Hydraulic Analysis Technical Support Data Notebook

Greenbrier County, West Virginia

Prepared By:

Wood Environment & Infrastructure Solutions, INC.
4795 Meadow Wood Lane, Suite 310E
Chantilly, VA 20151

Federal Emergency Management Agency (FEMA) Region III
Cooperating Technical Partners Program
Mapping Activity Statement No. WVDHSEM-2018-3

Prepared For:

Federal Emergency Management Agency (FEMA) Region III
Greenbrier County, West Virginia

March 2020

Table of Contents

List of Tables

List of Figures

Appendices

Appendix A - Greenbrier County, WV Studies Map

1.0 STUDY DESCRIPTION

1.1 COUNTY DESCRIPTION

Greenbrier County is located in southeast West Virginia and is bordered on the north by Webster County; to the northeast by Pocahontas County; to the east by the Commonwealth of Virginia; to the south by Monroe County; to the southwest by Summers County; to the west by Fayette County, and to the northwest by Nicholas County. Greenbrier County includes the Cities of Lewisburg, Ronceverte and White Sulphur Springs. Interstate highway 64 runs through the southern portion of the county and other major roads servicing the county include U.S. routes 60 and 219, and West Virginia routes 12, 20, 39, 55, 63 and 92. The county includes a total population of 35,480 (U.S. Census, 2010). Appendix A shows Greenbrier County, West Virginia, and the stream reaches included in this study.

1.2 PURPOSE OF STUDY

The purpose of this study is to conduct a hydraulic study to support the Federal Emergency Management Agency (FEMA) Region III Cooperating Technical Partners Program. The scope of study includes updating and developing approximate (Zone A) studies and select detailed studies (Zone AE). The HUC 8 watersheds covering Greenbrier County scoped reaches are 05050005 and 05050003.

1.3 SCOPE OF WORK

The scope of work includes the restudy of approximately 543 miles of approximate Zone A streams, and approximately 28 miles of detailed Zone AE streams. The purpose of this hydraulics report is to document the methodology and calculations used to develop the 10%, 4%, 2%, 1%, 1% plus, and 0.2%-annual-chance exceedance event water surface elevations (WSELs). The location of the approximate study reaches, and their corresponding HUC-8 watersheds are illustrated on the map provided in Appendix A.

1.4 TYPES OF FLOODING AND FLOODING HISTORY

All streams in this study are riverine and without tidal influences. According to the 2012 FIS report, principal causes of flooding include hurricane produced rainfall and rapid snowmelt in the spring (FIS 2012). The USGS gage Greenbrier River at Alderson (gage ID: 03183500) has 122 peak flow records spanning from 1896 to 2017. The second highest peak flow occurred November 1985, with a discharge value of 90,600 cfs. The remnants of Hurricane Juan along with other climatic conditions led to record flooding, and the 1985 event is known to be the most devastating flooding experienced by the state of West Virginia (FIS 2012). The highest measurement of the Alderson gage occurred in January 1996, with a peak flow value of 94,000 cfs. This severe flooding event was caused by heavy rainfall and snow melt, which resulted in flash flooding (FIS 2012).

More recently, June 2016, historic flooding in central and southern West Virginia occurred after a period of torrential rain, resulting in a disaster declaration by President Obama. A 1000-yr rainfall event was estimated to have occurred in Roane, Kanawha, Clay, Fayette, Nicholas and Greenbrier Counties (OFR2017-1140). According to NOAA’s State of the Climate report for June 2016, in some locations of West Virginia over 10 inches of rain fell on already saturated soils, resulting in record flooding. The flooding caused a reported 23 fatalities, and over 1,500 homes were destroyed (NOAA National Climate Report – June 2016). In June 2016, USGS gage Greenbrier River at Alderson recorded a peak flow of 80,700 cfs. This was the third highest peak flow ever recorded at the gage.

1.5 OTHER STUDIES

The US Geological Survey took high water measurements and reanalyzed gage flows after the 2016 extreme flooding event. Their findings were summarized in the Open-File Report 2017-1140, *Characteristics of Peak Streamflows and Extent of Inundation in Areas of West Virginia and Southwestern Virginia Affected by Flooding, June 2016*. This information was used in studying two sections of Greenbrier River during the Physical Map Revision (PMR), Case No. 19-03-0002S, in response to the June 23, 2016 West Virginia flooding disaster event.

2.0 HYDRAULIC ANALYSIS

2.1 STUDY LIMITS AND METHODOLOGY

A total of approximately 570 miles of stream reaches were modeled for the project. During the development of hydraulic modeling, the stream centerlines were updated to follow aerials and/or topographic datasets. The hydraulic models for streams studied under this task were developed with the USACE Hydraulic Engineering Center (HEC) River Analysis System (RAS), version 5.0.7 (HEC, 2019). All Zone A modeled streams were studied by approximate methods and Zone AE modeled streams were studied by detailed methods. One-dimensional steady state hydraulic models (HEC-RAS) were developed to estimate the 10%, 4%, 2%, 1%, 1% plus, and 0.2%-annual-chance exceedance event WSELs. Table 1 below lists 133 streams segments which were studied to update effective Zone-A flood hazard boundaries. Table 2 below lists 6 streams which were studied using detail methods.

Table 1. Streams Studied Using Approximate Methods

No.	Stream Name	Miles
1	Alum Run	2.6
2	Anglins Creek	0.49
3	Anthony Creek	15.5
4	Anthony Creek Tributary 1	1.8
5	Anthony Creek Tributary 2	3.6
6	Anthony Creek Tributary 2.1	0.4
7	Anthony Creek Tributary 3	2
8	Bear Run	1.3
9	Beaver Creek	3.5
10	Becky Run	1.4
11	Beech Run 1	1.2
12	Beverly Fork	0.2
13	Big Clear Creek	16.42
14	Boulder Run	0.2
15	Boggs Creek	5.6
16	Boggs Run	0.3
17	Broad Run	0.64
18	Brown Creek	3.2
19	Buffalo Creek	3.7
20	Burdette Creek	1.9
21	Burns Run	1.7
22	Burns Run Tributary 1	0.5
23	Callahan Branch	1.2
24	Culberson Creek	9.8
25	Culberson Creek Tributary 1	0.5
26	Culberson Creek Tributary 2	1
27	Culberson Creek Tributary 3	0.5

28	Culberson Creek Tributary 4	0.4
29	Coats Run	0.1
30	Cold Knob Fork	3.9
31	Cold Spring Branch	1.4
32	Davy Run	1.4
33	Dodson Branch	2.1
34	Dry Creek 2	6.5
35	Dry Run	1.8
36	Eagle Branch	1.3
37	Fleming Run	3.4
38	Fleming Run Tributary 1	1.6
39	Flynn Creek	1.9
40	Greenbrier River 5	36.5
41	Greenbrier River Tributary 1	0.7
42	Greenbrier River Tributary 2	1.8
43	Greenbrier River Tributary 4	0.8
44	Greenbrier River Tributary 5	0.7
45	Harts Run	5.4
46	Hogcamp Run	0.8
47	Hominy Creek	1.5
48	Howard Creek	4.7
49	Howard Creek Tributary 1	3.9
50	Hughart Creek	5
51	Hughart Creek Tributary 1	0.7
52	Hunters Run	0.4
53	Improvement Branch	2.1
54	Indian Creek	2.2
55	Jericho Draft	3.2
56	Jericho Draft Tributary 1	2.3
57	Job Knob Branch 1	1.8
58	Job Knob Branch 2	0.2
59	Kincaid Run	0.2
60	Kitchen Creek	7.9
61	Kitchen Creek Tributary 1	1.7
62	Kuhn Branch	0.8
63	Laurel Branch	0.7
64	Laurel Creek 1	1.6
65	Laurel Creek 2	0.8
66	Laurel Creek 3	2.0

67	Laurel Creek 4	8.2
68	Laurel Run 1	7.9
69	Laurel Run 2	3.1
70	Little Creek 1	8.2
71	Little Creek 2	0.6
72	Little Clear Creek	14.0
73	Little Laurel Creek	9.4
74	Little Roaring Creek	0.8
75	Little Sewell Creek	3.5
76	McMillion Creek	2.5
77	Meadow Creek 1	14.3
78	Meadow Creek 2	7.7
79	Meadow River 1	18.9
80	Meadow River 4	22.3
81	Middle Fork Anthonys Creek	11.8
82	Middle Branch	1.7
83	Mill Creek 1	8.2
84	Mill Creek 1 Tributary 1	0.6
85	Mill Creek 2	4.4
86	Milligan Creek	8.17
87	Milligan Creek Tributary 3	2.6
88	Milligan Creek Tributary 4	0.6
89	Milligan Creek Tributary 5	1.5
90	Morris Fork	2.9
91	Methodist Branch	2.8
92	Muddy Creek	21.0
93	North Fork Anthony Creek	8.5
94	North Fork Cherry River	16.6
95	Old Field Branch	2.1
96	Otter Creek	4.4
97	Patterson Creek	0.8
98	Peaser Branch	0.48
99	Piney Creek	0.4
100	Panther Camp Creek	2.8
101	Rockcamp Run	0.7
102	Renick Creek	4.0
103	Roaring Creek	3.4
104	Robbins Run	5.3
105	Rocky Run	4.5

106	Sam Creek	1.1
107	Second Creek	9.6
108	South Fork Big Clear Creek	5.8
109	South Fork Cherry River	15
110	Simms Run	1.2
111	Slabcamp Run	3.9
112	Sulphur Lick Run	1.9
113	Slash Lick Run	1.5
114	Smokehouse Branch	1.0
115	Snake Run	3.9
116	Sinking Creek	14.1
117	Sinking Creek Tributary 1	3
118	Sinking Creek Tributary 2	0.4
119	Sinking Creek Tributary 3	0.4
120	Sinking Creek Tributary 4	0.3
121	Snodgrass Run	1.2
122	Spice Run	5.2
123	Spring Creek	22.1
124	Spring Creek Tributary 3	1.2
125	Stony Run	1
126	Toms Creek	0.9
127	Tuckahoe Run	2.8
128	Tuckahoe Run Tributary 2	0.4
129	Twomile Run	0.2
130	Wades Creek 2	1.2
131	Wiley Run	0.9
132	Wolfpen Creek	0.7
133	Youngs Creek	3.1

Table 2. Streams Studied Using Detail Methods

No.	Stream Name	Start Description	End Description	Miles
1	Dry Creek 1	Confluence with Howard Creek	Approximately 100 feet downstream of Tuckahoe Road	2.43
2	Greenbrier River 2	Approximately 10,000 feet downstream of Seneca Trail S	Approximately 9,000 feet upstream of Seneca Trail S	3.50
3	Greenbrier River 3	Approximately 21,000 feet downstream of Fort Spring Pike	Approximately 10,000 feet downstream of Seneca Trail S	10.43
4	Greenbrier River 4	Approximately 9,000 ft upstream of Seneca Trail S	Approximately 1,500 ft upstream of Interstate 64	4.92
5	Meadow River 3	Approximately 6,000 feet upstream of Central Ave	Approximately 8,000 feet downstream of Tommy Hall Road	4.80
6	Wades Creek 1	Confluence with Howard Creek	Approximately 50 feet upstream of Interstate 64	2.25

Greenbrier River was divided into five sections. Two of these sections, Greenbrier 1 and Greenbrier 2 were studied during the Physical Map Revision (PMR), Case No. 19-03-0002S, in response to the June 23, 2016 West Virginia flooding disaster event. Greenbrier River 3 and Greenbrier 4 are detailed streams studied during this project. Greenbrier River 5 is an approximate study from this project.

2.2 ASSUMPTIONS FOR HEC-RAS MODELING

To use HEC-RAS for one dimensional steady state hydraulic computations for Greenbrier County, some assumptions were made: the flow regime was subcritical; the flow was steady and the flow through and around structures was unobstructed.

2.3 TOPOGRAPHY

Topographic data for the floodplain models were developed using 3.3 ft (1m) resolution Light Detection and Ranging (LiDAR) funded by FEMA. FEMA funded LiDAR collection was flown November 22 to December 28, 2016, by Quantum Spatial, Inc. 1m bare-earth Digital Elevation Model (DEM) tiles from the LiDAR deliverable were mosaicked together and projected into a single DEM in the West Virginia State Plate South (ft) coordinate system, with a cell size of 3.3. ft. The vertical unit of the DEM was converted to foot (NAVD88)

Source documentation, including project metadata, horizontal accuracy assessment reports, LiDAR collection map and vertical accuracy assessment report have been uploaded to the FEMA's Mapping Information Platform (MIP). Geospatial files such as the defined project areas, tile indices, and contours have been stored under the FEMA Data Capture supplemental data directory in shapefile format and have been uploaded to the MIP.

2.4 SURVEY

Survey data was collected Spring 2018 by Erickson Contract Surveying Inc. This survey data was used to model 34 of the 35 structures modeled for this PMR. On Meadow River one structure was modeled based off the previous effective study, LiDAR, aerial imagery and reasonable assumptions (descriptions are provided in the geometry files). Collected survey data included elevations along the road and on the immediate upstream and downstream faces of the structure. The survey included elevation data from the channel, channel centerline, edge of water, top of bank, toe of bank, face of abutment, bridge corners, low chord, high points, centerline of the bridge, piers, elevation shots, end of bridge and the road profile.

2.5 BOUNDARY CONDITIONS

For approximate studies, normal depth method was used for the starting water surface elevations for all streams that do not share an extent boundary. The normal depth is defined by the slope of stream channel. For areas that share an extent boundary or that were tying into the restudied detailed streams, Known Water Surface Elevation (KWSEL) was used for the boundary conditions.

Table 3 below lists starting conditions applied for streams studied using detail methods.

Table 3. Model Starting Conditions for Detail Studied Streams

No.	Stream Name	Boundary Condition
1	Dry Creek 1	Normal Depth S=0.00733
2	Greenbrier River 2	Known Water Surface Elevation
3	Greenbrier River 3	Known Water Surface Elevation
4	Greenbrier River 4	Known Water Surface Elevation
5	Meadow River 3	Known Water Surface Elevation
6	Wades Creek 1	Normal Depth S=0.00605

2.6 CROSS SECTIONS

Floodplain cross sections were placed perpendicular to flow at representative locations along the modeled streams. Cross sections were spaced at closer intervals at locations of sudden changes in stream geometry or direction as well as areas of expansion and contraction. At the structures, sections were located to follow the toe of the embankment of the structure, and to capture expansion and contraction of the floodplain, following guidelines from the HEC-RAS Reference Manual (HEC-RAS River Analysis System, 2016). The geometric information for the cross sections was extracted from the, 3.2 ft cell-size raster, LiDAR based topographic information.

For the detailed studies, cross section topographic data included LiDAR data, survey data located at the structures, and invert data from the effective models. Channel bathymetry data was determined from the best available data. Survey data collected in 2018 was considered the best available data for modeling the channel bathymetry. Where survey data was not available, LiDAR and effective data were considered and were interpolated from bounding surveyed cross sections. Additional details were noted in the “Description” field in hydraulic models.

The cross sections included within the models are depicted spatially (digitally) in the S_XS feature dataset and submitted to MIP within Hydraulics Data Capture in this DCS Hydraulics Data submittal. The hydraulic HEC-RAS models are also included in this submittal.

2.7 STRUCTURES

There are 25 structures conveying flood flows along the detailed studied reaches. These structures were field surveyed. The details and locations of surveyed structures were documented with a DCS compliant survey upload.

The structures were coded into HEC-RAS geometry based off the field survey data and photographs. LIDAR data was used to extend the top of road profile beyond the limits of the survey information. Survey data was augmented by orthoimagery and LiDAR. The structures were typically modeled using the Energy (Standard Step) method for Low Flow conditions and Pressure and/or Weir method for High Flow conditions, but exceptions were made for structures exhibiting different flow conditions. Additional details specific to input data were also included in the “Description” field in the HEC-RAS geometry files.

2.8 COEFFICIENTS

Contraction and expansion coefficients of 0.1 and 0.3 respectively were utilized within the analysis. Contraction and expansion coefficients were increased to 0.3 and 0.5, respectively, at the structures' upstream and downstream bounding cross sections and at the upstream approach section.

2.9 INEFFECTIVE AND STORAGE AREAS

Ineffective flow areas were used to model areas that provide storage within a cross section, but for which there is insignificant conveyance. These areas were set as appropriate near structures and in areas where natural contraction or expansion of the floodplain is apparent. Ineffective flow areas, modeled in the approximate studies, were applied visually based upon review of the delineated floodplain boundaries, LIDAR based topographic data and aerials. Ineffective flows were added at basin boundaries for likely split flow locations.

2.10 CHANNEL ROUGHNESS VALUES

The channel and overbank Manning's n values were based upon the 2011 Landuse/Landcover of West Virginia dataset (West Virginia GIS Technical Center, 2012). Channel Manning's n values typically ranged between 0.025-0.055. The values for different land covers are presented below in Table 4. For detailed streams the information within the Landuse/Landcover dataset was supplemented with aerial imagery to better define roughness coefficients.

Table 4. Manning's Roughness Values

Class Code	Land Use / Land Cover Class Description	Default Manning's n value
1	Forested	0.12
2	Grasslands/Pastureland/Agriculture	0.06
3	Barren/Developed	0.08
4	Open Water	0.04
5	Mine Grass	0.05
6	Mine Barren	0.06
7	Forested in SMCRA Permit Area	0.1
8	Pre SMCRA Grass	0.06

9	Pre SMCRA Barren	0.07
10	Pre SMCRA Forested	0.1
11	Herbaceous Wetlands	0.07
12	Woody Wetlands	0.08
25	Census Roads (2011)	0.016

2.11 BLOCKED OBSTRUCTIONS

For streams studied using detailed methods, blocked obstructions were coded for cross sectional segments overlaying buildings. The building data was obtained from the US Buildings Layer developed by Microsoft and available under the Open Data Commons Open Database License (US Building Footprints). The elevations for blocked obstructions were defined to be greater than all modeled recurrence events.

2.12 SPECIAL CIRCUMSTANCES

Detailed portion of Meadow River was divided in two sections. The downstream portion was studied and submitted during the Physical Map Revision (PMR), Case No. 19-03-0002S, in response to the June 23, 2016 West Virginia flooding disaster event. When studying the upstream portion in this county-wide project, updates were made to the upstream portion of the disaster reach (downstream portion of the detailed non-disaster study) to make sure the floodways of these two models will tie-in to each other appropriately. Approximately 1900 feet of the disaster reach at the upstream of it, was updated. Only the floodway encroachment stations were updated. The updated area is shown in red in Figure 1 below.

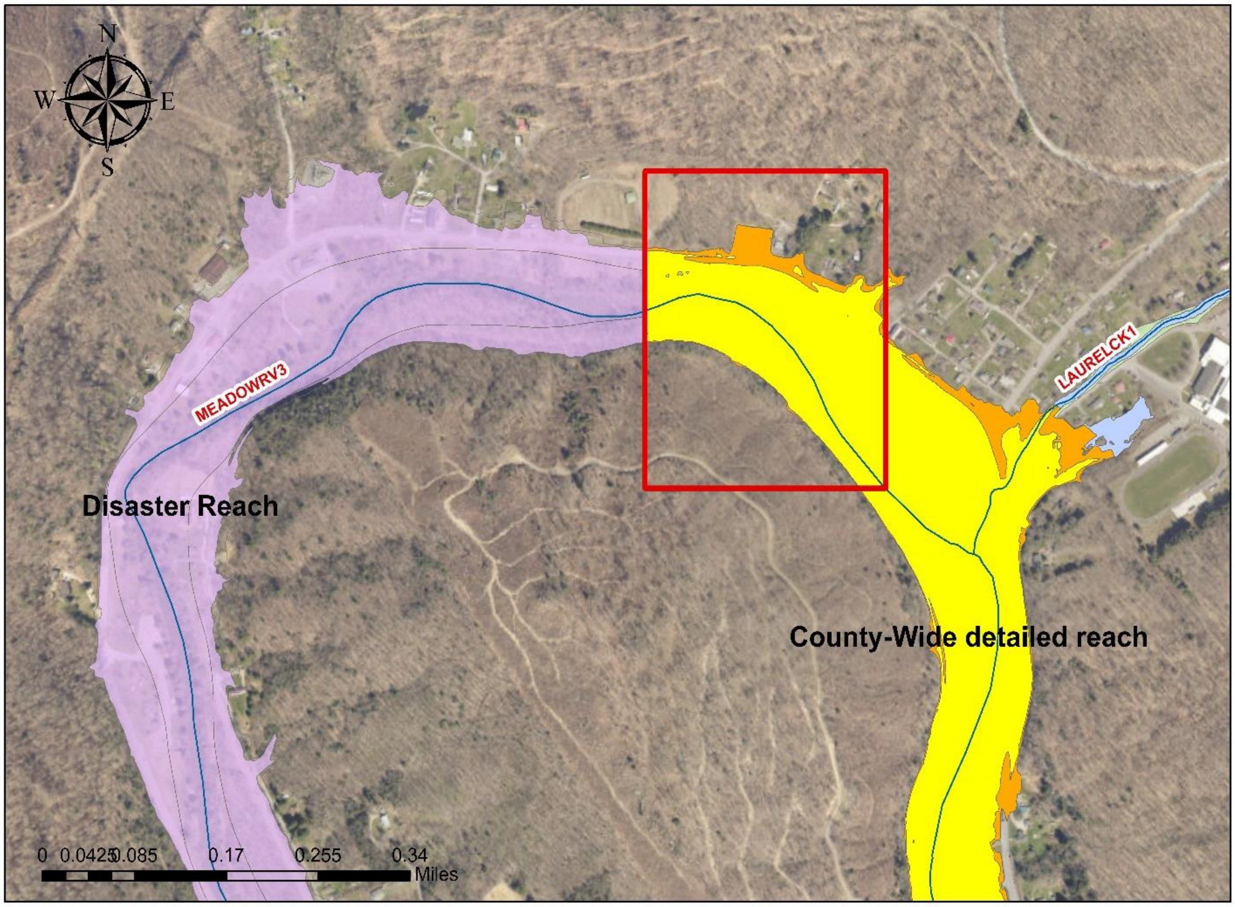

Figure 1. Meadow River disaster reach and non-disaster reach

Detailed portion of Greenbrier River was divided in four sections. Two sections, Greenbrier River 1 and Greenbrier River 2 were studied and submitted during the Physical Map Revision (PMR), Case No. 19-03-0002S, in response to the June 23, 2016 West Virginia flooding disaster event. When studying non-disaster reach Greenbrier River 3, updates were made to the disaster reach Greenbrier River 2, so it uses the correct Known Water Surface Elevation as a boundary condition. Also, floodway encroachment stations were updated for 4 cross sections at the downstream of Greenbrier River 2 so the floodway ties-in smoothly to Greenbrier River 3.

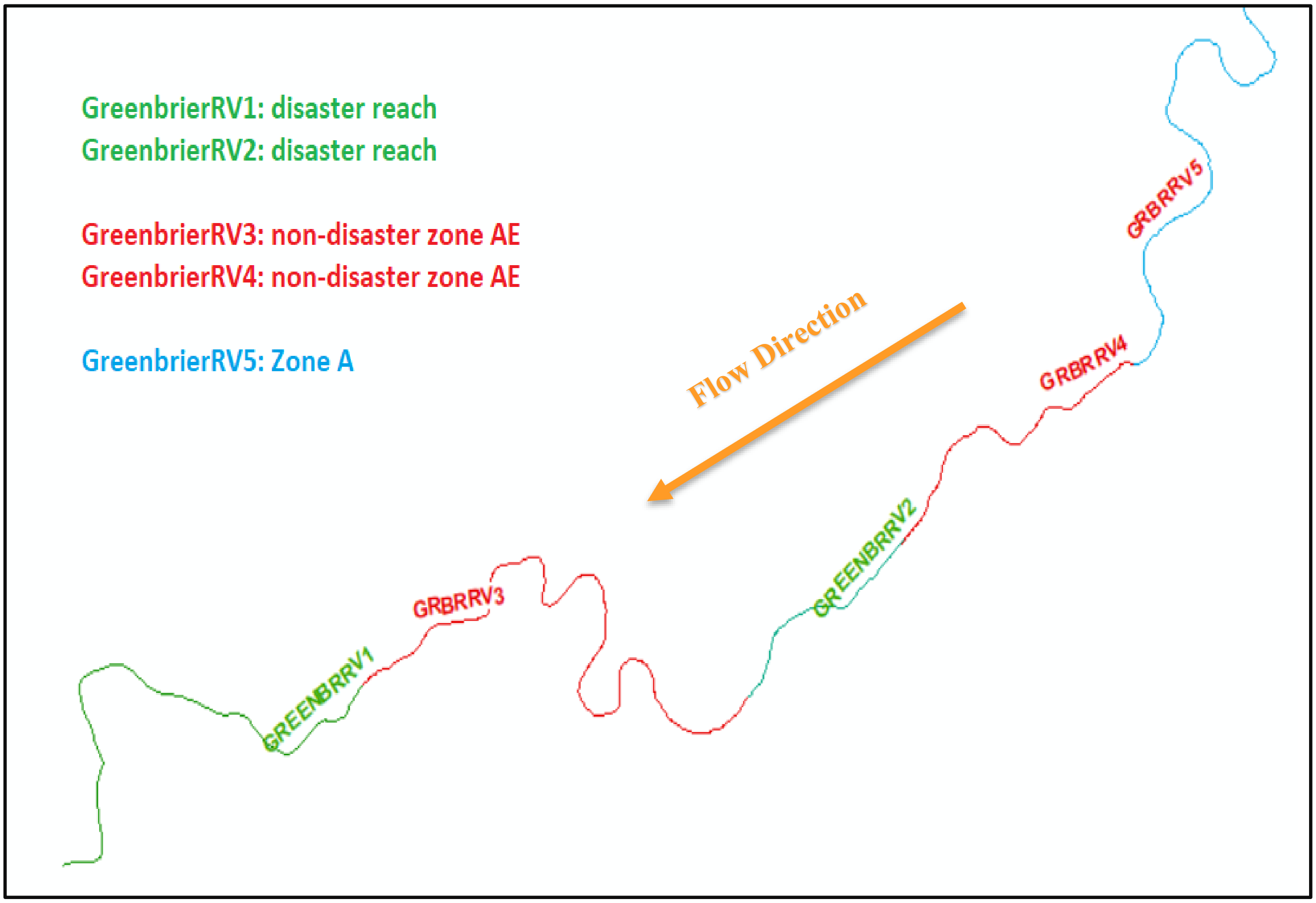

Figure 2. Greenbrier River disaster reaches, and non-disaster reaches

Culberson Creek Tributary 3 and Sinking Creek extended through a Karst area and a cross section was unable to be applied in this portion. The downstream and upstream portion of the karst area was modeled and for mapping purposes, the Karst area for Culberson Creek Tributary 3 and Sinking Creek was mapped as the effective floodplain.

Gage weighting analysis was performed for Meadow River. The area that was impacted by gage weighing analysis covered the detailed portion of Meadow River (Meadow River 3). For the remaining section of Meadow River which is an approximate study (Meadow River 4) and is not under the influence of the gage, regression equations were used to calculated discharges. This change in methodology caused a crossing profile in Meadow River 4, between the 1% plus and the 0.2%-annual-chance exceedance events. The reason is that 1% plus annual-chance exceedance event is calculated using the standard prediction error at 68% confidence level, while when applying gage weighting analysis, 1% plus annual-chance exceedance event is calculated at 84% confidence limit.

The crossing profile also exists between the 1% plus and the 0.2%-annual-chance between Anthony Creek and Middle Fork Anthony Creek. Gage weighted flows is applied at the tie-in between Anthony Creek and Middle Fork Anthony Creek and then regression is applied through the remainder of Middle Fork Anthony Creek. The gage weighting from Anthony Creek reached the limit of applicability at the tie-in with Middle Fork Anthony Creek and this change in methodology caused the crossing profile.

2.13 CALIBRATION

High Water Marks (HWMs) for the historic June 2016 event were used to calibrate Greenbrier River 1 and Greenbrier River 2. Greenbrier River 1 hasn't changed since the Physical Map Revision (PMR) study, Case No. 19-03-0002S. Greenbrier River 2 was updated as part of the county-wide study.

The location, quality, and elevation of these HWMs are documented with a DCS compliant survey upload for a PMR study for disaster reached, Case No. 19-03-0002S. Adjustments were made primarily in the ineffective placement, Channel Manning's n and bank station locations to calibrate the models. The June 2016 discharges were acquired from the USGS OFR2017-1140 report.

3.0 HYDRAULIC RESULTS

Widening and narrowing of the 1-percent-annual-chance floodplain extent compared to the current effective, was observed throughout the county. Meadow River, dry creek and Wades Creek floodways follow the current regulatory floodway mostly and they narrow or widen slightly at few places. Floodways were not established for Greenbrier rivers previously and they were created during this study.

Most streams experienced both increases and decreases when comparing the computed model WSELs to the current regulatory base flood elevations (BFEs). Changes in water surface elevations could be a result of implementing updated topography and hydrology data.

3.1 COMPARISON WITH EFFECTIVE FIS REPORT

The revised base (1-percent-annual-chance) flood elevations (BFEs) were compared to the effective BFEs at letter cross section locations. Table 5 through Table 10 compare the BFEs and statistics from the comparisons. The comparisons revealed both increases as well decrease in BFEs for all studied streams. Summary of hydrologic and hydraulics analysis for studied streams is also presented in Table 11 below.

Table 5. Comparison of BFEs (Effective versus Revised) for Dry Creek 1

River Station	Computed Water Surface Elevation (ft)	Current Regulatory Water Surface Elevation (ft)	Difference in Water Surface Elevation (ft)
1778	1855.8	1856.8	-1.0
2908	1863.4	1864.6	-1.2
7178	1891.8	1893.9	-2.1
8192	1900.7	1901.3	-0.6
9453	1911.4	1913.2	-1.9
10047	1915.7	1917.3	-1.6
11695	1930.3	1932.2	-1.9
12807	1939.6	1941.5	-1.9

Table 6. Comparison of BFEs (Effective versus Revised) for Greenbrier River 2

River Station	Computed Water Surface Elevation (ft)	Current Regulatory Water Surface Elevation (ft)	Difference in Water Surface Elevation (ft)
6043.1	1656.5	1656.4	0.1
10159.3	1661.3	1661.3	0.0
18248.3	1669.6	1669.6	0.0

Table 7. Comparison of BFEs (Effective versus Revised) for Greenbrier River 3

River Station	Computed Water Surface Elevation (ft)	Current Regulatory Water Surface Elevation (ft)	Difference in Water Surface Elevation (ft)
23865	1580.2	1580.2	0.0
26723	1586.0	1584.6	1.4
31013	1591.2	1590.1	1.1
76484	1651.3	1653	-1.7

Table 8. Comparison of BFEs (Effective versus Revised) for Greenbrier River 4

River Station	Computed Water Surface Elevation (ft)	Current Regulatory Water Surface Elevation (ft)	Difference in Water Surface Elevation (ft)
102597	1675.3	1678	-2.7
106778	1680.2	1681	-0.8
107104	1681.7	1681.2	0.5
107632	1682.6	1682.5	0.1
111402	1687.1	1686	1.0
117016	1689.0	1690.3	-1.3
117523	1690.1	1691	-0.9

Table 9. Comparison of BFEs (Effective versus Revised) for Meadow River 3

River Station	Computed Water Surface Elevation (ft)	Current Regulatory Water Surface Elevation (ft)	Difference in Water Surface Elevation (ft)
16674	2401.4	2401.4	0.0
18268	2402.2	2402.2	0.0
19030	2402.3	2403.9	-1.6
21280	2403.9	2404.8	-0.9
23935	2404.8	2405.6	-0.8
26383	2405.7	2406.5	-0.8
28371	2406.2	2406.7	-0.5
30597	2407.1	2407.4	-0.3
32688	2407.7	2408	-0.3
34187	2408.7	2408	0.7
36226	2408.9	2408.7	0.2
39357	2409.2	2408.8	0.4
41663	2409.3	2408.9	0.4

Table 10. Comparison of BFEs (Effective versus Revised) for Wades Creek 1

River Station	Computed Water Surface Elevation (ft)	Current Regulatory Water Surface Elevation (ft)	Difference in Water Surface Elevation (ft)
336	1854.0	1855	-1.0
1340	1864.0	1864.2	-0.2
3431	1881.9	1882.7	-0.8
6520	1919.0	1920.2	-1.2
6966	1925.9	1926.1	-0.2
7994	1934.7	1936.6	-1.9
9140	1952.3	1952.4	-0.1
10466	1971.2	1971.3	-0.1

The spatial data pertaining to the hydraulic analyses was submitted digitally to FEMA's Mapping Information Platform (MIP) meeting Data Capture Technical Reference, February 2019 version (FEMA, 2019a). The spatial data is projected to GCS_North_American_1983 and has a horizontal datum of NAD83 according to Flood Insurance Rate Map (FIRM) Database Technical Reference, February 2019 version (FEMA, 2019b).

Table 111. Summary of Hydrologic and Hydraulic Analysis

Flooding Source	Study Limits Downstream Limit	Study Limits Upstream Limit	Hydrologic Model or Method Used	Hydraulic Model or Method Used	Date Analyses Completed	Flood Zone on FIRM	Special Considerations
Dry Creek 1	Confluence with Howard Creek	Approximately 100 feet downstream of Tuckahoe Road	PeakFQ 17C Gage Analysis and Gage-Weighted Equations	HEC-RAS 5.0.7	March 2020	AE	
Greenbrier River 2	Approximately 10,000 feet downstream of Seneca Trail S	Approximately 9,000 feet upstream of Seneca Trail S	Gage Analysis weighted with Regional Regression Equations	HEC-RAS 5.0.7	March 2020	AE	Hydraulic model was calibrated to high water marks collected for 2016 event
Greenbrier River 3	Approximately 21,000 feet downstream of Fort Spring Pike	Approximately 10,000 feet downstream of Seneca Trail S	Gage Analysis weighted with Regional Regression Equations	HEC-RAS 5.0.7	March 2020	AE	
Greenbrier River 4	Approximately 9,000 ft upstream of Seneca Trail S	Approximately 1,500 ft upstream of Interstate 64	Gage Analysis weighted with Regional Regression Equations	HEC-RAS 5.0.7	March 2020	AE	
Meadow River 3	Approximately 6,000 feet upstream of Central Ave	Approximately 8,000 feet downstream of Tommy Hall Road	PeakFQ 17C Gage Analysis and Gage-Weighted Equations	HEC-RAS 5.0.7	March 2020	AE	
Wades Creek 1	Confluence with Howard Creek	Approximately 50 feet upstream of Interstate 64	Gage Analysis weighted with Regional Regression Equations	HEC-RAS 5.0.7	March 2020	AE	
ALUMRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
ANGLINSCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
ANTHONYCK	Downstream extent	Upstream extent	Gage Weighting	HEC-RAS 5.0.7	March 2020	A	

ANTNYCKT1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
ANTNYCKT2	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
ANTNYCKT2_1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
ANTNYCKT3	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BEARRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BEAVERCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BECKYRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BEECHRN1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BEVERLYFK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BIGCLEARCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BLDRRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BOGGSCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BOGGSRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BROADRN	Downstream extent	Upstream extent	HMS	HEC-RAS 5.0.7	March 2020	A	
BROWNCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	

BUFFALOCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BURDETTECK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BURNSRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
BURNSRNT1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
CALLAHNBR	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
CLBRSNCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
CLBRSNCKT1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
CLBRSNCKT2	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
CLBRSNCKT3	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
CLBRSNCKT4	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
COATSRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
COLDKNOBFK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
COLDSPRBR	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
DAVYRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
DODSONBR	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	

DRYCK2	Downstream extent	Upstream extent	HMS	HEC-RAS 5.0.7	March 2020	A	
DRYRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
EAGLEBR	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
FLMINGRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
FLMINGRNT1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
FLYNNCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
GRBRRV5	Downstream extent	Upstream extent	Gage Weighting	HEC-RAS 5.0.7	March 2020	A	
GRBRRVTR1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
GRBRRVTR2	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
GRBRRVTR4	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
GRBRRVTR5	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
HARTSRN	Downstream extent	Upstream extent	HMS	HEC-RAS 5.0.7	March 2020	A	
HOGCMPRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
HOMINYCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
HOWARDCK	Downstream extent	Upstream extent	HMS	HEC-RAS 5.0.7	March 2020	A	

HOWCKTR1	Downstream extent	Upstream extent	HMS	HEC-RAS 5.0.7	March 2020	A	
HUGHRTCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
HUGHRTCKT1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
HUNTERSRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
IMPRVMTBR	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
INDIANCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
JERCHODFT	Downstream extent	Upstream extent	HMS	HEC-RAS 5.0.7	March 2020	A	
JERCHODFTT1	Downstream extent	Upstream extent	HMS	HEC-RAS 5.0.7	March 2020	A	
JOBKNOBBR1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
JOBKNOBBR2	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
KINCAIDRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
KTCHNCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
KTCHNCKT1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
KUHNBR	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
LAURELBR	Downstream extent	Upstream extent	HMS	HEC-RAS 5.0.7	March 2020	A	

LAURELCK1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
LAURELCK2	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
LAURELCK3	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
LAURELCK4	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
LAURELRN1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
LAURELRN2	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
LITTLECK1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
LITTLECK2	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
LTCLEARCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
LTLAURELCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
LTROARCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
LTSEWELLCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MCMILLCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MEADOWCK1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MEADOWCK2	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	

MEADOWRV1	Downstream extent	Upstream extent	Gage Weighting	HEC-RAS 5.0.7	March 2020	A	
MEADOWRV4	Downstream extent	Upstream extent	Gage Weighting	HEC-RAS 5.0.7	March 2020	A	
MFANTNYCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MIDDLEBR	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MILLCK1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MILLCK1T1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MILLCK2	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MLGNCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MLGNCKTR3	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MLGNCKTR4	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MLGNCKTR5	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MORRISFK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MTHODSTBR	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
MUDDYCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
NFANTNYCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	

NFKCHERRYRV	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
OLFLDBR	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
OTTERCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
PATTSNCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
PEASERBR	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
PINEYCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
PNTHRCMPCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
RCKCMPRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
RENICKCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
ROARINGCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
ROBBINSRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
ROCKYRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SAMCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SECONDCK	Downstream extent	Upstream extent	Gage Weighting	HEC-RAS 5.0.7	March 2020	A	
SFBIGCLRCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	

SFKCHERRYRV	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SIMMSRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SLBCMPRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SLPHRLCKRN	Downstream extent	Upstream extent	HMS	HEC-RAS 5.0.7	March 2020	A	
SLSHLCKRN	Downstream extent	Upstream extent	HMS	HEC-RAS 5.0.7	March 2020	A	
SMKHSEBR	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SNAKERN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SNKNGCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SNKNGCKT1	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SNKNGCKT2	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SNKNGCKT3	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SNKNGCKT4	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SNODGRSRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SPICERN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
SPRINGCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	

SPRINGCKT3	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
STONYRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
TOMSCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
TUCKHORN	Downstream extent	Upstream extent	HMS	HEC-RAS 5.0.7	March 2020	A	
TUCKHORNT2	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
TWOMILERN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
WADESCK2	Downstream extent	Upstream extent	HMS	HEC-RAS 5.0.7	March 2020	A	
WILEYRN	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
WOLFPENCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	
YOUNGSCK	Downstream extent	Upstream extent	Regression	HEC-RAS 5.0.7	March 2020	A	

3.2 FLOODWAY

For detailed studies, the floodway was developed using HEC-RAS 5.0.7. A target surcharge of 1.0 foot was used to generate a draft floodway using Method 4. Then, encroachment stations were updated using Method 1 to create a reasonable floodway with surcharges within the range of -0.04 to 1.00 ft. Greenbrier River 2 was part of the PMR study, Case No. 19-03-0002S, however to ensure a smooth tie-in with Greenbrier River 3 and the surcharges stayed between the -0.04 to 1.00 foot range, the encroachment stations for the downstream four cross sections of Greenbrier River 2 were revised.

4.0 FLOODPLAIN MAPPING

The floodplains for all stream reaches were mapped utilizing the aforementioned 3.3 ft DEM based on 1-percent-annual-chance flood elevations at modeled cross sections. Water surface elevations between model cross sections were interpolated. The water surface and DEM were intersected with each other to create raster inundation areas. The raster is converted to polygons which were then smoothed with a tolerance of 25 feet to remove the boundary jaggedness originated from the raster input

5.0 REFERENCES

Federal Emergency Management Agency (FEMA) Data Capture Technical Reference, February 2019a.

Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) Database Technical Reference, February 2019b.

Hydrologic Engineering Center, HEC-RAS River Analysis System, Version 5.0.7, U.S. Army Corps of Engineers, Davis, California, March 2019.

Hydrologic Engineering Center, HEC-RAS River Analysis System Hydraulic Reference Manual Version 5.0, U.S. Army Corps of Engineers, Davis, California, February 2016.

Landuse/Landcover of West Virginia (2011), West Virginia GIS Technical Center, http://wvgis.wvu.edu/data/dataset.php?ID=451

US Building Footprints, Microsoft Open Source GitHub, downloaded January 2019
https://github.com/Microsoft/USBuildingFootprints
https://usbuildingdata.blob.core.windows.net/usbuildings-v1-1/WestVirginia.zip

United States Census Bureau, 2010. Quick Facts – Greenbrier County, West Virginia, Accessed online February 2020 online at https://www.census.gov/quickfacts/greenbriercountywestvirginia

6.0 APPENDICES

APPENDIX A

Greenbrier County, WV Studies Map

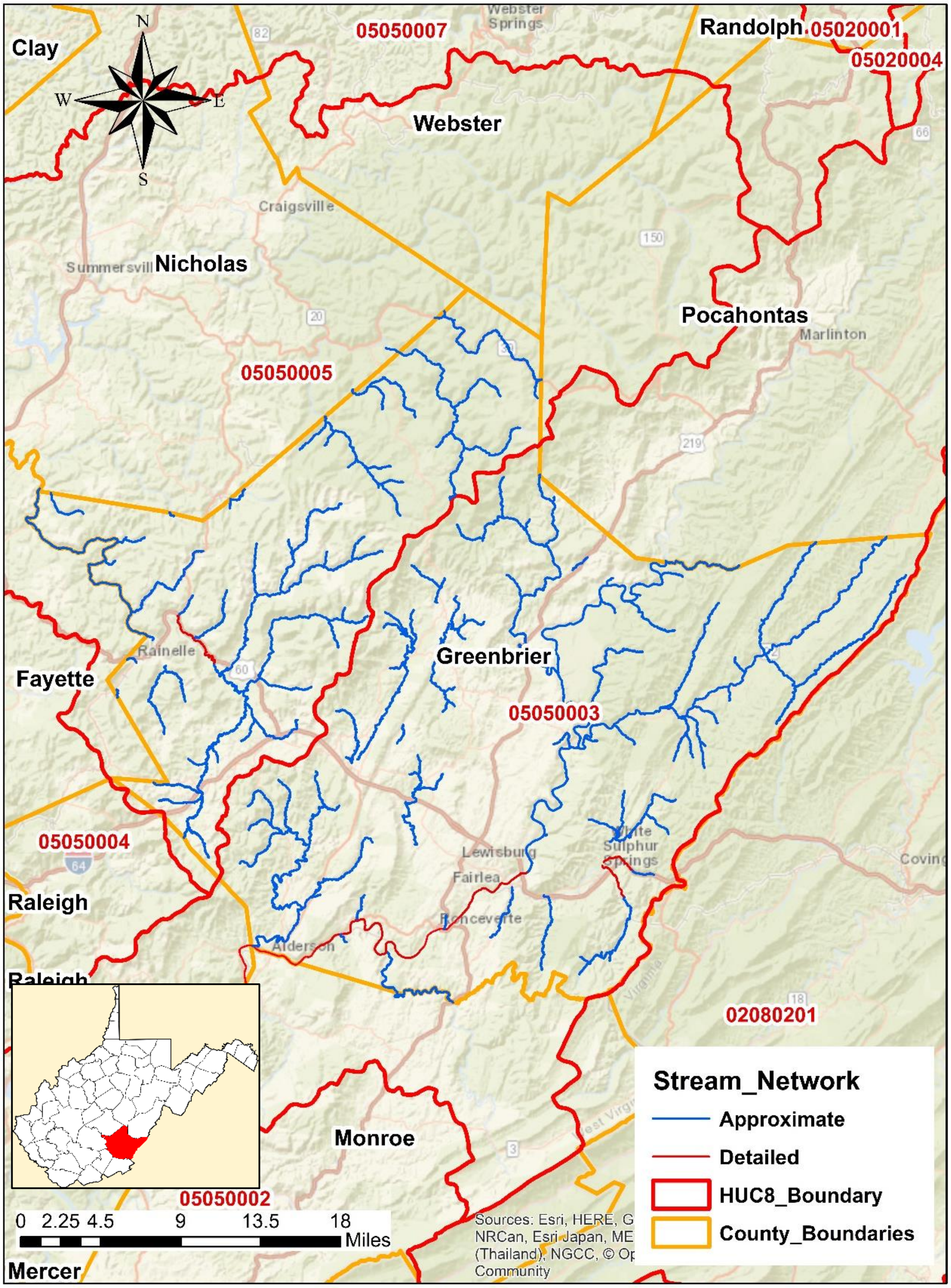

Figure 3. Greenbrier County Reach Studies Location