information can’t be justified and alternative topographic datasets are often used. For most of the intercontinental United States, the United States Geologic Survey (USGS) has produced the National Elevation Dataset (NED). Typically, these datasets allow for coarse hydraulic modeling and mapping that require substantial manipulation to incorporate subtle topographic features and channel geometry. Past studies have shown that modeling and mapping with these NED products generally leads to a high level of error when compared to efforts utilizing high resolution topographic datasets. For Montana, there are currently no established state guidelines for performing approximate level floodplain studies. However, FEMA has established approximate level study standards that apply.

While the engineering methods employed in the present study meet or exceed the FEMA standards set for a detailed or limited detailed analysis, the project as a whole merely satisfies the criteria of an approximate analysis. FEMA requires that a limited detailed and detailed study be composed of accurate topography, which was not available for the project area. For detailed studies, FEMA requires that survey data be utilized to describe hydraulic crossings and channel bathymetry. Utilizing a more accurate DEM product than the USGS DEMs was a practical approach to map the floodplains for the river, which is mostly rural in nature, and mostly unmapped. The cost of surveying all the structures and acquiring accurate topographic data for the project greatly exceeded the project budget. The State and stakeholders agreed that a new floodplain study exceeding FEMA's approximate level standards would be appropriate for the study reaches which are mostly rural in nature. The new enhanced study would provide products not typical of approximate studies, such as BFEs, profiles and data tables that the communities need to regulate and manage their floodplains.

Montana DNRC in cooperation with FEMA provides oversight and support to the Montana communities participating in the NFIP. One of DNRC Water Resource Division's goals is to establish guidelines and standards to be used by communities and technical specialists for the development of flood studies of approximate nature. Montana DNRC has identified this pilot project to evaluate methodologies and develop State Standards for hydrologic and hydraulic analyses and flood hazard mapping.

1.2. Basin Description

The Big Hole River originates high in the Beaverhead Mountains of the Bitterroot Range in Southwest Montana. From the headwaters, it flows north through the town of Wisdom and between the Anaconda Range located to the northwest and the Pioneer Mountains to the east. It then flows eastward along the northern boundary of the Pioneer Mountains and begins a south east course past the town of Wise River where the Wise River enters. Just south of Glen, Montana, the river turns back northward to join the Beaverhead River and Ruby River to form the Jefferson River, near Twin Bridges, Montana.

The upper watershed is characterized by a very broad, low sloping valley until just downstream of the North Fork Big Hole River where the river enters a steeper canyon. From this point, the river remains confined until the confluence with Wise River where it opens to a larger floodplain area. Just downstream of Wise River, the Big Hole River enters another steep canyon remaining fairly confined until north of Melrose where the valley becomes more broad with floodplain areas prevalent for the remaining reach to the confluence with the Beaverhead River.

The Big Hole River's flood risk is typical of most Montana rivers in that flooding primarily results from rapid snowmelt in the high elevation mountains of the upper watershed. The Big Hole River typically shows two spring melt peaks in the hydrograph. The first peak comes in early spring when the Upper Big Hole Valley begins to melt off the season's snowpack. This peak is followed by a larger peak occurring when the high elevation mountainous areas melt in late spring.

The Big Hole River can generally be broken into three distinct reaches related to the river character and its geologic controls. As mentioned, the upper watershed is a high elevation, broad, low sloping valley. The soils and channel substrate in this area are generally fine grained. The river is sinuous and braided with several historic channels filled with spring water. This multi-thread channel system and abundant wetland areas have many implications for the hydraulic component of this flood study. The possibility exists for several divided flow scenarios that may require special attention to be modeled appropriately. Furthermore, since the valley is so broad and low sloping, shallow overbank flooding is expected and backwater effects from road embankments and undersized culverts will likely play a large role on water surface elevations. The second distinct reach begins down valley from Wisdom where the river enters a confined steep canyon. The geologic controls imposed on the river have created a primarily bedrock channel with large boulders that produce much energy loss in the form of roughness and turbulence. The river is confined with steep canyon walls and high banks which will likely produce a floodplain confined to the banks with high velocity and depth through this reach. The third reach begins upstream of Melrose where the canyon gives way to broad floodplains and split channels. Similar to the Upper Valley, unless the split channels are submerged, special care should be taken during hydraulic modeling of this reach.

1.3. Big Hole River Approximate Flood Study

The Big Hole River floodplain study has been divided into three reaches with the previously analyzed SCS reach not being included in the Phase 2 investigation. The reach limits and lengths are shown in **Table 1.**

Table 1. Big Hole River Floodplain Study reach descriptions.

River Section	Hydraulic Reach	Length (mi)	Downstream Study Limit	Upstream Study Limit
Lower	**East**	39	River Mouth (Jefferson River Confluence)	Madison/Butte-Silver Bow County Boundary
SCS	**--**	34	Madison/Butte-Silver Bow County Boundary	Anaconda-Deer Lodge/Butte-Silver Bow County Boundary
Middle	**West**	22	Anaconda-Deer Lodge/Butte-Silver Bow County Boundary	Anaconda-Deer Lodge/Beaverhead County Boundary
Upper	**West**	55	Anaconda-Deer Lodge/Beaverhead County Boundary	Pioneer Creek Confluence

As illustrated in **Table 1**, the reaches of the study are divided by the county boundaries. The Lower Reach extends from the mouth of the Big Hole River to the Madison/Butte-Silver Bow County boundary at Melrose. The Middle Reach of the study begins at the Anaconda-Deer Lodge/Butte-Silver Bow County Boundary about 8.5 miles upstream of Wise River and terminates at the confluence with Pintler Creek which divides Anaconda-Deer Lodge and Beaverhead Counties. From there, the Upper Reach of the study initiates with the upstream limit of the study being the confluence with Pioneer Creek.

The reaches categorized in **Table 1** have been grouped into hydraulic reaches for the present study and are herein referred to as the East and West reaches. These reach limits are visually represented on **Figure 1**. The goal for this phase of the flood study is to develop approximate floodplain hazard maps for the East and West reaches. This report summarizes the hydraulic analysis for the 1- and 0.2-percent annual chance flood events along with a brief synopsis of past efforts on the Big Hole River.

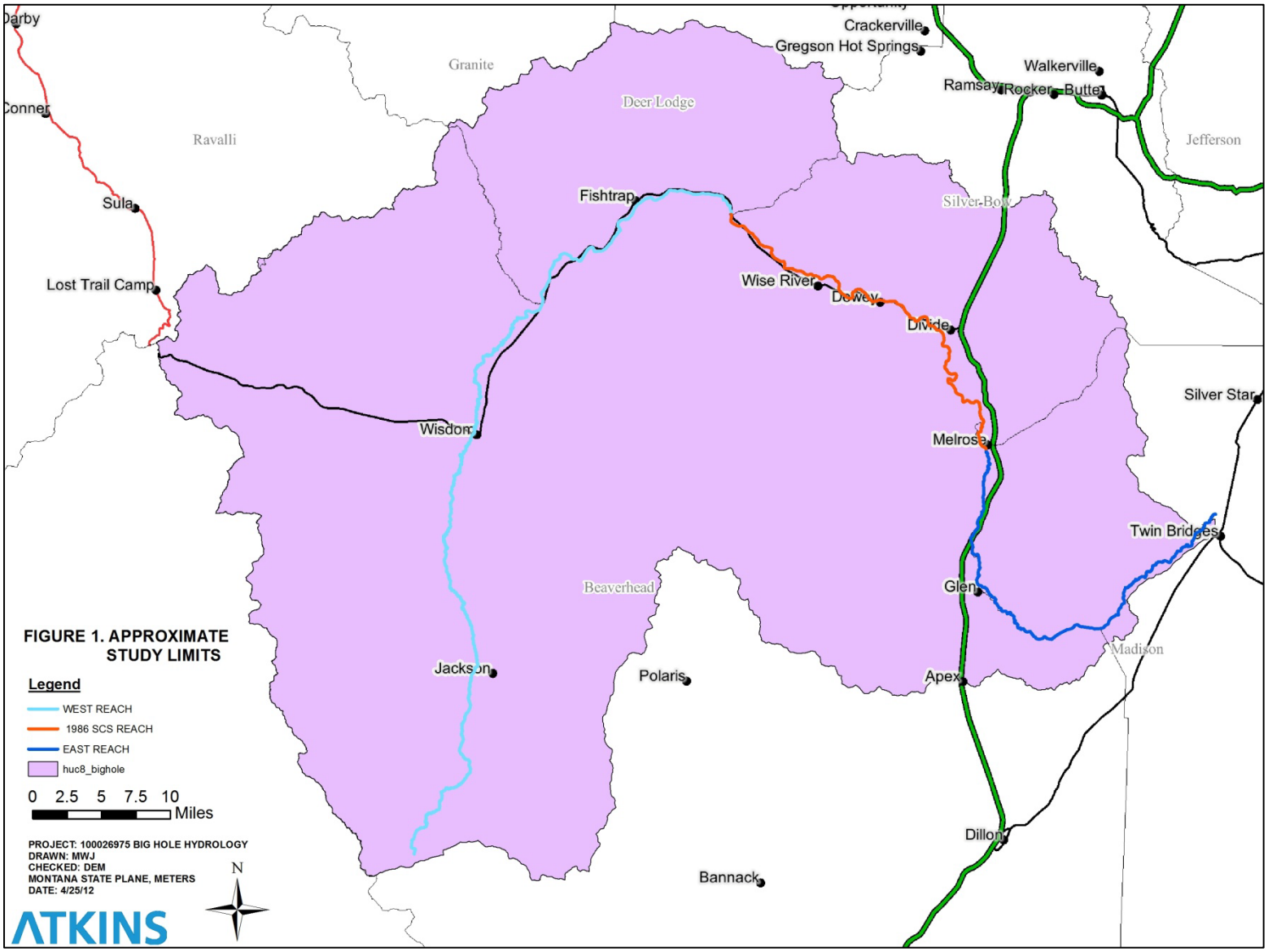


Figure 1. Overview of approximate study limits

2. Past Studies

The Big Hole River is an iconic Montana valley that is cherished by many groups of people from the ranchers that reside along the river and make their living from working the land to recreationalists that frequent the river for its world renowned blue ribbon fly fishing. Many agencies and other groups have conducted studies related to water resource management and fisheries. The variety of socioeconomic issues continues to evolve as expanding populations place an increasing demand on natural resources. A brief non-inclusive list of relevant past floodplain studies on the Big Hole River is presented here for reference.

2.1. SCS Flood Plain Management Study

The most relevant studies toward this flood discharge-frequency analysis are past flood studies conducted on the Big Hole River. The most recent is the Soil Conservation Service (SCS), presently known as the Natural Resource Conservation Service (NRCS), study, "Flood Plain Management Study, Big Hole River, Silver Bow County, Montana" (**Reference 19**). This study's upstream limit is the Butte-Silver Bow County boundary about 8.5 miles upstream of Wise River, Montana and the downstream limit is just downstream of Melrose, Montana. This study reach is shown visually on **Figure 1**, occurring between the West and East study reaches. The NRCS study was completed December, 1986.

The study utilized the USGS gage at Melrose as the primary source for flood flow frequency information. At the time of study, 63 years of annual peak flow information was recorded. The resulting annual peak flow records from the gage at Melrose were analyzed according to the methods set forth in Bulletin 17B (**Reference 20**). Several flow change locations were desired for development of the hydraulic model. To apply the flood discharge-frequency results of the gage analysis to sites upstream, a drainage area relationship regression was performed with 28 other USGS gaging stations surrounding the study reach. These locations and flow rates are presented in **Table 2**.

The hydraulic analysis of the 10-, 50-, 100-, and 500-year events were analyzed using the WSP-2 computer program which utilizes a subcritical backwater calculation by a modified step method. Cross sections for all hydraulic computations were obtained by SCS via field survey in the National Geodetic Vertical Datum of 1929 (NGVD29). The hydraulic analysis utilized the slope-area method for a downstream boundary condition with Manning values varying from 0.04 to 0.055 for the channel and 0.04 to 0.10 for the overbanks. The hydraulic analysis included the headloss and backwater calculations of the various structures found throughout the reach. As part of the study, the SCS also conducted a floodway analysis allowing for encroachment of the floodplain until a maximum increase of 0.5' in the 100-year WSEL was met.

The SCS state that flooding potential is 'not a major problem' through the analyzed reach as the 100-year event is contained within the channel banks for most of the reach. The SCS report does state that the 100-year flooding is likely to spread into adjacent low wetland areas within the upper study area. Results of the SCS study depicted channel flood depths varying from 5 – 15 feet deep with velocities ranging from 4 – 12 fps.

Table 2. Results and flow change locations of the 1986 SCS Flood Plain Management Study

		Discharge (cfs)			
Study Reach Description	**Drainage Area (mi^2)**	**10-Percent Annual Chance**	**2-Percent Annual Chance**	**1-Percent Annual Chance**	**0.2-Percent Annual Chance**
Downstream Study Limit, below Trapper and Camp Creeks	2,365	11,950	15,130	16,280	18,590
Just above Trapper and Camp Creeks	2,282	11,670	14,800	15,930	18,210
Just below Moose Creek	2,250	11,560	14,670	15,800	18,060
Just below Divide Creek	2,146	11,200	14,250	15,350	17,580
Just above Divide Creek	2,054	10,880	13,860	14,950	17,140
Just below Jerry Creek	1,999	10,690	13,640	14,710	16,880
Just below Wise River	1,942	10,490	13,390	14,450	16,600
Just above Wise River	1,682	9,530	12,250	13,250	15,280
Upstream Study Limit	1,609	9,260	11,920	12,900	14,900

2.2. FEMA Flood Insurance Study

The FEMA Flood Insurance Study (FIS) for Butte-Silver Bow County (**Reference 9**) describes several flood studies completed by Morrison-Maierle, Inc. in June 1977. In that FIS, the Big Hole River was studied by both detailed and approximate methods. Priority for detailed studies was given to areas being developed or that had proposed construction through 1982. The FIS detailed study on the Big Hole River near Melrose prepared a hydrologic investigation for flood discharge-frequency estimates similar to the SCS study described in Section 2.1 with the USGS gage at Melrose acting as the principal source of data. The FIS describes that the period of record used for the analysis was 1923 – 1977 and that a log-Pearson type III distribution of annual peak flow data was used under the methodologies set forth in Bulletin 17, not to be confused with Bulletin 17B that was published at a later date and used by the SCS during their study. The results of the hydrologic analysis are shown in **Table 3**.

Table 3. Results and flow change locations of the 1986 FEMA FIS

		Discharge (cfs)			
Study Reach Description	**Drainage Area (mi^2)**	**10-Percent Annual Chance**	**2-Percent Annual Chance**	**1-Percent Annual Chance**	**0.2-Percent Annual Chance**
Big Hole River near Melrose	2,362	12,300	16,542	18,261	22,072

The FIS detailed study on the Big Hole River was studied through Melrose for about one half mile and consists of only the east split channel since the west channel is in Beaverhead County. The standard step

backwater program HEC-2 was used to calculate water surface elevations through this reach. The starting water surface elevation of the study was determined using the slope-area method. Cross sections and hydraulic structures utilized in the analysis were obtained by field survey and reference the NGVD29 vertical datum. A roughness value of 0.04 was assigned to the channel through the modeled reach while the overbank Manning's values ranged from 0.075 to 0.08. Similar to the SCS study, the effective study consists of a floodway analysis with a maximum increase of 0.5' in the 100-year WSEL.

Through review of the available data, it appears that the effective hydraulic analysis was only performed for the east channel of the Big Hole River. The aforementioned SCS study includes a brief comparison with the effective study in which the SCS states that the profiles of the effective study are "about 2 feet higher" than the profiles computed in the SCS study. The SCS study points to possible shifts in flow volumes between the east and west channels of the Big Hole River through Melrose as a possible reason for the difference in profiles.

2.3. Flood Inundation Potential Mapping and Channel Migration Zone Delineation

DTM consulting, Inc. and Applied Geomorphology, Inc. teamed to study the Big Hole River under two related, but separate components (**Reference 1**). The primary goal for both components was to provide a regulatory tool that provides hazard mapping along the Big Hole River. The first component is the Flood Inundation Potential section where a multi-county initiative to coordinate land use planning lead to the desire for mapping of the 100-year floodplain for the main stem of the Big Hole River. The techniques used were in part both a qualitative assessment of geologic and geomorphic controls in addition to a series of "at a station" quantitative analyses to predict flood depths. The second component of this study was to delineate channel migration and channel avulsion hazard areas along the Big Hole River based primarily on aerial imagery.

Flood discharge-frequency estimates for this study were calculated from regional regression equations described in the USGS Water Resource Investigation Report 03-4308, "Methods for Estimating Flood Frequency in Montana Based on Data through Water Year 1998" (**Reference 14**). The estimates calculated in their study are shown in **Table 4** below.

Table 4. Results and flow change locations of the 2005 Flood Inundation Potential Mapping Study

Location	Drainage Area (mi^2)	1-Percent Annual Chance Discharge (cfs)
Miner Creek Bridge	116	6,462
Little Lake Road Bridge	380	14,528
Wisdom Bridge	591	19,607
Mudd Creek Bridge	1,274	33,283
Dickie Bridge	1,603	38,971

Based on proximity and similar drainage area, the flow results of this study at Dickie Bridge are suitable for comparison with the upstream study limit calculated flows of the SCS study. Although the SCS study based their estimates on a gage analysis and this study utilized regional regression equations, the results are

substantially different with regression estimates being three times higher. The results presented in their report and shown on **Table 4** suggest an erroneous flow rate was calculated from regression equations which inevitably propagated through their analysis to the final floodplain mapping product.

The Flood Inundation Potential Mapping component of this study was performed using the WinXSPRO program with a blend of previously surveyed cross sections and elevation data taken from the respective 1:24,000 topographic maps. WinXSPRO performs a single station analysis using the Manning's equation and therefore neglects the associated backwater effects. The results of the study were compared with the 30 meter DEM for mapping and an approximation method for determining flood depths at a single cross sections throughout the reach. Those depths were then interpolated between sections and projected onto the 30 meter DEM. This methodology mimics that of detailed flood study hydraulics and mapping workflow processes, however the results are rather coarse and approximate in nature.

3. Hydrologic Analyses

Table 5 and **Figure 2** below provide the summary of recommended discharges that were calculated during the hydrologic analysis (Phase 1 of the present project) and selected for incorporation within the hydraulic analysis. The discharges were calculated using the Two Station Comparison Gage Analysis at five gages located throughout the Big Hole River watershed. Upon completion of the gage analysis, the log interpolated values calculated from the Two Station Comparison method results while using the logarithms of drainage areas. For locations downstream of the USGS gage at Melrose (USGS 06025500), the gage transfer method based upon the drainage area ratio was utilized to transfer the gage analysis results of USGS 06025500. Further information in regards to the hydrologic analysis and results being utilized in the present approximate hydraulic analysis can be referenced in the report titled “Flood Discharge-Frequency Hydrologic Analysis for the Big Hole River, Montana, Hydrologic Analysis Report” submitted March 15, 2013 (**Reference 3**).

Table 5. Utilized Discharges and Hydrologic Methods for the Big Hole River

Node/Gage ID	Location Description	River Station (miles)[1]	Profile/Model Station (feet)[2,3,4]	Hydrologic Method	Discharge (cfs)	
					100-year	500-year
6023500	NEAR JACKSON, MT	149.1	401,150	Two Station Comparison	1,340	1,970
50	BELOW BERRY CREEK	144	374,530	Log Interpolation	2,040	2,910
75	ABOVE GOVERNOR CREEK	137	330,300	Log Interpolation	2,710	3,800
85	ABOVE MINER CREEK	131.4	308,000	Log Interpolation	5,340	7,140
100	ABOVE BIG SWAMP CREEK	128.3	291,500	Log Interpolation	5,960	7,900
200	ABOVE BIG LAKE CREEK	118.5	231,750	Log Interpolation	6,410	8,460
300/06024450	BELOW BIG LAKE CREEK AT WISDSOM, MT	110.7	198,475	Two Station Comparison	6,980	9,160
350	ABOVE SWAMP CREEK	105.9	173,150	Log Interpolation	7,590	9,790
400	ABOVE NORTH FORK BIG HOLE RIVER	102	152,700	Log Interpolation	8,230	10,500
500	BELOW PINTLER CREEK	94.5	113,150	Log Interpolation	10,700	12,900
550/06024540	BELOW MUDD CREEK NEAR WISDOM	89	83,850	Two Station Comparison	11,000	13,200
600	ABOVE FISHTRAP CREEK	82.1	47,700	Log Interpolation	11,300	13,500
700	ABOVE DEEP CREEK	75.8	14,300	Log Interpolation	12,300	14,700
800	BELOW BRYANT CREEK	73.1	0	Log Interpolation	13,200	15,700
900	ABOVE WISE RIVER	63.9		Log Interpolation	13,700	16,300
1000	ABOVE JERRY CREEK	61.7		Log Interpolation	15,400	18,200
1100	ABOVE DIVIDE CREEK	50.7		Log Interpolation	16,000	18,900
1200	ABOVE CANYON AND MOOSE CREEKS	48.1		Log Interpolation	16,600	19,600
6025250	AT MAIDEN ROCK NEAR DIVIDE, MT	47.3		Two Station Comparison	16,900	19,900
1300	ABOVE TRAPPER AND CAMP CREEKS	39.4		Log Interpolation	17,000	20,000
1350	ABOVE CHERRY CREEK	36.6	193,489	Log Interpolation	17,200	20,100
1400	ABOVE ROCK CREEK	31.1	164,100	Log Interpolation	17,200	20,200
6025500*	NEAR MELROSE, MT	30.9	163,235	Single Station Analysis	17,300	20,200
1500	ABOVE WILLOW CREEK	25.4	134,110	DA Gage Transfer	17,400	20,300
1600	ABOVE BIRCH CREEK	23.9	126,420	DA Gage Transfer	17,700	20,600
1625/06026210	NEAR GLEN, MT	16.9	89,480	DA Gage Transfer	18,100	21,000
1650	UPSTREAM OF OWSLEY SLOUGH	11.1	58,550	DA Gage Transfer	18,200	21,100
1675	UPSTREAM OF NEZ PERCE CREEK	5.4	28,620	DA Gage Transfer	18,300	21,200
1700	AT MOUTH	0	0	DA Gage Transfer	18,600	21,500

*[1]Miles above mouth of Big Hole River. [2]Locations between USGS 06023500 and Node ID 800 are in feet above Beaverhead County/Anaconda County boundary (West Reach). [3]Locations between Node ID 1350 and Node ID 1700 are in feet above mouth (East Reach). [4]Locations between Node ID 900 and 1300 are within the previously studied SCS reach. *Denotes flow change location that are coincident with previously studied SCS reach.*

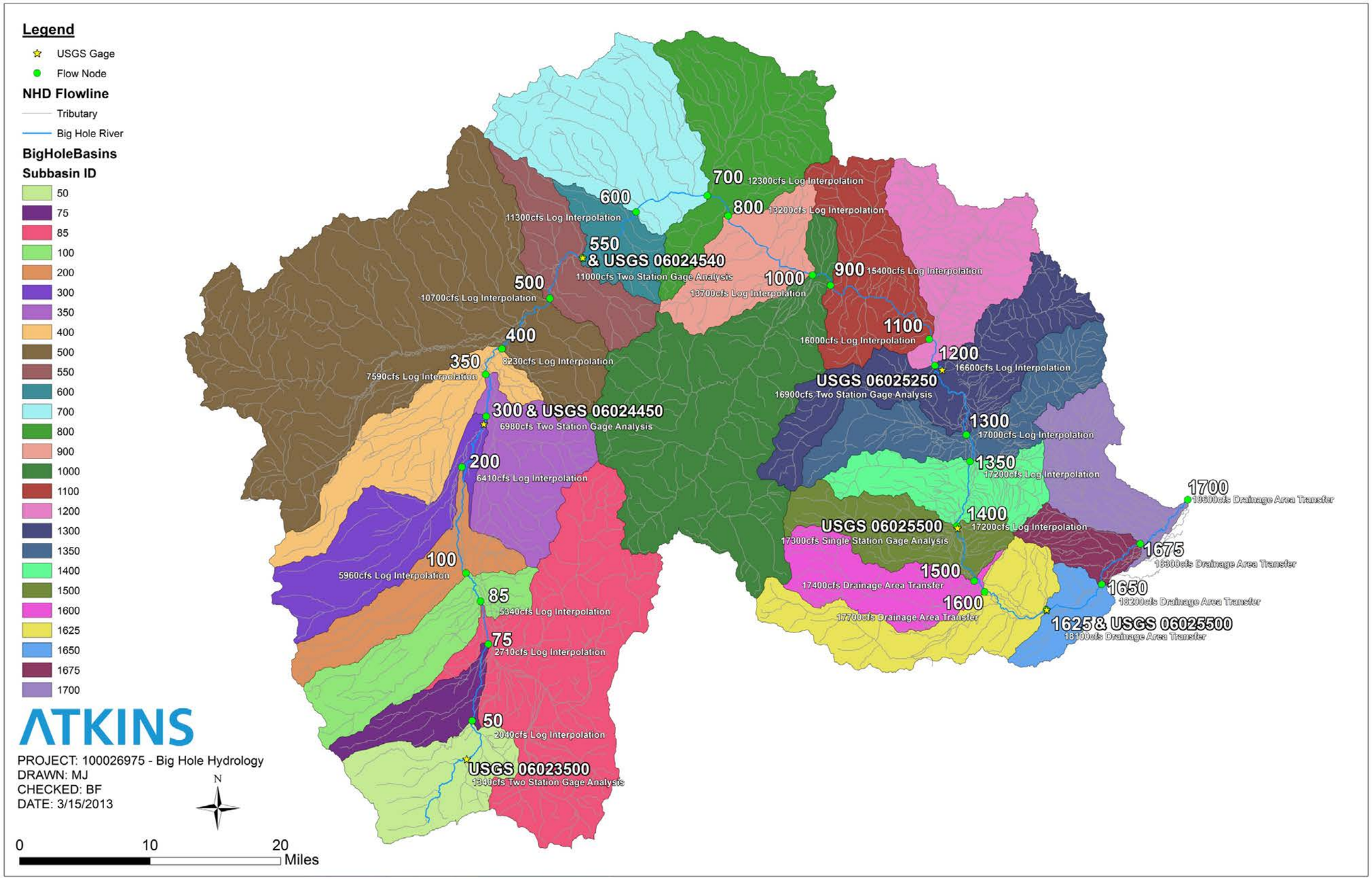


Figure 2. Recommended 1-percent annual discharge for each location.

Hydraulic analysis of the Big Hole River revealed multiple locations of split flows and overflows being diverted away from the Big Hole River. A summary of the resulting discharges is provided in **Table 6** and **Table 7**. The discharges listed in **Table 6** and **Table 7** detail the final discharges utilized to perform the floodplain mapping for the Big Hole River. The discharge overflowing the right bank and leaving the river corridor downstream of Sta. 36781 of the East Reach are not detailed in **Table 6** as they were not utilized to produce the final mapping water surface elevations of the Big Hole River. Further discussion in relation to the split and diverted flow analyses is located in Section 6.1.

Table 6. Summary of discharges for the East Reach of the Big Hole River

River Stations	Hydrologic Node/Gage ID	Location	Percent-Annual-Chance Discharge (cfs)				
			10	4	2	1	0.2
204833 - 193400	**1350**	Big Hole River above Cherry Creek	12100	14300	15800	17200	20100
193400 - 164100	**1400**	Big Hole River above Rock Creek	12100	14300	15800	17200	20200
164100 - 162759	**06025500**	Big Hole River near Melrose	12200	14400	15900	17300	20200
162759 - 133973	**1500**	Big Hole River above Willow Creek	12300	14500	16000	17400	20300
133973 - 126291	**1600**	Big Hole River above Birch Creek	12600	14800	16300	17700	20600
126291 - 89259	**1625/06026210**	Big Hole River near Glen	12900	15100	16700	18100	21000
89259 - 58318	**1650**	Big Hole River upstream of Owsley Slough	13000	15300	16800	18200	21100
58318 - 28620	**1675**	Big Hole River upstream of Nez Pearce Creek	13100	15400	16900	18300	21200
28620 - 0	**1700**	Big Hole River at Mouth	13300	15600	17200	18600	21500

Table 7. Summary of discharges for the West Reach of the Big Hole River

Reach Segment	River Stations	Hydrologic Node/Gage ID	Location	Percent-Annual-Chance Discharge (cfs)				
				10	4	2	1	0.2
South	409000 - 374147	50	Big Hole River below Berry Creek	1060	1410	1710	2040	2910
South	374147 - 341696	75	Big Hole River above Governor Creek	1450	1910	2300	2710	3800
South	341696 - 331256	--	Big Hole River - Jackson split flow; West conveyance path	1450	1873	2187	2512	3241
South	331256 - 329490	75	Big Hole River above Governor Creek	1450	1910	2300	2710	3800
South	329490 - 307940	85	Big Hole River above Minor Creek	3030	3920	4620	5340	7140
South	307940 - 291176	100	Big Hole River above Big Swamp	3410	4400	5160	5960	7900
South	291176 - 277856	200	Big Hole River above Big Lake Creek	3700	4750	5570	6410	8460
Mid	277856 - 231562	200	Big Hole River above Big Lake Creek	3700	4750	5570	6410	8460
Mid	231562 - 222085	300/06024450	Big Hole River at Wisdom	4060	5200	6080	6980	9160
Mid	222085 - 208257	--	Big Hole River - Wisdom split flow; West conveyance path	3976	4989	5721	6485	8344
Mid	208257 - 198212	300/06024450	Big Hole River at Wisdom	4060	5200	6080	6980	9160
Mid	198212 - 172978	350	Big Hole River above Steel Creek	4540	5750	6660	7590	9790
Mid	172978 - 152524	400	Big Hole River above N. Fork Big Hole River	5060	6340	7290	8230	10500
Mid	152524 - 114000	500	Big Hole River below Pintler Creek	7150	8650	9670	10700	12900
North	114000 - 113002	500	Big Hole River below Pintler Creek	7150	8650	9670	10700	12900
North	113002 - 83848	550/06024540	Big Hole River near Wisdom	7450	8970	10000	11000	13200
North	83848 - 47345	600	Big Hole River above Fishtrap Creek	7650	9210	10300	11300	13500
North	47345 - 14128	700	Big Hole River above Deep Creek	8410	10100	11300	12400	14800
North	14128 - 0	800	Big Hole River below Bryant Creek	9070	10900	12100	13300	15900
Wisdom Split	12489 - 0	--	Wisdom split flow; East conveyance path	84	211	359	495	816

4. Hydraulic Analysis

Details of the methods and techniques used to complete the approximate hydraulic analysis of the East and West Reaches of the Big Hole River are presented below.

4.1. Hydraulic Analysis Overview and Procedures

The new approximate study begins at the confluence with the Jefferson River at Twin Bridges, MT and concludes at the confluence with Pioneer Creek. The East and West Reaches of the present study are separated by the aforementioned SCS study bounds. In total, the East and West reaches combine to make up 117 miles of the Big Hole River. A summary of the profile baseline features and stations is presented in **Table 9** through **Table 12**.

Appendix C of FEMA Guidelines and Specifications (FEMA, November 2009) (**References 11**) was used as a guide for the development of the Big Hole River hydraulic models. The water surface elevations used for floodplain mapping were calculated with HEC-RAS, Version 4.1.0 hydraulic modeling software (USACE, January 2010). Cross sections were placed with ArcMap 10.0 (ESRI, 2010) (**References 7**) at key locations along the floodplain, including: slope breaks, changes in floodplain width, structures in the floodplain, and in general, every 10 to 20 active channel widths. HEC-RAS, for steady flow analysis, performs the standard step energy balance calculation between cross sections, starting at the most downstream cross section and moving upstream for a fully subcritical analysis. **Table 8** lists the various models and associated plans utilized to analyze the East and West Reaches of the Big Hole River. The East Reach was modeled in a single reach while the West model is comprised of three sections due to its length. **Figure 3** displays the separate sections of the West Reach analysis.

In order to develop the hydraulic model for the respective reaches of the Big Hole River, Atkins utilized software titled “Rapid Floodplain Delineation” (RFD) and RASGEO. RFD and RASGEO are proprietary software that allows Atkins personnel to automate many aspects of the floodplain modeling and mapping process. RFD generates cross sectional geometries, performs a backwater calculation, and delineates a floodplain in one step. The actual single step backwater calculation is performed through HEC-RAS. Therefore, Atkins can deliver a globally accepted model that can be referenced in the future.

Utilizing Atkins’ proprietary software titled ‘Rapid Floodplain Delineation’ (RFD), initial cross sections were placed normal to the assumed equipotential lines. Once the cross sections were placed, RFD then creates the cross sectional geometries from a referenced topographic source. RFD then uses HEC-RAS and predefined roughness values to calculate the roughness values and water surface profiles through the modeled reach. RFD then creates a shapefile defining the flooding extents. This allows the user to make changes in cross sections and identify the contraction and expansion of the resultant floodplain.

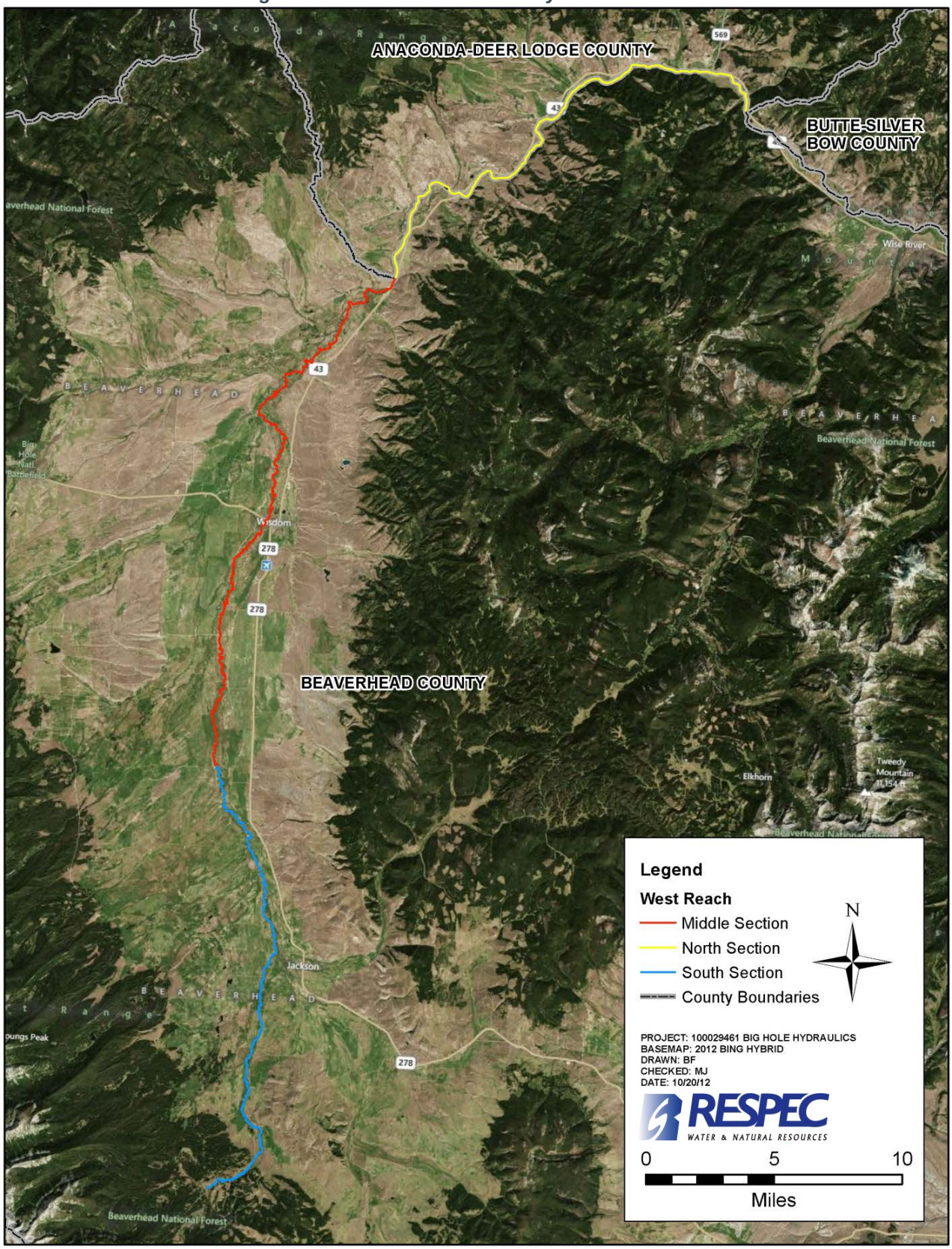
Once the HEC-RAS model geometry is created through RFD, Atkins personnel utilize RASGEO to simulate multiple profiles and further refine the model with the definition of roughness breaks and ineffective flow areas. RASGEO serves as a medium between HEC-RAS and ArcGIS in that it affords Atkins personnel to make the required changes within HEC-RAS and review the results spatially within ArcGIS. Once the user is satisfied with the model geometry, RASGEO is utilized to spatially generate the floodplains as well as the final cross section stationing and resultant water surface elevations utilized in creating the final floodplain maps.

It should be emphasized that although Atkins utilized proprietary software to expedite hydraulic model and floodplain mapping, the final product is a globally accepted model (HEC-RAS) that can be utilized by anyone familiar with the publicly available software.

Table 8. Summary of HEC-RAS models and associated plans utilized for the present study

Study	Plan Title	Geometry File	Flow File	Description
East Reach	**East Overflow**	East Reach	East Discharges	Existing conditions hydraulic analysis of the 10-, 4-, 2-, 1-, and 0.2-percent-annual-chance events of the East Reach. Overflow discharge downstream of Sta. 36781 is allowed to leave the Big Hole River corridor.
	Main Channel	East Reach	East Discharges	Existing conditions hydraulic analysis of the 10-, 4-, 2-, 1-, and 0.2-percent-annual-chance events of the East Reach. All potential overflow is conservatively assumed to remain within the Big Hole River corridor.
West Reach	**North Section**	North Section	North Discharges	Existing conditions hydraulic analysis of the 10-, 4-, 2-, 1-, and 0.2-percent-annual-chance events; Sta. 0 – 114,587 of the West Reach.
	Middle Section	Middle Section	Middle Discharges	Existing conditions hydraulic analysis of the 10-, 4-, 2-, 1-, and 0.2-percent-annual-chance events; Sta. 114,587 – 280,314 of the West Reach.
	South Section	South Section	South Discharges	Existing conditions hydraulic analysis of the 10-, 4-, 2-, 1-, and 0.2-percent-annual-chance events; Sta. 280,314 – 407,488 of the West Reach.

Figure 3. Sections of the analyzed West Reach



4.2. Topographic Data Acquisition

The 5-m digital elevation model (DEM) utilized in the study was purchased by the DNRC from Intermap Technologies Corp. (**References 13**) and received in June of 2012. The data for the hydro-enforced DEM was collected between the dates of July 16 – September 26, 2008 by interferometric synthetic aperture radar (IFSAR). The received IFSAR DEMs consisted of 3.25 m cells and in the following specifications:

		Units
Projection:	Montana State Plane	
Datum:	Horizontal – MT 2500 St Pl NAD83 CORS96	International feet
	Vertical – NAVD88, Geoid03	US survey feet

Accuracy of the dataset varies depending upon the slope and vegetation of the respective areas. As outlined in the report titled "Big Hole River MT Vertical Accuracy Assessment Report V3DW - JAM" provided in **Appendix F**, Intermap states that the dataset has a "1m vertical and 2 m horizontal RMSE accuracy in regions that are unobstructed with flat to moderately sloped terrain."

As previously mentioned, the dataset is hydro-enforced which means that elevation points have been removed from hydraulic structures in order to provide the waterways with a consistent downstream slope. Areas of the channel bathymetry that is inundated at the time of data collection is neglected within the topographic dataset. This proves to be fairly insignificant in the present study as a majority of the studies discharges are found within the overbanks.

Upon comparison of the 5-meter data with that of survey data, it was apparent that the geometry and general shape of the surveyed cross section was represented fairly well by the 5-m data. The actual differences in elevations of the 5-m and survey datasets varied by as much as approximately eight feet in the channel to roughly 14 feet in the steeper slopes of some overbank sections. However, these large discrepancies were typically found on steeper hill side slopes and were generally isolated to the SCS reach. On average, the 5-m data source showed a difference of ± 2.01' with a standard deviation of 1.98' when compared to the survey data. Further information in regards to the accuracy measurements of the utilized DEM along with comparisons to other reviewed topographic sources are available in the report titled '*Big Hole River Approximate Level Floodplain Study, Phase 2 – Hydraulic Analysis and Mapping, Topographic Data Assessment*' (**References 4**) submitted August 6, 2012.

4.3. Profile Baseline

The stream channel centerline of the Big Hole River was utilized to define the Profile Baseline and river stationing as stream distance in feet above the confluence with the Jefferson River for the East Reach and stream distance in feet above Butte-Silver Bow County boundary for the West Reach. The stream centerline (Profile Baseline) was created using the 2011 National Agricultural Imagery Program (NAIP) aerial photograph (USDA, 2011) (**References 18**). A summary of key features along each reach is presented below in **Table 9** through **Table 12**.

Table 9. Summary of key features along the profile baseline of the East Reach

River Station (ft)	River Station (mi)	Feature	Profile Number	Map Panel
0	**0.0**	Butte-Silver Bow Co./Anaconda-Deer Lodge Co. Boundary;	01E	W1
2,316	**0.4**	Downstream limit of study; Tie-in with approximate study	01E	W1
3,625	**0.7**	Confluence with Bear Creek	01E	W1
4,945	**0.9**	Confluence with Bryant Creek	01E	W1
14,233	**2.7**	Confluence with Deep Creek	03E	W2
14,715	**2.8**	Location of flow change	03E	W2
20,971	**4.0**	Confluence with Seymour Creek	04E	W3
32,532	**6.2**	Confluence with Pony Creek	06E	W4
36,708	**7.0**	Confluence with La Marche Creek	06E	W4
45,206	**8.6**	Confluence with Fishtrap Creek	07E	W5
45,765	**8.7**	Confluence with Walker Creek	08E	W5
47,932	**9.1**	Location of flow change	08E	W5
53,018	**10.0**	Confluence with Tucker Creek	09E	W6
53,337	**10.1**	Confluence with Calvert Creek	09E	W6
55,462	**10.5**	Confluence with Stewart Creek	09E	W6
60,745	**11.5**	Confluence with Sawlog Creek	10E	W6
73,614	**13.9**	Confluence with Toomey Creek	12E	W7
84,435	**16.0**	Location of flow change	13E	W8
85,134	**16.1**	Montana Highway 43	14E	W8
87,522	**16.6**	Confluence with Mudd Creek	14E	W8
109,176	**20.7**	Confluence with Salefsky Creek	17E	W10
113,589	**21.5**	Location of flow change	18E	W11
114,587	**21.7**	Upstream extent of the North Section of West Reach	18E	W11

Table 10. Summary of key features along the profile baseline for the North Section of the West Reach

River Station (ft)	River Station (mi)	Feature	Profile Number	Map Panel
0	**0.0**	Butte-Silver Bow Co./Anaconda-Deer Lodge Co. Boundary;	01W	W1
2,316	**0.4**	Downstream limit of study; Tie-in with approximate study	01W	W1
3,625	**0.7**	Confluence with Bear Creek	01W	W1
4,945	**0.9**	Confluence with Bryant Creek	01W	W1
14,233	**2.7**	Confluence with Deep Creek	03W	W2
14,715	**2.8**	Location of flow change	03W	W2
20,971	**4.0**	Confluence with Seymour Creek	04W	W3
32,532	**6.2**	Confluence with Pony Creek	06W	W4
36,708	**7.0**	Confluence with La Marche Creek	06W	W4
45,206	**8.6**	Confluence with Fishtrap Creek	07W	W5
45,765	**8.7**	Confluence with Walker Creek	08W	W5
47,932	**9.1**	Location of flow change	08W	W5
53,018	**10.0**	Confluence with Tucker Creek	09W	W6
53,337	**10.1**	Confluence with Calvert Creek	09W	W6
55,462	**10.5**	Confluence with Stewart Creek	09W	W6
60,745	**11.5**	Confluence with Sawlog Creek	10W	W6
73,614	**13.9**	Confluence with Toomey Creek	12W	W7
84,435	**16.0**	Location of flow change	13W	W8
85,134	**16.1**	Montana Highway 43	14W	W8
87,522	**16.6**	Confluence with Mudd Creek	14W	W8
109,176	**20.7**	Confluence with Salefsky Creek	17W	W10
113,589	**21.5**	Location of flow change	18W	W11
114,587	**21.7**	Upstream extent of the North Section of West Reach	18W	W11

Table 11. Summary of key features along the profile baseline for the Middle Section of the West Reach

River Station (ft)	River Station (mi)	Feature	Profile Number	Map Panel
114,587	**21.7**	Downstream extent of the Middle Section of West Reach	18W	W11
114,861	**21.8**	Beaverhead Co./Anaconda-Deer Lodge Co. Boundary; Confluence with Pintler Creek	18W	W11
120,512	**22.8**	Confluence with Doolittle Creek	19W	W11
133,406	**25.3**	Confluence with Plimpton Creek	21W	W12
136,768	**25.9**	Confluence with North Fork Big Hole River	22W	W13
147,939	**28.0**	Confluence with McVey Creek	23W	W13
153,111	**29.0**	Location of flow change	24W	W14
171,817	**32.5**	Confluence with Swamp Creek	27W	W15
173,565	**32.9**	Location of flow change	27W	W15
193,484	**36.6**	Confluence with Steel Creek	30W	W17
199,136	**37.7**	Location of flow change	31W	W17
204,303	**38.7**	Montana Highway 43	32W	W17
219,124	**41.5**	Confluence with Rock Creek	34W	W19
229,570	**43.5**	Confluence with Big Lake Creek	36W	W19
233,222	**44.2**	Location of flow change	36W	W20
235,601	**44.6**	Rock Creek Road	36W	W20
256,695	**48.6**	Twin Lakes Road	40W	W21
280,314	**53.1**	Upstream extent of the Middle Section of West Reach	44W	W23

Table 12. Summary of key features along the profile baseline for the South Section of the West Reach

River Station (ft)	River Station (mi)	Feature	Profile Number	Map Panel
280,314	**53.1**	Downstream extent of the South Section of West Reach	44W	W23
281,201	**53.3**	Big Lake Creek Road	44W	W23
289,668	**54.9**	Confluence with North Branch Big Swamp Creek	45W	W24
289,922	**54.9**	Private Crossing	45W	W24
292,564	**55.4**	Confluence with South Branch Big Swamp Creek (1)	46W	W24
293,634	**55.6**	Location of flow change	46W	W24
302,092	**57.2**	Big Swamp Creek Road	47W	W25
304,026	**57.6**	Confluence with South Branch Big Swamp Creek (2)	47W	W25
309,849	**58.7**	Confluence with Miner Creek	48W	W26
310,368	**58.8**	Location of flow change	48W	W26
310,469	**58.8**	Private Crossing	48W	W26
319,168	**60.4**	Little Lake Creek Road	50W	W26
328,515	**62.2**	Confluence with Warm Springs Creek	51W	W27
332,101	**62.9**	Location of flow change	52W	W27
339,766	**64.3**	Confluence with Spring Creek	53W	W28
340,486	**64.5**	Miner Lake Road	53W	W28
341,464	**64.7**	Confluence with Englejard Creek	53W	W28
349,956	**66.3**	Private Crossing	54W	W29
355,439	**67.3**	Private Crossing	55W	W29
364,449	**69.0**	Confluence with Little Swamp Creek	57W	W30
374,531	**70.9**	Location of flow change	59W	W31
374,654	**71.0**	Private Crossing	59W	W31
376,938	**71.4**	Confluence with Berry Creek	59W	W31
382,372	**72.4**	Skinner Meadows Road	60W	W31
388,724	**73.6**	Confluence with Saginaw Creek	61W	W32
394,082	**74.6**	Saginaw Road	62W	W32
400,940	**75.9**	Private Crossing	63W	W33
407,488	**77.2**	Upstream extents of study; Confluence with Pioneer Creek	64W	W33

4.4. Boundary Conditions

4.4.1. East Reach

The HEC-RAS model of the East Reach was simulated utilizing the normal depth boundary condition. The energy slope assigned to calculate the normal depth starting water surface elevation (WSEL) was assumed to match the slope of the utilized 5-m DEM. The slope was calculated over the most downstream 500' of the modeled reach and was found to be 0.0028 ft/ft. Typically, the energy slope assigned in HEC-RAS is assumed to approximate the friction slope (i.e. channel thalweg). This slope is utilized to calculate the water surface elevations under normal depth conditions at the first simulated cross section. The assignment of normal depth as the downstream boundary condition agrees with Section C of the FEMA's Guidelines and Specifications and assumes that the flood flows experienced by the Big Hole River are not coincident with the Jefferson River.

4.4.2. West Reach

It is noted that the downstream limit of the West Reach coincides with the upstream extent of the aforementioned SCS study performed in 1986. The intent was to utilize the calculated water surface elevation from the upstream limit of the SCS study as the downstream boundary condition for the West Reach and provide continuous floodplain mapping. When this starting water surface elevation was used, an obvious backwater was observed in the profile, suggesting a discrepancy in the two topographic data sources. It was noted during the topographic data assessment that substantial error exists in the Intermap data in this area. Regardless, cross section station and elevation information was extracted from the SCS study WSP-2 printout. Water surface elevations were extracted from the SCS report table for cross section CX (S10 in the WSP-2 model). A datum shift of 4.1' was applied to all elevations extracted from the SCS study which utilized the NGVD29 datum. The 25-year event was not simulated by SCS. Consequently, a normal depth calculation with of 0.003 ft/ft corresponding to the slope observed for the initial few cross sections upstream extracted from the Intermap data.

4.5. Development of Cross Sectional Geometries

The terrain data in the East and West HEC-RAS models were based on the aforementioned 5-m topographic data delivered by Intermap Technologies Corp. Utilizing ArcMap 10.0, cross sections were placed perpendicular to channel and overbank flow paths and along assumed equipotential lines. Cross sections were extended in order to capture the boundaries of the 0.2-percent annual chance floodplain. Cross sections were placed approximately every 500' and at key locations along the reach, including: noted breaks in channel shape and slope, abrupt changes in floodplain width, changes in overbank roughness classifications, as well as structure embankments represented within the topographic data. Due to variables such as the sinuosity of the stream, the distance between some cross sections approach lengths greater than 800' of stream length. However, in such cases, the overbank lengths are typically much less. Cross sections are shown in the Floodplain Maps attached in **Appendix A**.

4.6. Bank Station Assignments

Upon creation of the cross sectional geometries it was apparent that the aerial imagery and topographic data were not coinciding at all cross sections. The upper reaches of the West Reach model showed many instances where the main channel, as defined by the aerial imagery, was not represented in the topographic data. For these cases, the channel was defined solely by referencing the topographic data. The main conveyance path represented in the topographic data was assigned as the channel. Due to the large magnitude of flood volume found in the overbanks within the Big Hole River, this situation turned out to be a moot point. However, care should be taken when performing similar studies along smaller floodplain corridors in which the conveyance of the channel plays a more prominent role.

4.7. Hydraulic Structures

For the present approximate study, no structures were included in the hydraulic analysis. As specified in Appendix A of FEMA's Guideline and Specifications, hydraulic structures are not required when performing an approximate flood hazard analysis. Hydraulic structures are typically not included within approximate studies as the structures are usually not reflected in coarser topographic sources normally utilized for approximate studies. Given that the topographic data of the present study is more detailed than that of a typical approximate study, it was thought that the hydraulic crossings of the modeled reaches could be incorporated into the study. During Phase 1 of the project, Atkins performed a structure inventory and compiled a detailed database detailing the 48 hydraulic structures throughout the Big Hole River. Of the 48 structures, 12 are within the modeled east reach and 28 for the west reach. The database includes all measurements required for a hydraulic analysis (i.e. culvert opening, length, bridge span, etc.), an assessment of the backwater potential under flood flows, and multiple photographs. It should be noted that the measurements performed for the structure inventory were not tied to surveyed elevations. Hence, any inclusion within a hydraulic model would require the measurements to be related to a topographic source or detailed survey.

The decision to not include the structures in the hydraulic analysis was made by the stakeholders after the TAC meeting of August 9, 2012. During the field visits and structure assessment of Phase 1 of the project, it was recognized that the majority of the structures would have little impact on the assumed water surface profiles with the majority of the effect only being realized for short reaches. Along with the extra financial burden and accuracy of the utilized topographic data, inclusion of the hydraulic structures was thought to provide little benefit to the final product. However, it should be noted that where roadways were represented in the topographic data, the embankments of such structures were included to better simulate the contraction and expansion of the floodplain. For reference, all major hydraulic crossings are identified on the floodplain maps and profiles.Further information in regards to the structure database, photographs, and inclusion of structures within the hydraulic analysis is available in the report titled '*Big Hole River Approximate Level Floodplain Study, Phase 2 – Hydraulic Analysis and Mapping, Topographic Data Assessment*' (**Reference 4**) submitted August 6, 2012.

4.8. Roughness Coefficients

The Manning's roughness values assigned within the hydraulic model were determined based on field observations, aerial photography, and on recommendations from Chow's *Open Channel Hydraulics* (**References 6**). A Manning's value of 0.040 was assigned for the channel to represent a channel that is clean, winding, with some pools and shoals. Reaches showing a higher degree of sinuosity were assigned a Manning's value of 0.045 to simulate the greater momentum losses in the channel bends. The Manning's values assigned to the overbank areas range from 0.045 to 0.08 to represent the presence of tall grassed floodplains to the moderate to dense brush. Through the heavier treed overbank areas of the East Reach, Manning's values of 0.08 to 0.12 were assigned based upon denseness of the treed areas noted during the field visits. Vegetation density throughout the West Reach increases in the upstream direction and assigned Manning's values ranged from 0.06 to 0.1, for tall grass areas to dense willow stands, respectively. The overbank Manning's values of some of the cross sections of the East Reach were horizontally varied in order to better define the presence of significant secondary channels and the varying roughness within the overbanks. For much of the West Reach, secondary channels were not distinguishable from the Topographic data so horizontal stratification was not used.

Overall, the values utilized in the present study approximate the values utilized within the aforementioned SCS and FEMA studies. The SCS study utilized roughness values of 0.04 to 0.055 for the channel with overbank roughness values ranging from 0.04 for open areas to 0.10 for brushy areas. The FEMA study located at Melrose utilized a channel roughness of 0.04 with overbank values of 0.075 to 0.08 through its relatively short reach.

4.9. Areas of Non-Conveyance

During the hydraulic analysis, it was apparent that the analyzed reaches are comprised of multiple areas that are considered backwater or can be assumed to contain limited conveyance in the stream wise direction. For these areas, the Ineffective Flow Area Method was implemented in order to correctly and conservatively calculate the total effective conveyance for each cross section. The flow contraction and expansion areas were calculated using a 1:1 (stream wise: lateral) and a 2:1 ratio, respectively. The ratios of expansion and contraction were developed using the cross sectional velocities, *HEC-RAS Technical Reference Manual* (**References 14**), and engineering judgment.

4.10. Model Calibration

Although multiple stream gages are located throughout the studied reaches, the ability to perform a confident calibration is minimal. This is partly due to the limited amount of data made available by some of the gages as well as most of the gages having an unreliable gage datum. At the time of the analysis, eight (8) of the available gages had less than 10 years of record with the majority of the gages' rating curves not having data that extends to the discharges being simulated. Since most of the gages have only been in operation for a limited time, there are fewer data points correlating to the larger discharge events that would allow comparison with the events being simulated. Nevertheless, the available rating curves were obtained from the USGS and compared with the results of the hydraulic model. Also added to the comparison are the annual peak events recorded by the USGS. These comparisons can be reviewed in **Appendix H**. A comparison of elevations could not be performed for each location as the gage datum elevations defined by the USGS appear to be approximations. In discussions with USGS personnel, it was discovered that the gage datum elevations were based off of interpolation of the contours found on the USGS quad maps. As illustrated in **Appendix H**, the results of the model approximate the slope of the measured data reasonably well. As previously stated, little confidence can be given to the rating curve for the less frequent events being modeled as there is minimal data to be utilized for the creation of the curve. Hence, since the model approximates the assumed slope, it is felt that the model represents the hydraulic characteristics of the system.

Another issue with calibration of the model is the fact that most gages are located at hydraulic crossings and are therefore influenced by the headloss at the respective structure. Since structures were not included within the hydraulic analysis, calibrating the present study with measurements accounting for hydraulic crossings would require introducing error throughout the remaining reach.

4.11. cHECk-RAS

FEMA's automated review software cHECk-RAS was utilized to verify the acceptability of the hydraulic analyses described above. The cHECk-RAS messages from the five separate review categories are included in **Appendix B**. A few messages were left unresolved as they were either the product of erroneous checks performed by cHECk-RAS or the noted error didn't correctly pertain to the cited location. Explanations for leaving these messages unresolved are summarized in the 'Comments' column of the tables located in **Appendix B**.

5. Floodplain Mapping

Floodplain mapping was performed utilizing ESRI ArcMap 10.0 in conjunction with Atkins' aforementioned proprietary floodplain mapping tool RASGEO. Using RASGEO, the results of the modeled 1- and 0.2-percent-annual-chance events were utilized to create a DEM of the respective water surface profiles. RASGEO then intersects the water surface DEMs with the 5-m DEM in order to delineate the boundaries of the respective floodplains.

During the creation of the final floodplain shapefiles, the majority of islands found within the floodplains of the 1- and 0.2-percent-annual-chance events were removed. All island areas that were deemed higher than the adjacent 1- and 0.2-percent-annual-chance water surface profile that were less than one acre in size were removed utilizing ArcMap 10.0. Any backwater areas that extended through multiple cross sections were also modified to represent the elevation associated at the point which the backwater initiates from the main channel. These adjustments provide a slight variance in the mapped widths versus the top widths described by the HEC-RAS model. A model and mapped top width check was performed where discrepancies are documented, included as **Appendix C**. It should be noted that larger islands and islands relating to residences or roadway embankments were left as originally mapped.

5.1. Zone Descriptions

The resulting floodplains of the 1- and 0.2-percent-annual-chance floodplains are displayed within the floodplain maps provided in **Appendix A**. The mapped floodplains for the present study are labelled as Zone A and Zone X. The Zone A designation describes areas that have been identified to be at risk of flooding under from the 1-percent-annual-chance event. The Zone X designation describes areas that area at risk of flooding from the 0.2-percent-annual-chance event or experience flooding from the 1-percent-annual-chance event with a depth less than one foot. For example, the Zone X area located in the right overbank beyond the cross section extents of Sta. 0 – 36,781 for the East Reach indicates areas of either 1-percent-annual-chance floodplains that are less than one foot in depth or areas of 0.2-percent-annual-chance flooding hazard.

In addition to the aforementioned Zone A and Zone X designations developed from the present study, the floodplain maps also display existing effective flood designations along the studied reach and surrounding areas. The effective flood areas found within the maps consist of Zone A, Zone AE, Floodway, and 0.2-percent-annual-chance flood hazard. FEMA defines these areas as followed:

> Zone A – Areas subject to inundation by the 1-percent-annual-chance flood event generally determined using approximate methodologies. Because detailed hydraulic analyses have not been performed, no Base Flood Elevations (BFEs) or flood depths are shown.
>
> Zone AE – Areas subject to inundation by the 1-percent-annual-chance flood event determined by detailed methods. Base Flood Elevations (BFEs) are shown.
>
> Floodway – A Floodway defines the channel of a river and the adjacent land areas that must be reserved in order to discharge the base flood (1-percent-annual-chance) without cumulatively increasing the water surface elevation more than a designated height (0.5' for Montana).
>
> 0.2-percent-annual-chance flood hazard – the areas between the limits of the base flood and the 0.2-percent-annual-chance (or 500-year) flood.

Along with the flooding extents, the maps also display the stream centerline, cross sections utilized during the hydraulic analysis, and base flood elevations (BFE). The basemap of the hydraulic work map is 2011 NAIP.

Mapped BFE lines were positioned to display whole foot elevations of backwater. The river stationing and resultant 1-percent-annual-chance WSEL is represented along each respective cross section as well as lettered cross sections to provide a more efficient reference point.

5.2. Tie-In to Effective Mapping

The upstream study limit of the East Reach ties into the aforementioned FEMA study at Melrose. According to Section C.5.2 in Appendix C of FEMA's Guidelines and Specifications, the floodplain widths of the new and effective studies must match. According to the results of the original study and the effective FEMA data (**Appendix G**), the mapped 1-percent-annual-chance WSEL at the downstream extent of the detailed reach is 5168.33' NAVD88. The present analysis results in a 1-percent-annual-chance WSEL of 5165.75. The glaring difference in results can be attributed to multiple reasons. Similar to the present study, the effective hydrology was based off of a statistical gage analysis. However, the study was performed in 1977 and therefore did not have the lengthy period of record utilized for the present study. Review of the HEC-2 microfiche also shows that the original model only accounted for the eastern channel while the present study represents the full cross section. However, given that the present study is an approximate analysis, there is no requirement concerning the tie-in of water surface elevations. Therefore, one only needs to ensure that the widths of the mapped floodplains are approximate at map scale. Visual inspection and measurements of the floodplain widths at tie-in location show close approximation.

The West Reach ties in at the upstream extent of the SCS study. As previously mentioned, differences in the topographic data used in the present study and that of the SCS study created issues in the hydraulic model and floodplain mapping when the WSELs of the SCS study were used as a downstream tie-in. Therefore the elevation tie-in with the upstream end of the SCS study was foregone with focus solely given to the tie-in of the floodplain widths. This creates a more realistic map which is likely the primary source of information for the communities moving forward. The problems associated with the West Reach tie-in point are further elaborated in the *Unique Modeling and Mapping Scenarios Section*, Section 6 of this report.

6. Unique Modeling and Mapping Scenarios

Throughout the hydraulic analysis and floodplain mapping of the 117 miles of the Big Hole River, there were many instances that were unique and required special consideration. These issues were found throughout the modeled reaches and are further described in the paragraphs below.

6.1. Diverted and Split Flows

6.1.1. East Reach Diverted Flow

When simulating the flood events within the lower sections of the East Reach, there were many instances where the modeled discharges overtopped the containment of the immediate river valley and flow through the fields beyond the right overbank. The first occurrence of flow escaping the containment of the river valley is the reach between Stations 36781 and 31251. The Big Hole River approaches this reach at an eastward direction. As the river comes to Station 36781 it bends north. However, there are multiple channels and irrigation canals that continue east through the right overbank. An aerial of this respective reach is shown in **Figure 4**. Once the flows overtop the break in grade on the right overbank, they are lost from the system and continue in an east to northeast direction towards and along Hwy 41 towards Twin Bridges and the Jefferson River.

The second location of flow leaving the immediate river valley of the East Reach occurs between Stations 12959 and 6254. An aerial of this respective reach is shown in **Figure 5**. According to the resultant water surface elevations calculated in the hydraulic analysis, the 1- and 0.2-percent-annual-chance discharges overtop the right overbank with a large percentage of the discharge continuing east to Hwy 41 and northeast towards Twin Bridges and the Jefferson River. Given the slope of the topography, it was assumed that all of the diverted discharge was lost from the main channel of the Big Hole River without rejoining the system before the mouth of the river. Similar to the first reach of diverted flow (Sta. 36781 – 31251), the areas receiving the diverted flows provide little topographic relief and are populated with numerous irrigation canals and structures that are not accurately portrayed in the utilized topographic data.

In order to simulate the diverted flows escaping the containment of the Big Hole River overbanks, lateral weirs were employed to simulate the low lying divides of the overbanks and overflows areas. The lateral weirs are specified as a broad crested weir with a specified width of one foot and utilize a weir coefficient of 2.0. Throughout the East Reach, there are a total of 21 lateral weirs employed. Discharges passing over the series of weirs are presented in **Table 13** below. A comparison of the resultant WSELs when accounting for the possible diversion of discharges is detailed in **Table 14**.

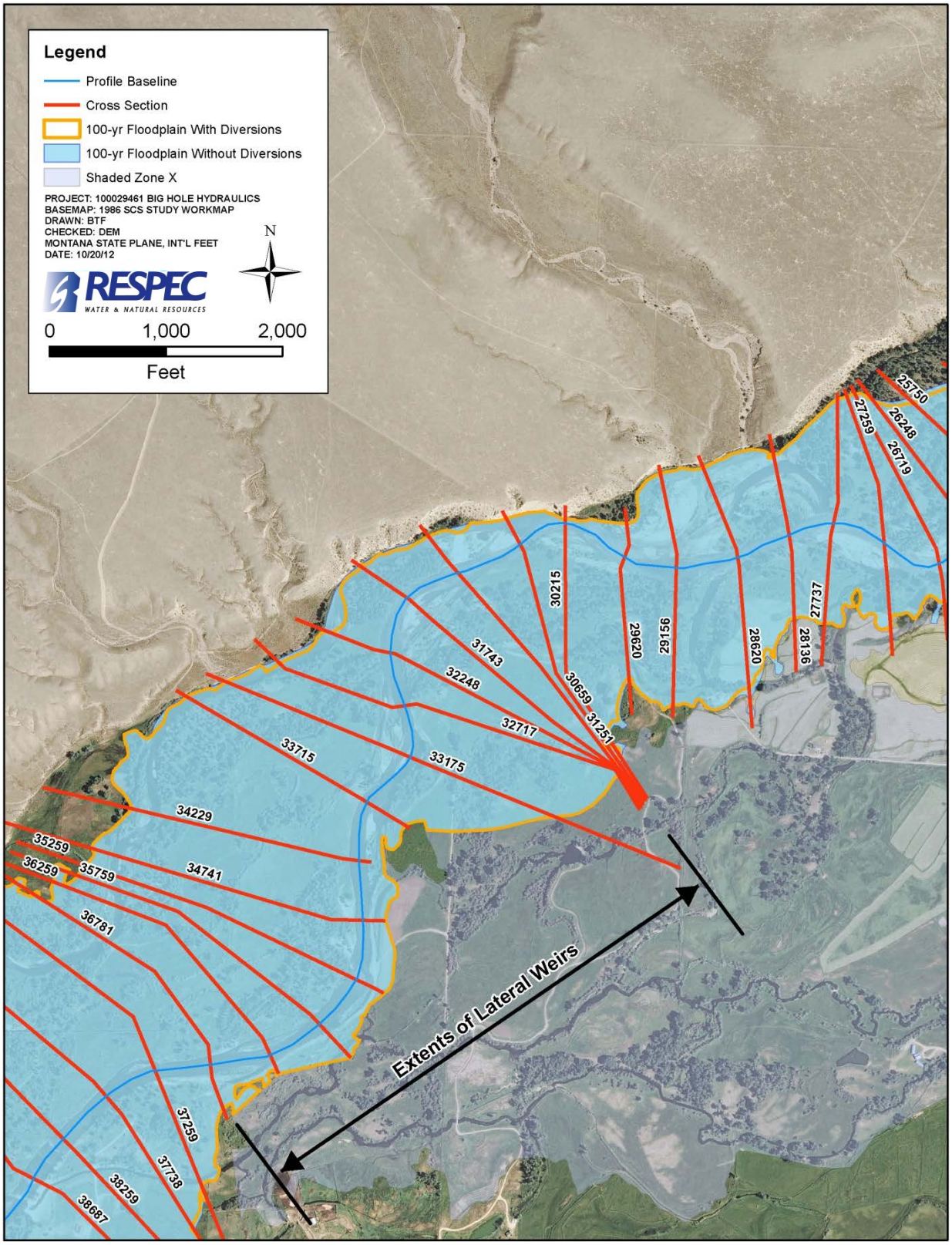


Figure 4. Difference in floodplains below the most upstream overflow of the East Reach

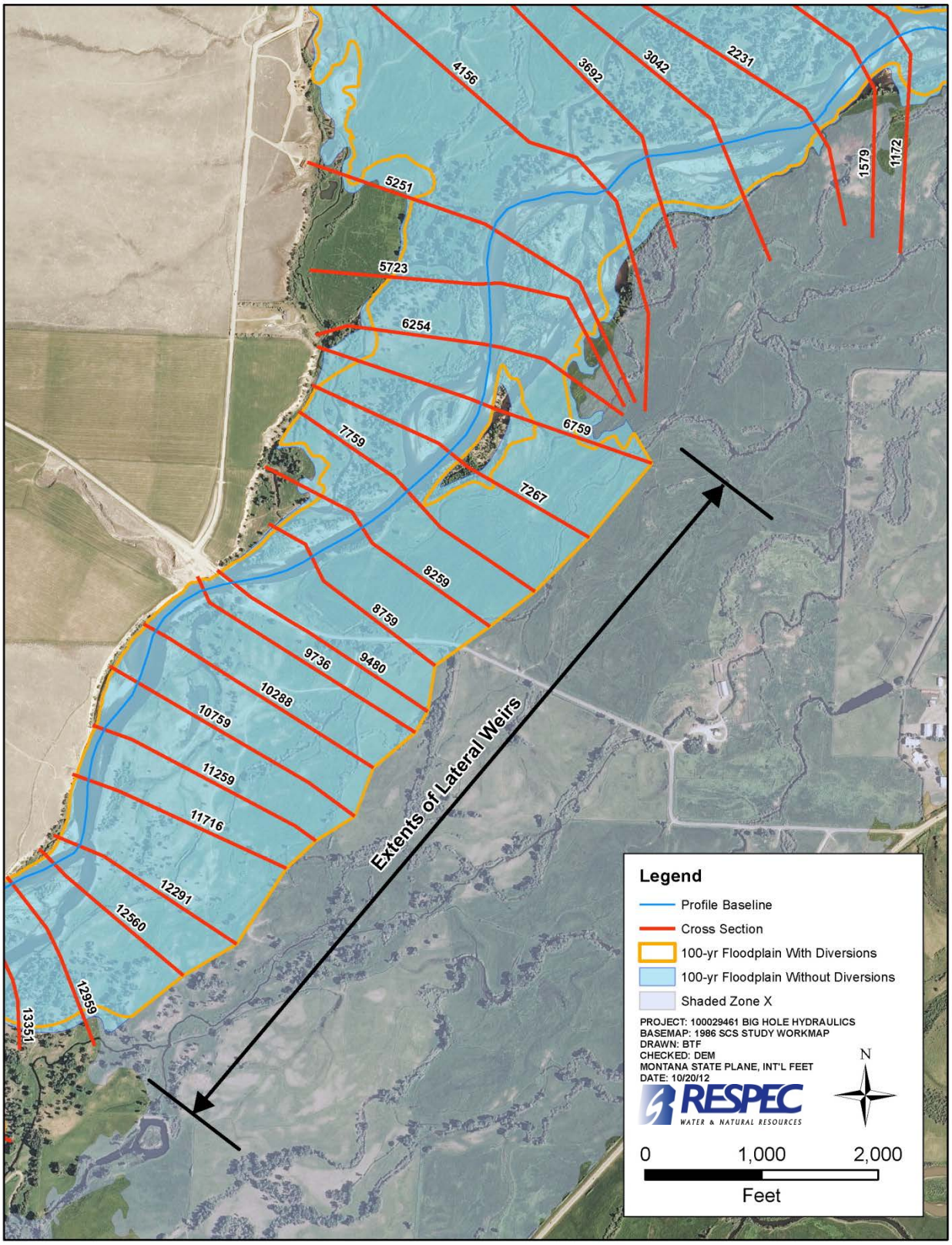


Figure 5. Difference in floodplains below the most downstream overflow of the East Reach

Table 13. Summary of overflow discharges of the East Reach

Scenario	No Overflow		With Overflow			
River Sta	Contained Discharge (cfs)		Overflow Discharge (cfs)		Remaining Discharge (cfs)	
	100-yr	500-yr	100-yr	500-yr	100-yr	500-yr
36781	18300	21200	0	0	18300	21200
36259	18300	21200	84	183	18216	21017
35759	18300	21200	631	1081	17669	20119
35259	18300	21200	887	1616	17413	19584
34741	18300	21200	995	1921	17305	19279
34229	18300	21200	1268	2417	17032	18783
33715	18300	21200	1283	2457	17017	18743
33175	18300	21200	3251	4747	15049	16453
12959	18600	21500	3251	4747	15349	16753
12560	18600	21500	3251	4747	15349	16753
12291	18600	21500	3353	4936	15247	16564
11716	18600	21500	4391	6252	14209	15248
11259	18600	21500	5427	7481	13173	14019
10759	18600	21500	5683	7813	12917	13687
10288	18600	21500	5729	7906	12871	13594
9736	18600	21500	6948	9327	11652	12173
9480	18600	21500	7289	9723	11311	11777
8759	18600	21500	7428	9900	11172	11600
8259	18600	21500	8487	11074	10113	10426
7759	18600	21500	9011	11665	9589	9835
7267	18600	21500	9015	11671	9585	9829

Table 14. Comparison of WSELs affected by the application of diverted flows

	No Overflow		With Overflow			
	Water Surface Elevations (ft)				Difference (ft)	
River Station (ft)	1-Percent-Annual-Chance	0.2-Percent-Annual-Chance	1-Percent-Annual-Chance	0.2-Percent-Annual-Chance	1-Percent-Annual-Chance	0.2-Percent-Annual-Chance
36,781	4725.49	4725.81	4725.47	4725.77	0.02	0.04
36,259	4724.50	4724.81	4724.43	4724.69	0.07	0.12
35,759	4723.67	4724.00	4723.56	4723.80	0.11	0.20
35,259	4722.93	4723.27	4722.77	4723.01	0.16	0.26
34,741	4722.25	4722.52	4722.07	4722.28	0.18	0.24
34,229	4719.41	4719.93	4719.31	4719.58	0.10	0.35
33,715	4718.14	4718.48	4717.79	4717.98	0.35	0.50
33,175	4716.88	4717.19	4716.49	4716.67	0.39	0.52
12,959	4656.44	4657.04	4655.61	4655.91	0.83	1.13
12,560	4655.67	4656.27	4654.87	4655.16	0.80	1.11
12,291	4654.24	4654.65	4653.57	4653.76	0.67	0.89
11,716	4652.56	4652.91	4651.80	4651.93	0.76	0.98
11,259	4650.69	4651.08	4650.09	4650.20	0.60	0.88
10,759	4648.89	4649.56	4647.14	4647.29	1.75	2.27
10,288	4648.69	4649.35	4646.88	4647.03	1.81	2.32
9,736	4646.64	4647.13	4645.11	4645.23	1.53	1.90
9,480	4645.38	4645.82	4644.09	4644.19	1.29	1.63
8,759	4643.73	4644.19	4641.96	4642.04	1.77	2.15
8,259	4642.44	4642.82	4640.93	4640.98	1.51	1.84
7,759	4641.35	4641.70	4640.05	4640.10	1.30	1.60
7,267	4639.12	4639.33	4638.02	4638.06	1.10	1.27
6,759	4636.93	4637.29	4635.41	4635.46	1.52	1.83
6,254	4633.56	4633.91	4632.48	4632.52	1.08	1.39
5,723	4632.30	4632.61	4631.19	4631.23	1.11	1.38
5,251	4631.14	4631.47	4629.94	4629.98	1.20	1.49
4,156	4627.91	4628.23	4626.72	4626.76	1.19	1.47
3,692	4625.79	4626.07	4624.64	4624.69	1.15	1.38
3,042	4624.09	4624.33	4623.16	4623.19	0.93	1.14
2,231	4622.45	4622.69	4621.53	4621.56	0.92	1.13
1,579	4620.39	4620.57	4619.63	4619.66	0.76	0.91
1,172	4619.19	4619.36	4618.47	4618.49	0.72	0.87
143	4616.16	4616.35	4615.40	4615.43	0.76	0.92

To best portray the diverted discharges leaving the East Reach, multiple models portraying the overland floodplain of the diverted discharges were developed to provide a boundary of overland flooding. The model has been submitted and the plans are outlined below in **Table 15**. Due to the lack of a major channel or defined flow path within the topographic data, as well as the numerous canals and irrigation structures present, accurately simulating the discharge and direction of the overland flow with the available topographic data and one-dimensional models is extremely difficult. Given the lack of the highly accurate data required along with the difficulty to assign a risk to the overland flows, a Shaded Zone X was utilized to illustrate the potential hazard. While not a regulatory area, the utilization of the Shaded Zone X notifies the communities that there is a flood risk associated with the area. The Shaded Zone X defines areas of either 1-percent-annual-chance floodplains that are less than one foot in depth or areas of 0.2-percent-annual-chance floodplains. The Shaded Zone X noted on the Floodplain Maps ties-in at the low lying divides of the diverted flow locations as well as areas where discharge can possibly re-enter the immediate floodplain of the main channel. The mapped Shaded Zone X was concluded at Hwy 41 and the Jefferson River.

Table 15. Summary of overflow models of the East Reach

Study	Plan Title	Geometry File	Flow File	Description
Overflow	**Overflow_1**	**Overflow_1**	**Overflow_1**	Existing conditions hydraulic analysis of the 1- and 0.2-percent-annual-chance events of the potential overflow of the East Reach. Model simulates the ***upstream*** overflow location.
	Overflow_2	**Overflow_2**	**Overflow_2**	Existing conditions hydraulic analysis of the 1- and 0.2-percent-annual-chance events of the potential overflow of the East Reach. Model simulates the ***downstream*** overflow location.

Although there is the potential for discharge to exit the system of the main channel, for mapping purposes, another simulation was conducted in which it was conservatively assumed that all discharge was contained within the system without allowing for diversions. As displayed by **Table 13** above, there is the possibility for a large percentage of discharge to be diverted. However, upon inspection of **Figures 4** and **5**, the comparison of the resultant 1-percent-annual-chance floodplains shows that there is little difference in the mapped areas when accounting for diversions or not. Therefore, the 1- and 0.2-percent-annual-chance floodplains and elevations illustrated on the Floodplain Maps portray WSELs that do not account for the possible diversion present within the East Reach.

6.1.2. West Reach Wisdom Split Flow

In addition to the overflow locations discovered in the East Reach, the West Reach contains an area of split flow just upstream of Wisdom. For the split located in the West Reach, the aerial imagery shows flow separated from the main channel by an elevated land mass to reconvene with the primary floodplain corridor downstream.

The area of split flow is located about 2.5 miles upstream of Wisdom. Initial modeling and mapping revealed no water reaching the far right overbank area as suggested by aerial imagery. Consequently, junctions were created to model the flow split and a secondary flow path was created and named Wisdom Split. Flow optimizations at the downstream junction satisfied continuity while balancing the energy equation resulting in flows in the split channel as shown in **Table 16**.

Table 16. Summary of split discharges of the West Reach at Wisdom Split

	Discharge (cfs)	
Split Flow Area	**1-Percent-Annual-Chance**	**0.2-Percent-Annual-Chance**
Upstream	6,980	9,160
Wisdom Split	500	820
Main Channel	6,480	8,340
Downstream	6,980	9,160

Several other possible split flow locations were identified from the aerial imagery that were not supported by the topographic data. These situations are likely due to the inherent limitations found when utilizing a DEM with a coarser resolution such as that found in the present study. Further discussion about the topographical data conflicting with the aerial imagery is found in Section 6.2 of this report.

6.2. Conflicting Data Sources

Another difficulty encountered when modeling and mapping the flood flows through the Big Hole River was the number of discrepancies noted between the aerials and the topographic data. There were numerous areas that were denoted as being outside of the floodplain but the aerials showed water present with a direct connection to the main channel. These areas were typically found to be located at the toe of steeper slopes. It was assumed that during the creation of the topographic data, the grid cells were 'averaged' over this steeper area to result in a widened hillside with a lower slope. For most of these areas, the floodplain bounds were slightly extended to include the areas noted to contain water on the basemap. Although the resulting floodplain extents of the model may not perfectly match the mapped width, they are typically within map tolerance (50' for the 1":1,000' scale of the floodplain maps). It should be noted that it was assumed that the Floodplain Maps would be the main source of information for the communities and that accurate representation of flooding hazards on the map preceded the need to match the model results exactly. Along those same lines, there are many instances where irrigation canals and minor channels were not represented in the 5-m topographic data. This sometimes resulted in these minor hydraulic features being shown outside of the floodplain. For these instances, the extents of the floodplain boundaries were not relocated. It was assumed that there would be volume within the minor hydraulic features but the quantity would be negligible and difficult to accurately represent given the accuracy of the data sources.

Citizens and communities utilizing the maps should refer to the Administrative Rules of Montana (ARM) 36.15.501 (6): "The designated floodplain boundary is based on base flood elevations. The mapped floodplain boundary may be used as a guide for determining whether property is within the designated floodplain, but the exact boundary shall be determined according to the base flood elevation…" Hence, when using the floodplain maps, the user is cautioned to utilize the respective base flood elevation instead of the illustrated floodplain boundaries. It is advised the floodplain maps be used as a guide to approximate floodplain boundaries with the base flood elevations utilized as the primary source of information when determining the flood hazard associated with a property.

Another discrepancy between the topography and basemap was the represented location and geometry of the main channel. Upon creation of the cross sectional geometries it was apparent that the two data sources were not coinciding. The upper reaches of the West Reach model showed many instances where the main channel, as defined by the aerial imagery, was not represented in the topographic data. For these cases, the channel was defined solely by referencing the topographic data. The main conveyance path represented in the topographic data was assigned as the channel. Due to the large magnitude of flood volume found in the overbanks within the Big Hole River, this situation turned out to be a relatively moot point. However, care should be taken when performing similar studies along smaller floodplain corridors in which the conveyance of the channel plays a more prominent role. Review of the floodplain maps for the upstream section of the

West Reach shows that the streamline does not always match that of the aerial. This is due to the streamline reflecting the modeled streamline of the topographic data rather than that of the aerial imagery.

Locations affected by the alteration of the stream centerline area as follows:180019, 181269 – 199136, 201654, 203661, 203767, 206229, 223667, 229485 – 242628, 304414 – 308648, 311247, 311920, 317660 – 325302, 334798, 336720 – 337916, 339192 – 339593, 341633 – 345549, 351001, 351451, 357152 – 358400, 363976 – 372964, 374473 – 377550, 378371 – 379660, 380888 – 383484, 385781 – 389146, 393021 – 397793, 400283, 403269, and 403836 – 404660.

Possible reasoning for the discrepancy in the channel location of the topographic data and aerial imagery is the continual evolution and lateral shifting of the Big Hole River. Since the aerial imagery and topographic data were collected years apart, it is possible that the Big Hole River could have migrated between the dates of the data collection.

6.3. West Reach Tie-in to SCS Study

As previously mentioned, differences in the topographic data used in the present study and that of the SCS study created issues in the hydraulic model and floodplain mapping when the WSELs of the SCS study were used as a downstream tie-in. The SCS study was completed in 1986, when the National Geodetic Vertical Datum of 1929 (NGVD29) was widely used for a vertical datum. The present study utilizes the North American Vertical Datum of 1988. A datum conversion of +4.12 feet is applied to NGVD29 elevations to correspond to NAVD88 elevations. The datum conversion does not cause the discrepancy in the two data sets.

Inspection of the SCS study revealed no structures were modeled downstream of the tie-in point that could explain the 1300 feet of backwater affect the known water surface elevations impose. Further investigation of the topographic data revealed discrepancies between the datasets.

From the SCS study, the streambed elevation indicated on Table 2, “Flood Frequency – Elevation Data” at Section CW is 5729.7 (ft NGVD29). The 4.1 ft conversion factor is added for an SCS streambed elevation of 5733.82 (ft NAVD88). This elevation matches closely to the field surveyed channel for the present study about 250’ south with elevation of 5733.81 (FT NAVD 88). For the same surveyed point, the Intermap data reports an elevation of 5726.69 (FT NAVD 88), a difference of 7.12’. Considering that the Intermap elevation incorporates the water surface elevation at the time of measurement, the Intermap data is low when compared to the SCS study and present field survey. Other points of comparison in this area were noted to differ by up to 14’. Based on this information, there are two possible ways to present the new flood study at the tie in point. **Table 17** summarizes different BFE and top width conditions at the tie-in section (SCS XS CW, West Reach XS 1728) for the two different scenarios

Table 17. Comparison of WSEL and top width at West Reach tie-in to SCS Study

Source	1% Annual Chance Water Surface Elevation (ft NAVD88)	Top Width (ft)
SCS – XS CW	5741.7	670
West Reach 1728 (SCS WSEL)	5741.7	785
West Reach 1728 (Normal Depth)	5735.41	434/600*

**top width includes islands shown as flooded*

The first option is to use the SCS known water surface elevation and the new top width of 785’. This produces a top width discrepancy to the SCS study of about 115’, greater than mapping error tolerance (50 ft) for the defined map scale (1:12,000). Since the Intermap elevation data is known to be low in this location, the forced BFE remains accurate however the inundation mapping will appear much higher than where that elevation should plot on accurate terrain data. The alternative option extends the model downstream four additional cross sections and uses Normal Depth as the starting condition. This option favours the mapping

product, by producing a visually accurate Floodplain Map; however the BFE, based solely on the Intermap data, is low. These two options are shown visually on **Figures 6** and **7**. It was determined that the water surface elevations presented in the SCS study should be utilized for the starting condition and the top width from their mapping product will be shown on the new floodplain map. Furthermore, incorporation of the station and elevation information of the SCS study tie in section to the present study model will provide a sound conveyance calculation for calculating the water surface elevation for the next section upstream.

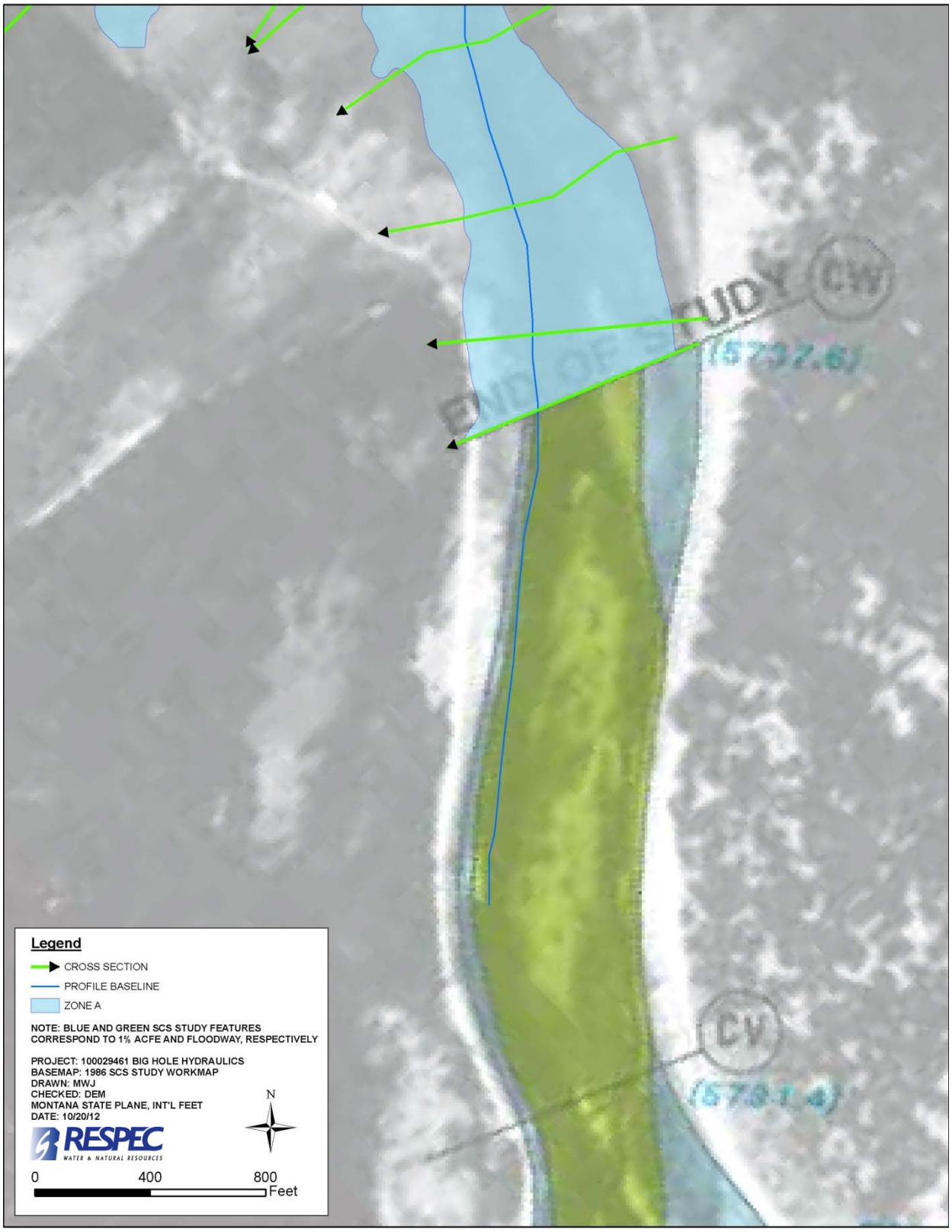


Figure 6. West Reach downstream tie-in utilizing SCS WSEL for boundary condition.

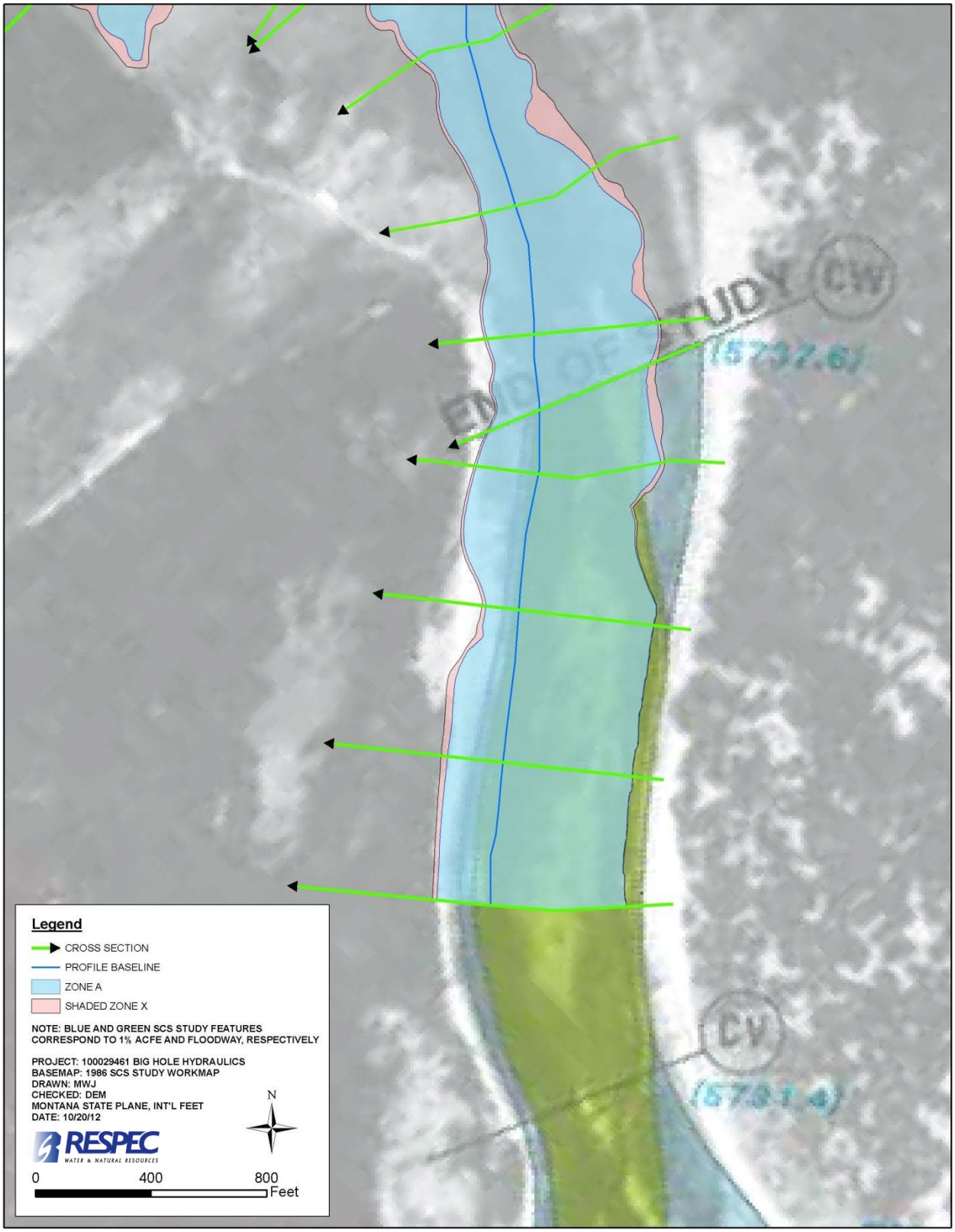


Figure 7. West Reach downstream tie-in utilizing normal depth for boundary condition

6.4. Urbanized Areas

One potentially unfavorable outcome from the Big Hole River Approximate Level Floodplain Study is that half the town of Wisdom was originally shown inundated by the 1-percent-annual-chance event. This had many potential ramifications for the citizens of Wisdom. If the 5m DEM data is correct, the area shown as inundated should be insured from the base flood and residents should be aware of their risk. However, upon inspection of the 5m DEM it is was discovered that during data refinement and preparation of the DEM, interpolation algorithms may have inaccurately altered the elevations of the urbanized area. **Figure 8** shows the town of Wisdom inundated by the 1-percent-annual-chance event. Further information in regards to the accuracy measurements of the utilized DEM around Wisdom are available in the report titled '*Big Hole River Approximate Level Floodplain Study, Phase 2 – Hydraulic Analysis and Mapping, Topographic Data Assessment'* (**References 4**) submitted August 6, 2012.

Understanding the potential ramifications, Beaverhead Co. collected additional survey data necessary to complete a localized hydraulic model geometry composed of survey data. The model describing the the hydraulic characteristics and surveyed geometry through the Wisdom reach of the Big Hole River was incorporate into the Middle Section of the model of the West Reach. With the incorporation of the detailed geometry, Atkins was also able to incorporate the Hwy 43 bridge west of Wisdom to create a more accurate accurately detailed water surface profile than originally created when only utilizing the 5m DEM. Beaverhead Co. also collected enough survey points throughout the community of Wisdom that allowed for the creation of a detailed DEM. As illustrated in **Figure 9**, the survey based DEM allowed for the floodplain boundaries within Wisdom to be more accurately defined. It should be noted that the DEM was only created for a short reach through Wisdom. The floodplain boundaries on the west side of the Wisdom reach are delineated from the 5m DEM. For future studies, it is recommended that higher accuracy data simulations be performed at higher populated areas.

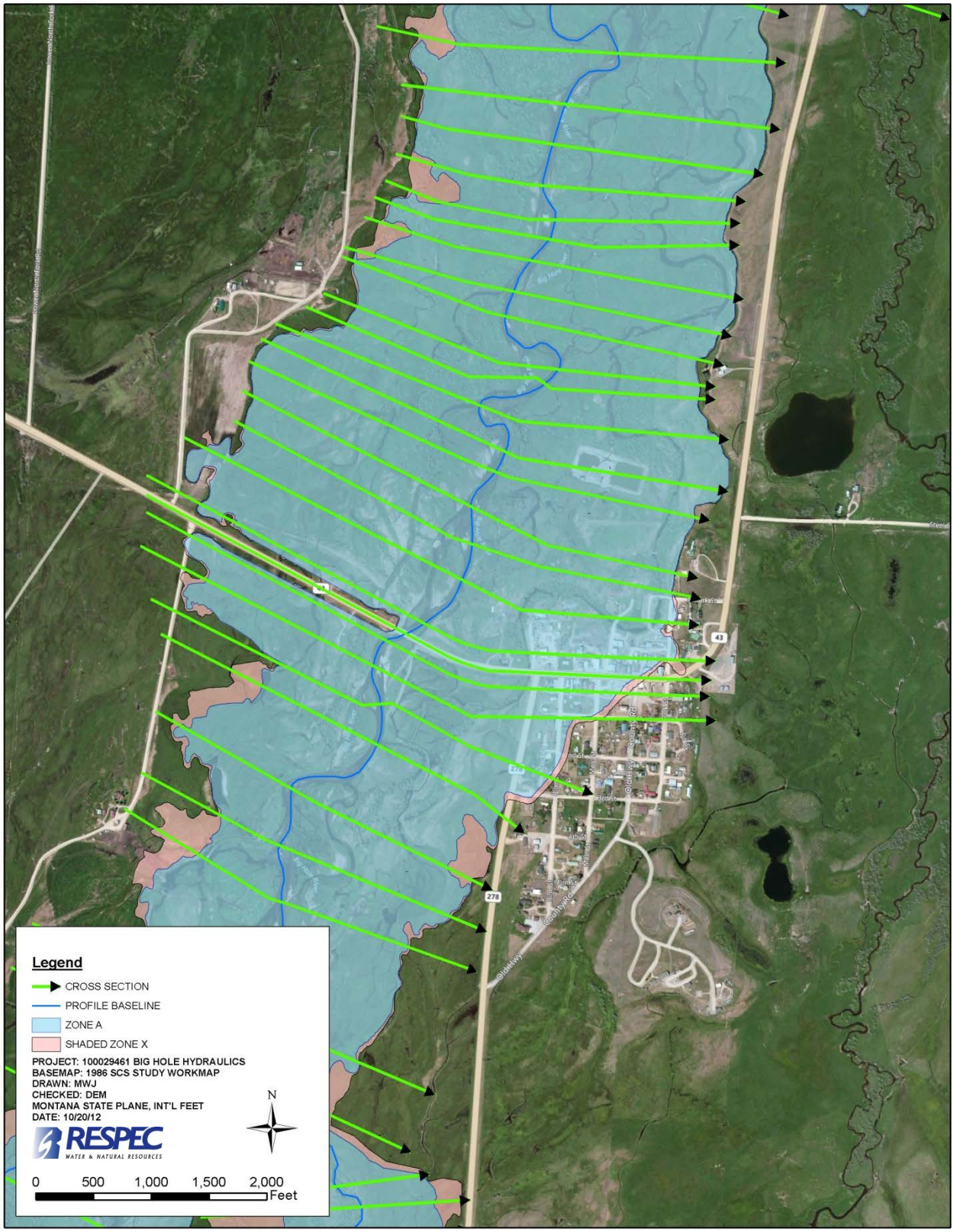


Figure 8. Originally delineated floodplains at the Town of Wisdom

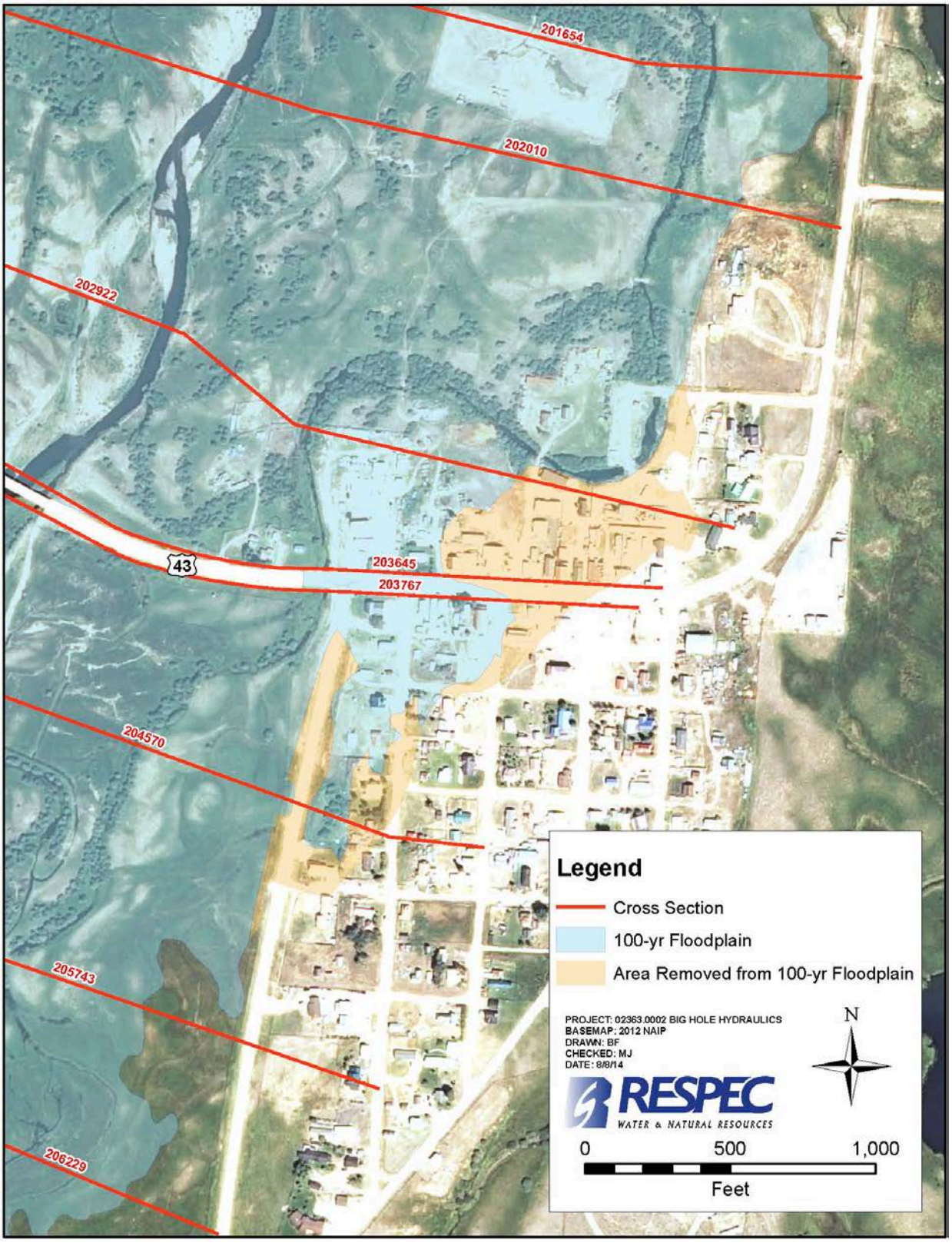


Figure 9. Updated 100-year floodplain at the Town of Wisdom

7. Summary

This report details the approximate hydraulic analysis and floodplain mapping that was performed approximately 117 miles of the Big Hole River by Atkins under contract with Montana Department of Natural Resources and Conservation (DNRC), the Montana Department of Environmental Quality (DEQ), Anaconda-Deer Lodge County, Beaverhead County, Butte-Silver Bow County, Madison County, the Big Hole River Watershed Committee (BHWC), and Future West. This analysis is the final of two phases to conduct a National Flood Insurance Program Approximate level floodplain study for most of the entire Big Hole River. The great majority of the river has never been mapped for flood hazard and local regulators and planners have struggled to provide a technical basis for regulating land development. Many studies have commenced in the past but the most relevant is the SCS Flood Plain Management Study of 1986. Summarized in this report are the topographic data source, hydraulic methods utilized, and the assignment of hydraulic variables. The report also outlines areas that required special consideration due to the hydraulic nature at those specific locations. The results of the approximate hydraulic analysis were mapped using NAIP (2011) as a basemap and a 5-meter digital elevation model provided by Intermap Technologies Inc. (2012).

Throughout the topographic assessment previously submitted, as well as the present hydraulic analysis and mapping procedures, it was evident that the accuracy of the results would be largely dependent upon the accuracy of the utilized topographic data. As witnessed in *Section 6.3 - West Reach Tie-in to SCS Study*, the results of the hydraulic analysis and mapping can be greatly altered by the differences in topographic data. However, given that the Big Hole River valley is largely uninhabited, utilization of a financially more feasible topographic dataset is recommended. However, care should be taken when creating the floodplain maps to ensure that reality is represented to furthest extent allowed. As can be seen in *Section 6.4 - Urbanized Areas*, use of a coarse dataset around populated areas can present possible misrepresentations. Therefore it is recommended that the dataset possessing higher accuracy standards be utilized for communities with a larger population.

8. References

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Appendices

Appendix A. Floodplain Maps

Appendix B. cHECk-RAS

Appendix C. Top Width Checks

Appendix D. Profiles

Appendix E. Floodplain Data Tables

Appendix F. Topographic Data Report

Appendix G. FEMA Effective Data

Appendix H. Big Hole Rating Curves

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