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Flood Study
Sugar River Model, USH18/151 to White Crossing Road

Town and City of Verona, WI;
Dane County, WI

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1. Project Summary

AECOM, on behalf of the City of Verona, has developed a flood study for the Sugar River from just downstream of U.S. Highway (USH) 18/151 to just upstream of White Crossing at a confluence between the Sugar River and an Unnamed Tributary, a total reach length of approximately two miles (heretofore referred to as “Flood Study”). The effective floodplain in the Flood Study area is Zone A and is located in the City of Verona and Town of Verona, Dane County.

There is an effective hydraulic model for the Sugar River located just downstream of the Flood Study that extends upstream from the Sugar River confluence with Badger Mill Creek to just downstream of USH 18/151 (see Figure 1). The study was effective in 2006 and modeled using the United States Army Corps of Engineers (USACE) program Hydrologic Engineering Center – River Analysis System (HEC-RAS) version 3.1.3. AECOM initially considered extending this effective model upstream to encompass the Flood Study; however, updating the model version resulted in changed model results which would expand the scope of the study. In discussions with Wisconsin Department of Natural Resources (WDNR) staff, it was determined that developing a new existing conditions model for the Flood Study area would be acceptable. The Flood Study Existing Conditions model has three overlapping cross sections with the effective downstream model. The effective downstream model was also used to establish boundary conditions for the Flood Study.

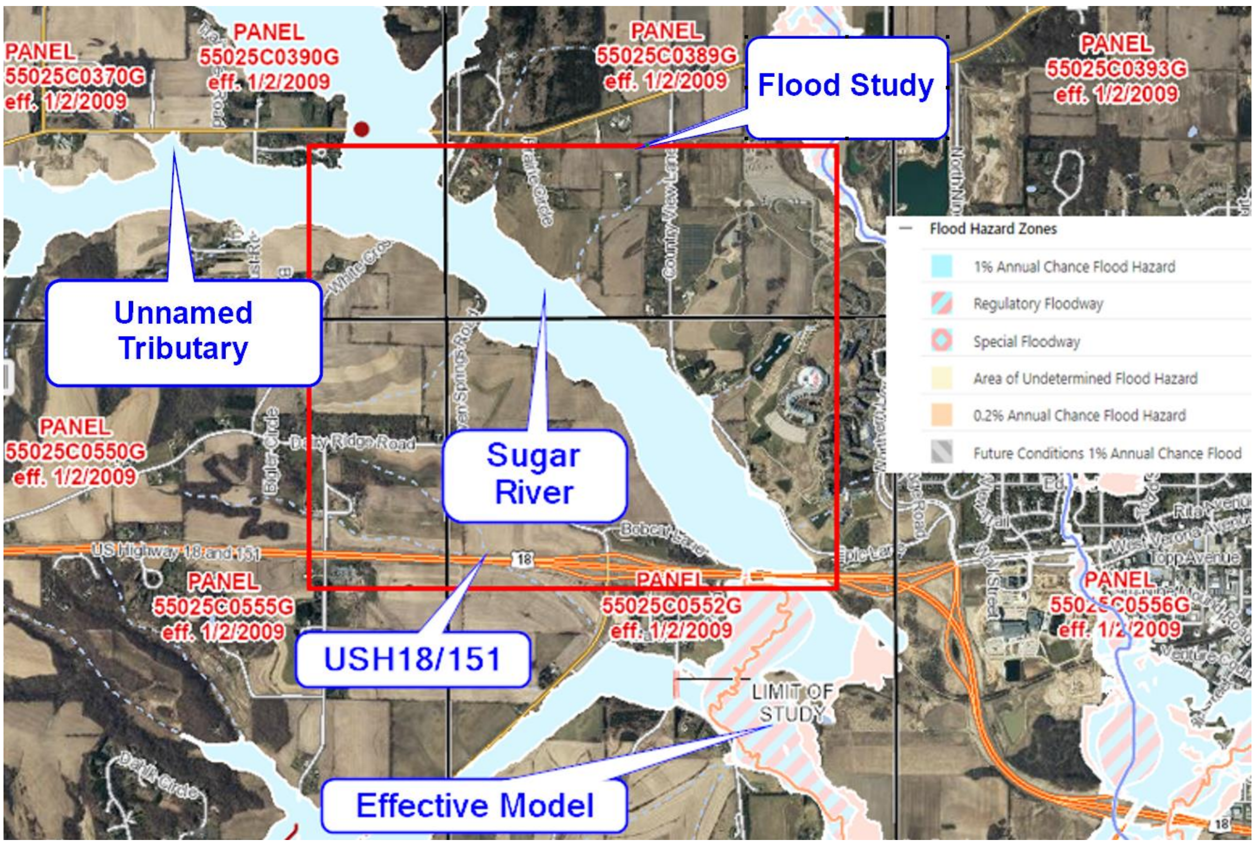

Figure 1. Project Location

2. Hydrology

Wisconsin Administrative code, specifically chapter natural resources (NR) 116, requires the demonstration of two hydrology methods for use in a hydrologic study. The following two methods were used for this Flood Study: Method 1 (Preferred): Effective Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model (2005) and Method 2: Flood Frequency Characteristics of Wisconsin Streams Scientific Investigations Report 2016-5140, Version 2.2, April 2020.

2.1. Method 1 (Preferred): Effective HEC-HMS Model

An effective HEC-HMS model was developed by WDNR in 2005 to establish 100-year flood flows in the Sugar River from the confluence of Badger Mill Creek to USH 18/151. The effective HEC-HMS model is in version 2.2.2. The model applies the Soil Conservation Service (SCS) curve number (CN) loss method using land use data and a combination of National Resources Conservation Service (NRCS) and the Soil Survey Geographic Database (SSURGO) soils data. The antecedent soil moisture condition II (average) was assumed for this area. The meteorological model was a custom Madison distribution based on large storms measured at the Madison, Wisconsin National Weather Service gage from 1975-2003. This gage is located at the Dane County Regional Airport.

The 46.6 square mile watershed is broken into multiple sub watersheds in the effective HEC-HMS model (Figure 3). The HEC-HMS model was calibrated to a streamgage in the watershed, #5435900 (located at Sugar River Tributary Near Pine Bluff, WI) as seen in Figure 2. This gage is located at the confluence of subbasins R120W120 and R110W110 (Figure 3). The 2003 100-year flow at the gage was measured to be 850 cfs. To calibrate to this value, the CNs for all basins in the model were reduced to 55.

While the effective model does not meet current WDNR standards for new hydrologic studies (ie, current rainfall depths and intensities), it was appropriately calibrated at the time of development and is therefore the preferred method for determining flows for this Flood Study. No updates to the model or version were made to the effective model; flows were pulled directly from the model in version 2.2.2 as detailed below. A junction was added to verify the 1,984 cfs flow value applied at the upstream end of the effective HEC-RAS model (cross section 110230).

Based on the effective HEC-HMS model, two flow change locations were added to the Existing Conditions HEC-RAS model (Figure 3):

1. At the upstream end of the Existing Conditions HEC-RAS model (cross section 123802), the 100-year flow of 2,298 cfs is applied, equal to the flow value at Junction JR70 in the HMS model. This is the confluence of the Sugar River with subbasin R60W60 in the HMS model.

2. At cross section 110230 (just downstream of the USH 18/151 bridge), the 100-year flow of 1,984 cfs is applied, equal to the flow value just upstream of the confluence of JR90 (the confluence of the Sugar River with subbasin R80W80). 1,984 cfs is also the flow applied at the upstream boundary in the effective model of the Sugar River downstream of USH 18/151.

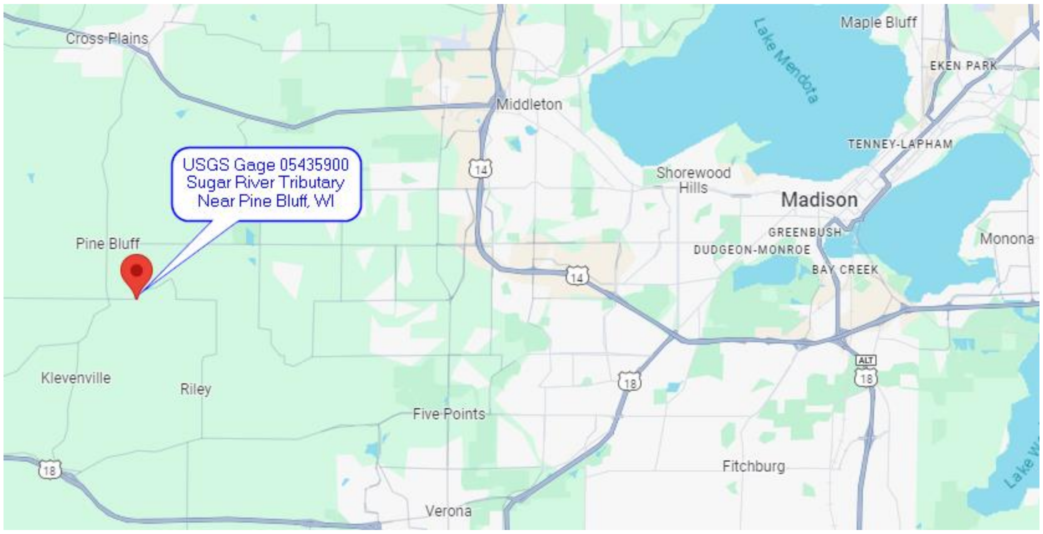

Figure 2. Streamgage Location

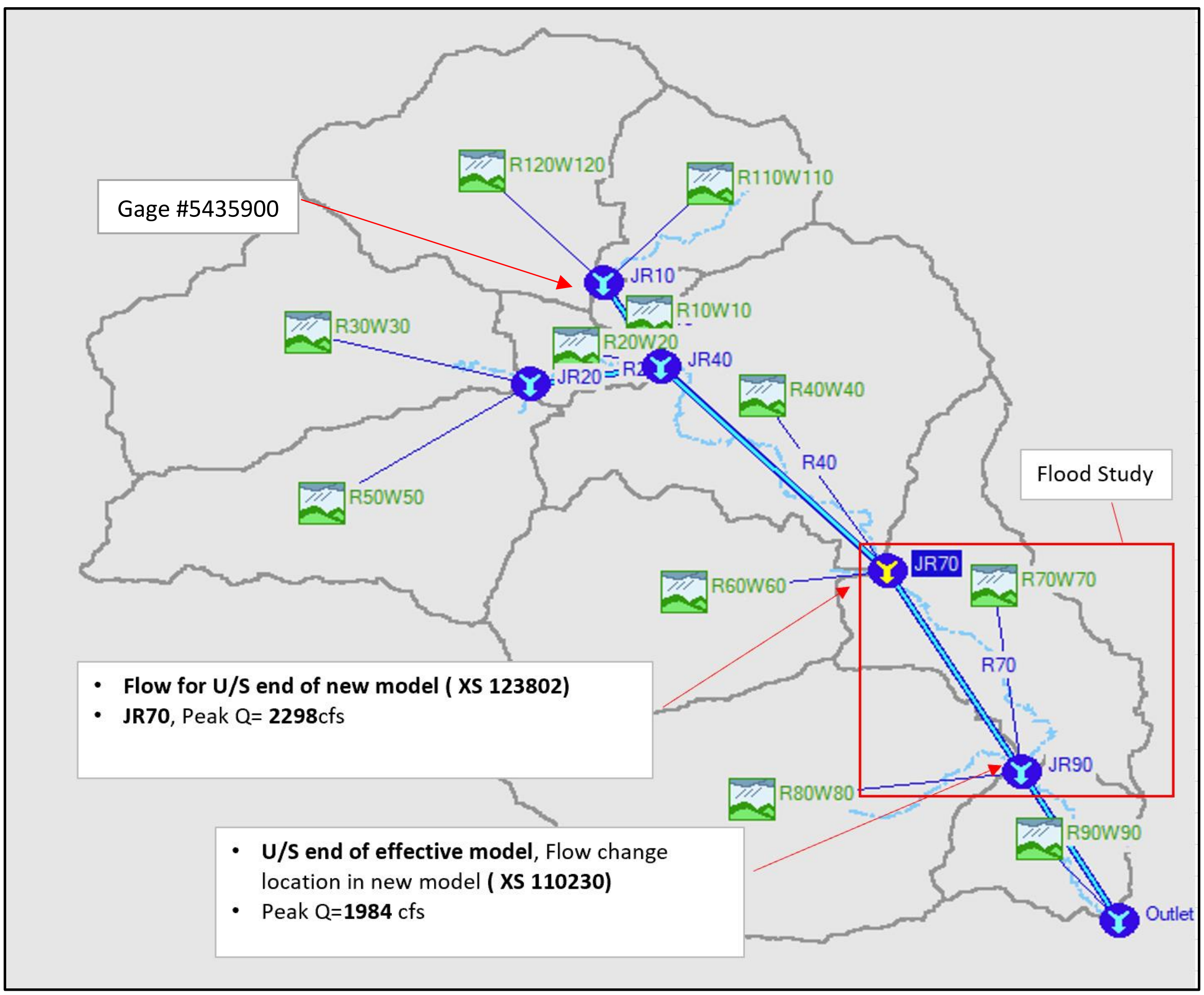

Figure 3. HEC-HMS model watershed (46.6 square miles) and location of 100-year flows applied in HEC-RAS model

2.2. Method 2: Regression Equations

The second hydrologic method evaluated was regression. The equation used is from Table 2 of the Flood Frequency Characteristics of Wisconsin Streams Scientific Investigations Report 2016-5140, Version 2.2, April 2020 (https://pubs.er.usgs.gov/publication/sir20165140). The drainage area for this location is in Area 6. This equation is a function of drainage area, slope and percent of forests. These parameters were obtained from StreamStats (U.S. Geological Survey, 2019, https://streamstats.usgs.gov/ss/) for the locations of interest.
The regression and HEC-HMS flows are compared in Table 1.

Table 1. Results of Hydrology Approaches

Method	Location of Flow	
	100-year Flow White Crossing Rd (cfs)	**100-year Flow USH 18/151 (cfs)**
HEC-HMS Model	2,298	1,984
2020 Regression Eq.	3,630	3,050

2.3. Conclusion

With both hydrology methods it can be observed that some downstream points have lower peak flows than upstream points (i.e., the flow at the USH 18/151 bridge crossing is less than at the White Crossing). This attenuation is reasonable, given the length of the reaches and the gradual slopes.

Method 1, the HEC-HMS model approach, is utilized for this study as it is more detailed than the regression equations and is calibrated to gage data.

3. Steady Flow Data

3.1. HEC-HMS Storm Events

In addition to the 100-Year flow, the 10, 50, and 500-Year events were computed within the effective HEC-HMS Model. The 100-Year event was computed from gage data while the other events were computed using precipitation depths. The flows for each storm event are shown in Table 2. The flows below are used in the HEC-RAS model for both the Existing and Proposed Conditions.

The 2-Year flow is required for erosion control purposes within Section 8.1.6. of the WisDOT Bridge Manual (WBM). The 2-Year flow was not included in the effective model and therefore was calculated in accordance with the 10, 50, and 500-Year events. A 2-Year precipitation depth of 2.90 in (referenced from TP-40 and Atlas 14) was added to the HMS model under meteorological data.

Table 2. HEC-HMS Flood Study Flows

Location	Storm	02-Year	10-Year	50-Year	100-Year	500-Year
123802	Flows (cfs)	155	778	1615	2298	3649
110230	Flows (cfs)	155	537	1398	1984	3102

4. Existing Hydraulic Conditions

The Existing Conditions model for this project was modeled using HEC-RAS version 6.2. The plans listed in Table 3 are included in the submitted model. The 2006 effective model plans are included for comparing geometries at overlapping cross sections, as discussed below in this section.

Table 3. Plans Included in Submitted Model

Plan Name	Plan file number	Description
2005 DTM	.p01	Effective model (non-final) only using DTM geometry
2005 DTM w/ channel survey	.p02	Effective model (non-final) using DTM and channel survey
2005 DTM w/ channel modification	.p03	2006 Effective model (final)
Floodway run	.p04	2006 Effective model Floodway Run
Ineffective Flow Determination	.p07	Temporary model to confirm ineffective flow areas (IFA)
Existing Conditions Alt 3.2	.p14	Existing Conditions model
Proposed Conditions Alt 3.2	.p30	Proposed Conditions model

4.1. Model Extents

The Existing Conditions model extents span 800 feet downstream of U.S. Highway (USH) 18/151 to just upstream of White Crossing at a confluence between the Sugar River and an Unnamed Tributary, a total reach length of approximately two miles (Figure 4). The most upstream cross section is 123802. The downstream end of the Existing Conditions model ties into cross section 108021 of the downstream effective hydraulic model. This section is also the FEMA lettered cross section CE shown in Figure 5. This location was selected as a tie-in between the models because it allows for appropriate hydraulic modeling of the USH18/151 crossing. In the downstream effective model, USH 18/151 crossing was outside the limits of study and therefore was not previously modeled.

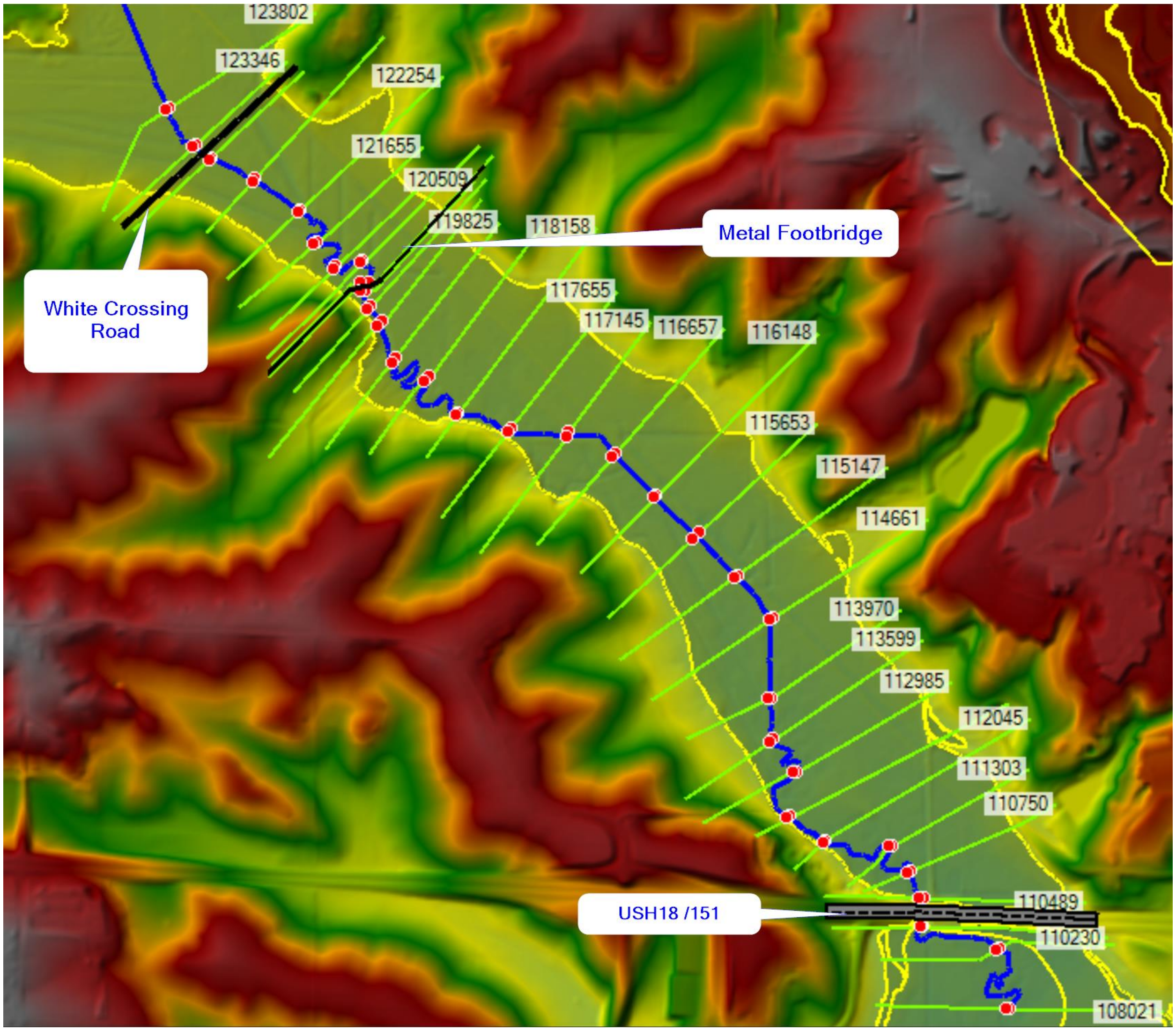

Figure 4. Existing Conditions model cross sections

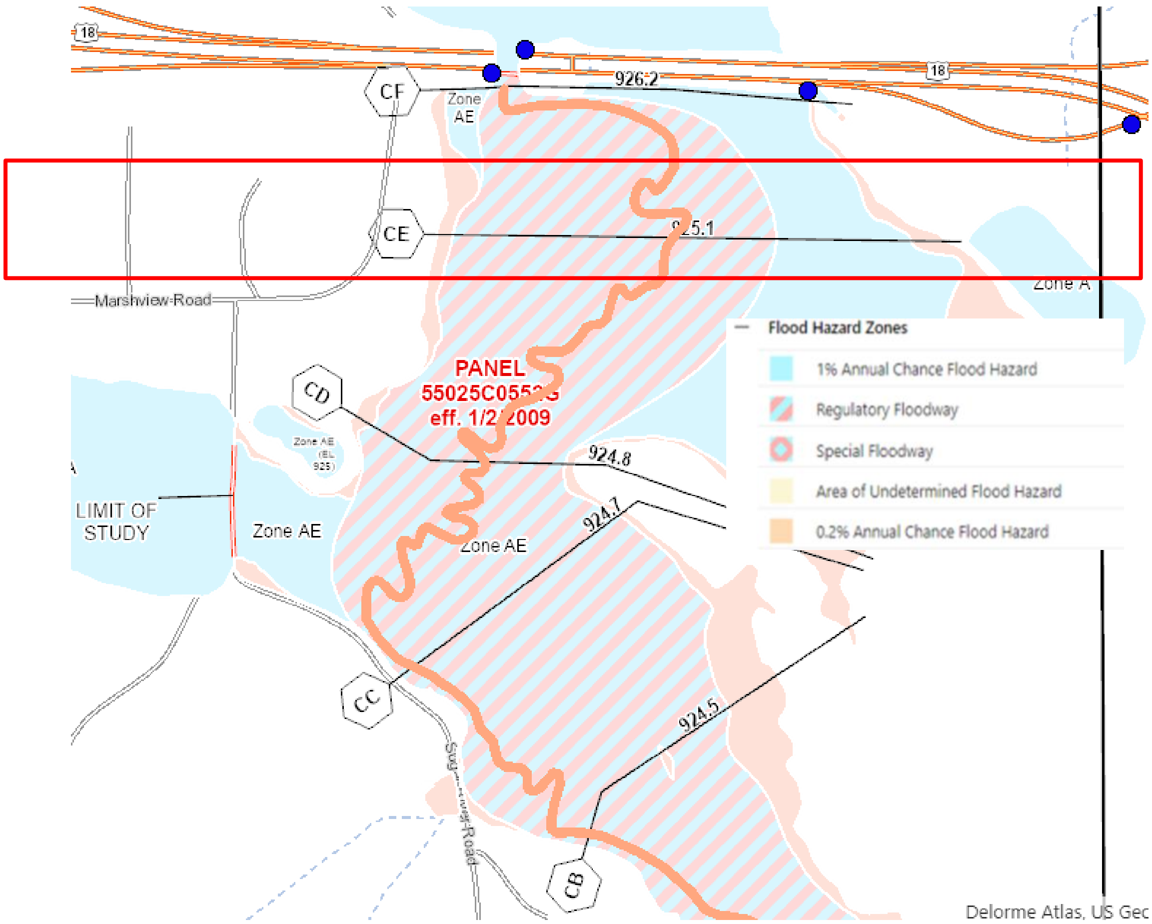

Figure 5. Location of Existing Conditions downstream model boundary

Upstream of cross section 108021 in the downstream effective model are four interpolated cross sections and two non-interpolated cross sections (Figure 6). New survey data was collected for the two non-interpolated cross sections (110230 and 109332) as well as for the tie-in cross section 108021. These three cross sections were therefore included in the Existing Conditions model. The interpolated cross sections were not retained as they were not hydraulically necessary.

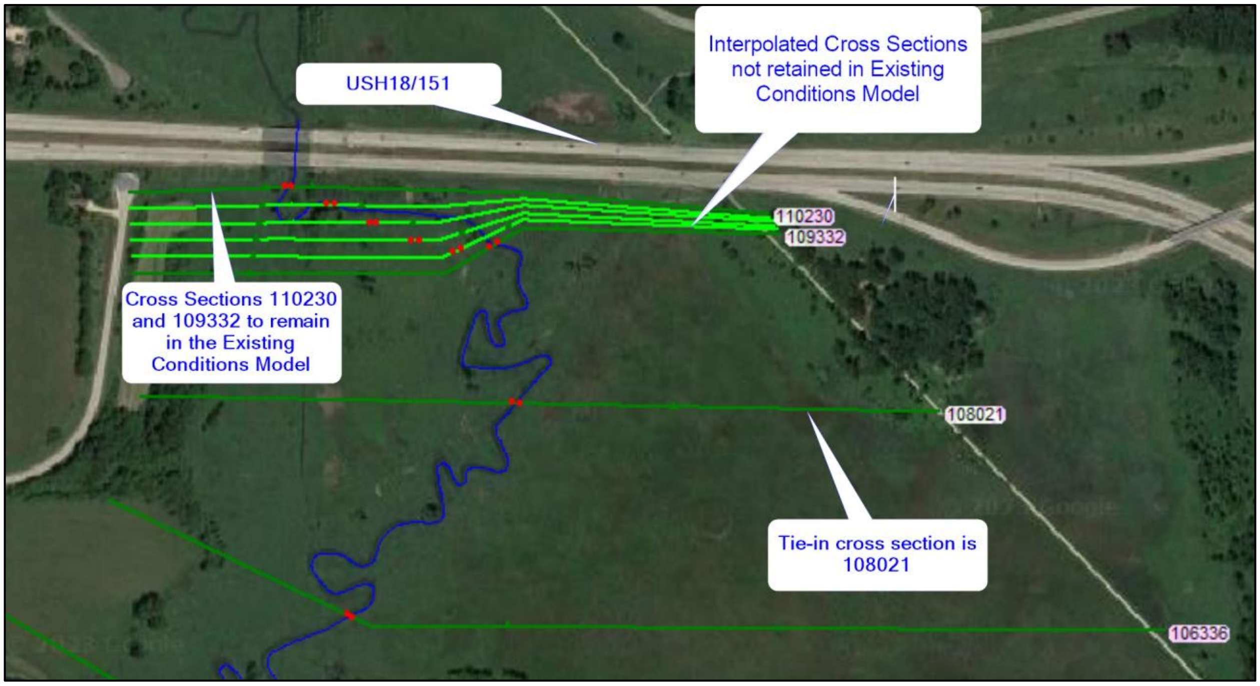

Figure 6. Tie-in cross sections with downstream effective hydraulic model

4.2. Topography

The Existing Conditions model includes updated topography data developed from survey collected in 2022 by D'Onofrio Kottke and Associates (DKA) and supplemented with Dane County Light Detection and Ranging (LiDAR) data (March 2017). Cross sections were surveyed approximately every 500 feet. Also included in the topographic survey are three hydraulic structures: two roadway crossings and one metal footbridge.

4.3. Stream Alignment

The stream alignment was based on topography and aerial imagery. Additionally, the stream alignment was slightly updated in the area of the three most upstream (non-interpolated) cross sections (110230, 109332 and 108021) from the downstream effective model that are also included in the Existing Conditions model.

The names of the new cross sections correspond to the new reach lengths associated with the new stream alignment. However, the cross sections (110230, 109332 and 108021) from the downstream effective model were not renamed, even though the updated stream alignment lengths vary slightly from that model. This is to retain cross section naming convention between the Existing Conditions model and the downstream effective model cross sections.

4.4. Cross Sections

Flow paths were manually refined in RASmapper. These were used to calculate the left and right overbank reach lengths for the cross sections.

To model contraction and expansion at hydraulic structures, two cross sections upstream and one cross section downstream of the hydraulic structure were updated to have a contraction ratio of 0.3 and an expansion ratio of 0.5. This falls in line with standard hydraulic modeling practices as well as guidance from the HEC-RAS Hydraulic Reference Manual.

4.5. Manning's n Values

Manning's n values were selected based on aerial photos and photos taken at the existing site, as well as review of the downstream effective model. Manning's n values for streams and floodplains are selected from "Open-Channel Hydraulics" (Chow, 1959).

4.5.1. Overbank

The downstream effective model uses manning's n values of 0.085 to 0.09 in the denser tree areas, 0.07 to 0.06 in the brush areas, and 0.05 in agricultural areas. It is observed that the overbank areas in the new model are largely scrub shrub as seen in Figure 7. Thus, to be consistent with the downstream effective model, a conservative yet composite manning's n value of 0.07 is applied in the overbank areas.

Figure 7. The floodplain overbanks are generally medium to dense brush

4.5.2. Channel

For the stream channel, the downstream effective model generally applied a Manning's n value of 0.04. This corresponds to a natural stream that is clean and winding, with some pools and shoals. Intermittently, a Manning's n value of 0.035 was selected for the main channel, which corresponds to a natural stream that is clean, straight and full, with no rifts or deep pools, but with stones and weeds. This approach to the channel roughness estimation was carried over into the Existing Conditions model.

4.5.3. Canals

Additionally, canals exist throughout the overbank areas. Most of the canals are narrow and are determined to have a minor effect on the hydrodynamics. A blocked obstruction was placed at cross section 117145 to simulate the flow through a canal. Due to the same canal crossing this cross section twice, it was determined that blocking the portion that would be moving upstream (against the floodplain) would be appropriate as seen in Figure 8. An additional blocked obstruction was placed at a disconnected channel (Cross Section 116657) where the width and direction of the channel are not appropriate for effective flow. The elevation of the blocked obstructions are roughly placed at the LiDAR elevations to simulate the standing water surface elevation.

4.5.4. USH 18/151 Internal Bridge Cross Sections

The main channel within the internal bridge cross sections were modeled using a Manning's n value of 0.04 to be consistent with the channel modeling upstream and downstream of the bridge. The internal bridge overbank areas were modeled using a value of 0.05 to represent weeds and stones between the channel and bridge abutments.

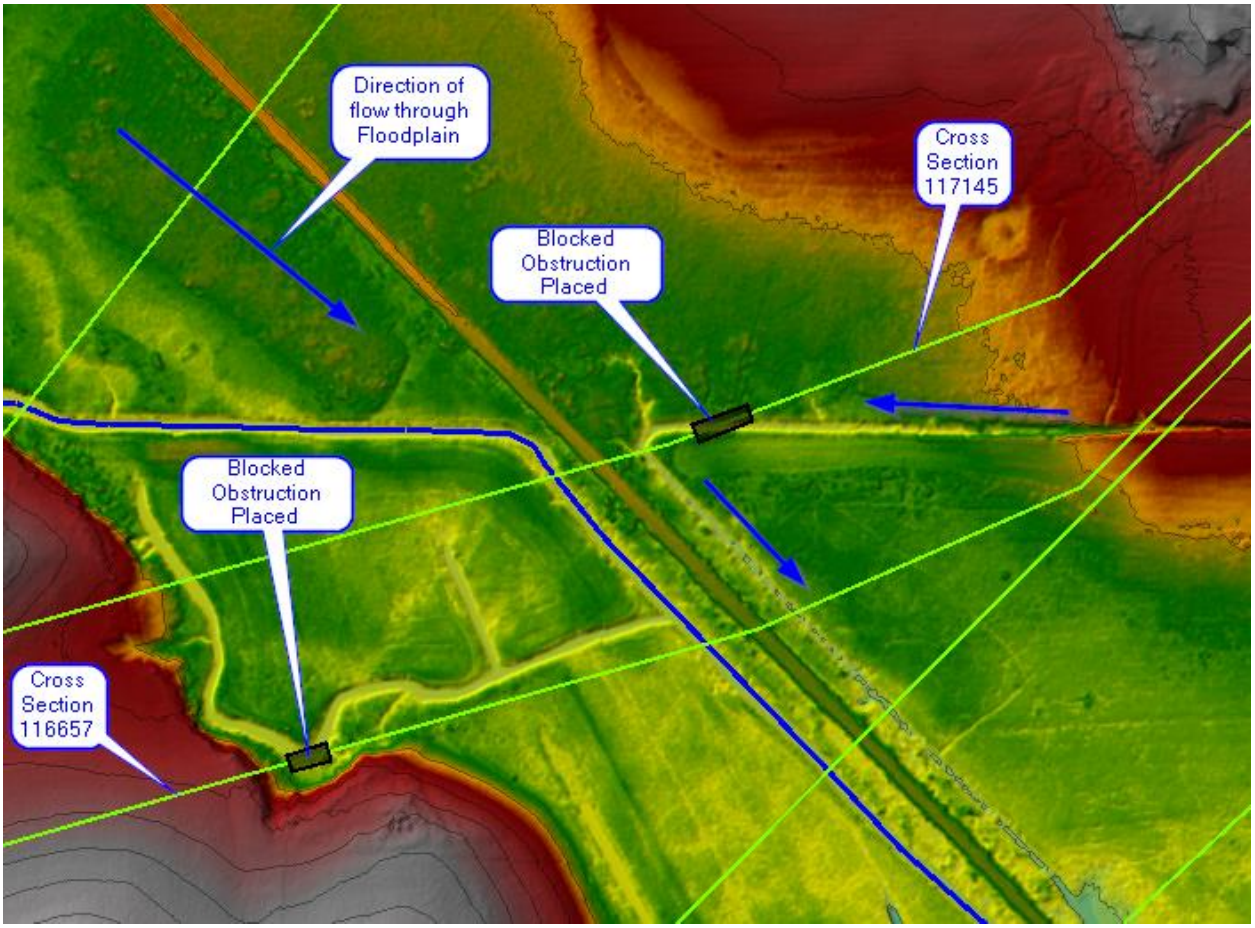

Figure 8. Existing conditions blocked obstructions

4.6. Structures

Three hydraulic structures were added to the Existing Conditions model: Two roadway crossings (White Crossing and USH 18/151) and one metal footbridge.

4.6.1. White Crossing Road Crossing

At the upstream end of the Existing Conditions model, White Crossing Road was modeled. The 2022 survey data as well as Wisconsin Department of Transportation as-builts dated 1988 were utilized to incorporate the structure in the model. The main bridge spans approximately 40 feet (Figure 9). Additionally, two 48-inch by 66-inch diameter culverts are located to the east of the bridge (Figure 10). This crossing is overtopped during the 100-year flood event and is modeled under pressure flow. Internal cross sections were used to refine the topography at the culvert inverts to effectively model the culverts.

Figure 9. White Crossing Road Bridge span is 40 feet

Figure 10. White Crossing Road 48-inch by 66-inch culverts

4.6.2. Metal Footbridge

A small metal footbridge in the floodplain is modeled and is shown in Figure 11. This footbridge is located (at river station 120554) approximately 2700 feet downstream from the White Crossing Road (at river station 123256). Survey shots were used to model the deck of the bridge and two piers. This crossing is overtopped in the 100-year profile and is modeled under pressure flow.

Figure 11. Modeled Metal Bridge

4.6.3. USH 18/151 Crossing

The USH 18/151 crossing consists of a bridge and two culvert groups in HEC-RAS. In addition to the Sugar River, the Military Ridge State Trail (MRST) passes under USH 18/151 as well as a 48-inch Reinforced Concrete Pipe (RCP) for drainage in the left overbank. The USH 18/151 bridge spans roughly 150 feet of the Sugar River and contains two piers (Figure 12). These are modeled as elongated piers with semi-circular ends. The 2022 survey data as well as Wisconsin Department of Transportation as-builts dated 1991 are applied to inform the modeling of the bridge.

At the east end of the crossing, the MRST crosses USH 18/151 with a 10-foot by 9-foot reinforced concrete box culvert (Figure 13). Wisconsin Department of Transportation as-builts dated 1991 and new survey data is used to inform the geometry of the pedestrian tunnel. Finally, a 48-inch RCP culvert with an apron endwall is modeled about halfway along the crossing. Survey data was used to inform the modelling of this culvert. Internal cross sections were used to refine the topography at inverts to effectively model the MRST and culverts.

Figure 12. USH 18/151 Crossing Bridge

Figure 13. Military Ridge State Trail box culvert under the USH 18/151 Crossing

4.7. Ineffective Flow Areas (IFA)

Ineffective flow area locations are applied to model bridge upstream and downstream cross sections.

Additionally, the MRST lies parallel to the Sugar River. This old railroad embankment generally has a crest elevation four to five feet higher than the surrounding topography. At the upstream cross sections of the Existing Conditions model, during the 100- year event, the Sugar River does not overtop this berm and the effective flow is only on the west side of the embankment. As the Sugar River continues downstream, it begins to overtop the embankment and becomes effective east of the MRST.

To determine where the MRST overtops during the 100-year event and at what magnitude a scenario named “Ineffective Flow Determination” was created in HEC-RAS. A lateral structure was placed along the crest of the MRST in this area. A low spot in the crest of the MRST (figure 14) between sections 117145 and 116148 sees 350-400 cfs overtop during the 100-year event. This flow represents 15-17% of the total flow. Additionally, cross drains penetrate the MRST (Figure 15). These promote the equalization of water levels between the left and right side of the trail. Thus, it appears reasonable to model the east side of the MRST as fully effective flow starting at cross section 116148.

Based on the results of the lateral weir overtopping analysis, the effective flow area in the east side of the MRST is gradually expanded at a 2:1 ratio across the floodplain beginning between cross section 117655 and 117145. The entire cross section is fully effective by cross section 116148 for the 100-year event. Thus, upstream of section 117145, the ineffective elevation is set to the crest of the embankment, and at section 116148 and subsequent sections downstream, they are manually set below the 100-year water surface level. The trail is shown in Figure 14.

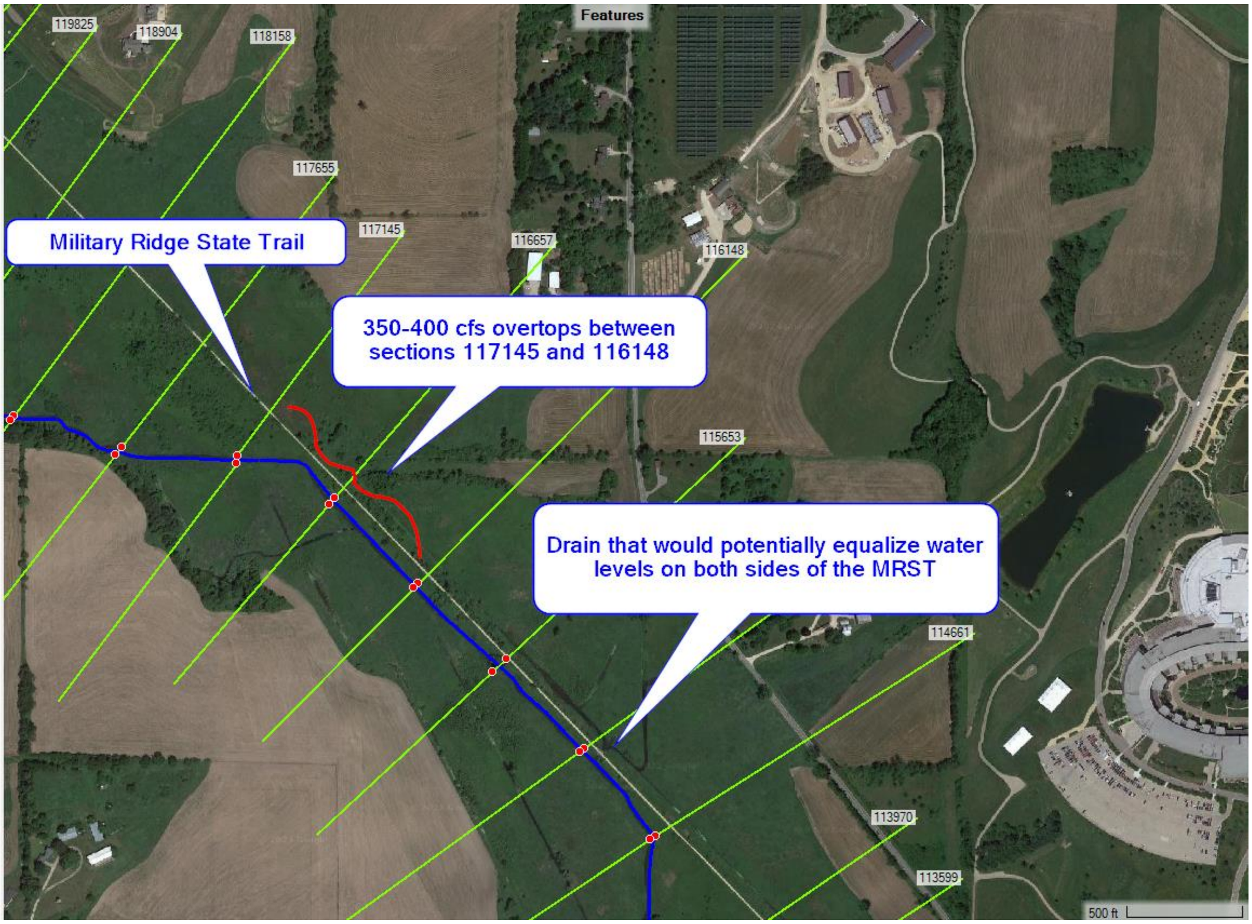

Figure 14. 350-400 cfs overtops the low spot on the Military Ridge State Trail near cross section 117145

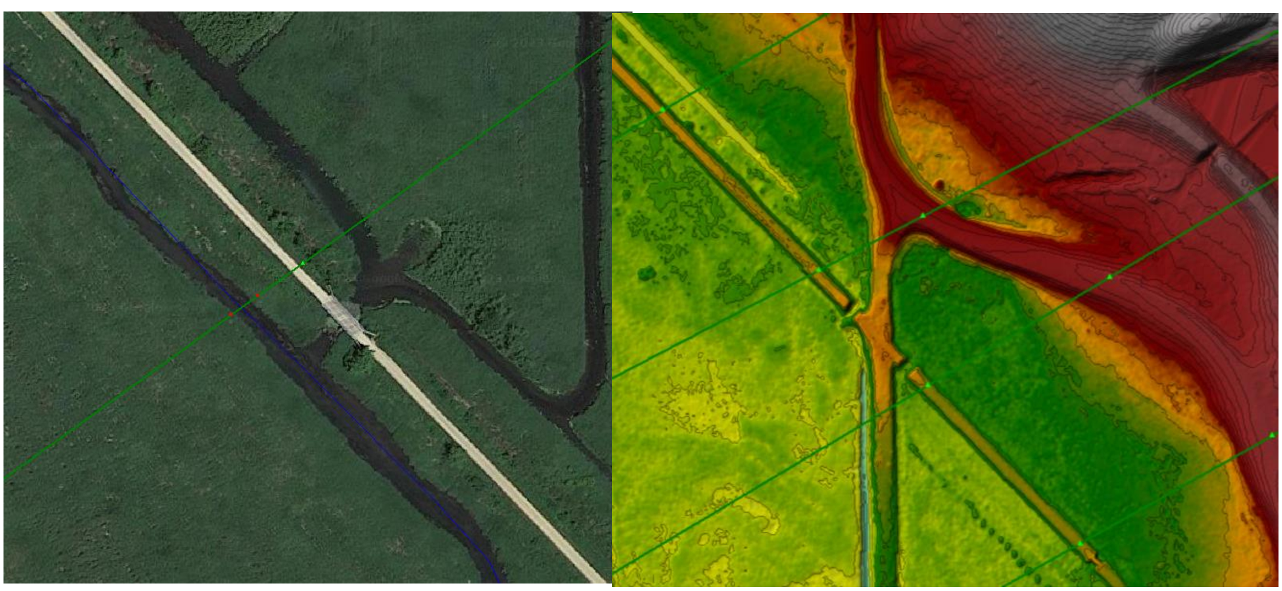

Figure 15. Drains that could potentially equalize water levels on either side of the MRST

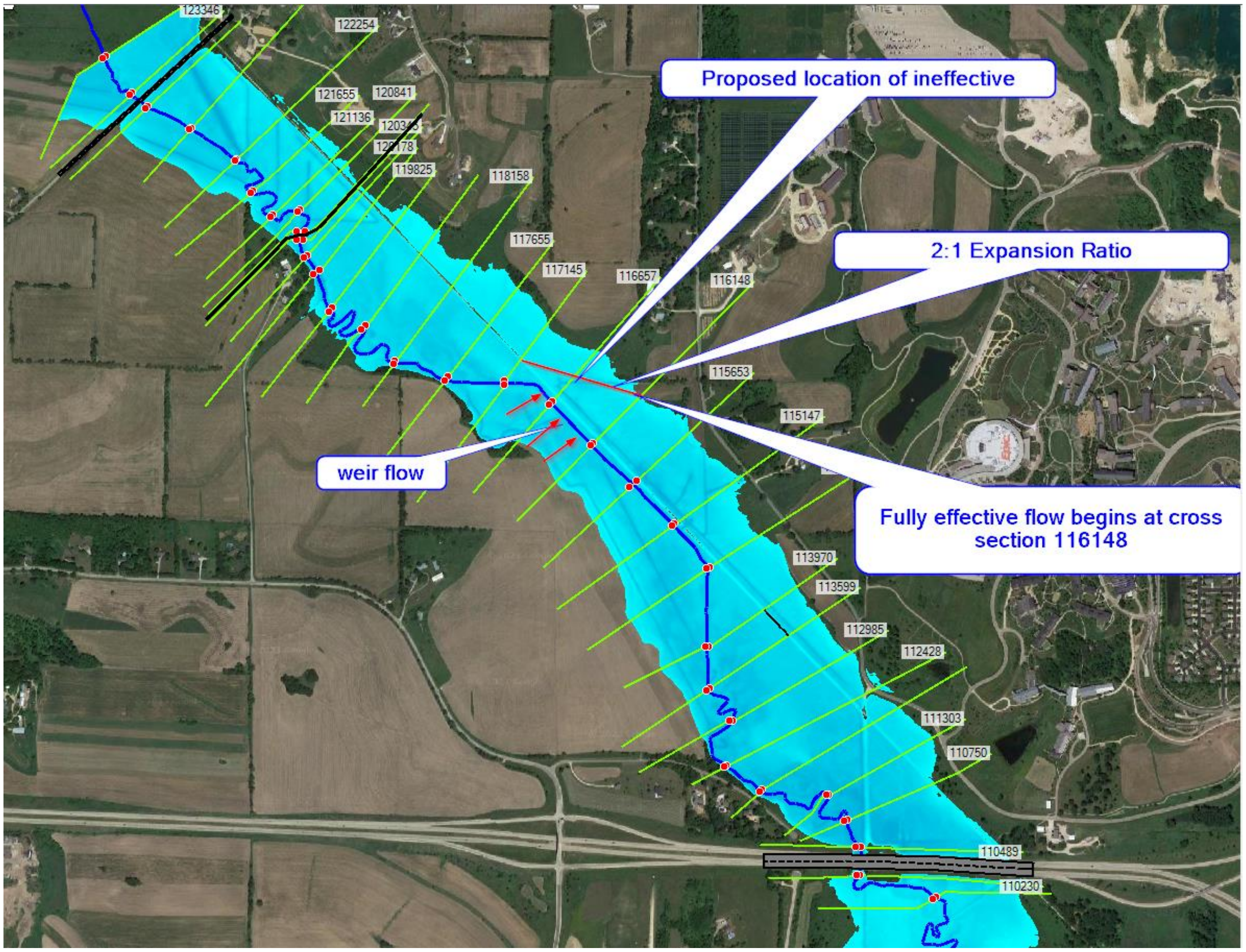

Figure 16. Raised ineffectives are placed to model expanding effective flow area downstream of cross section 117145

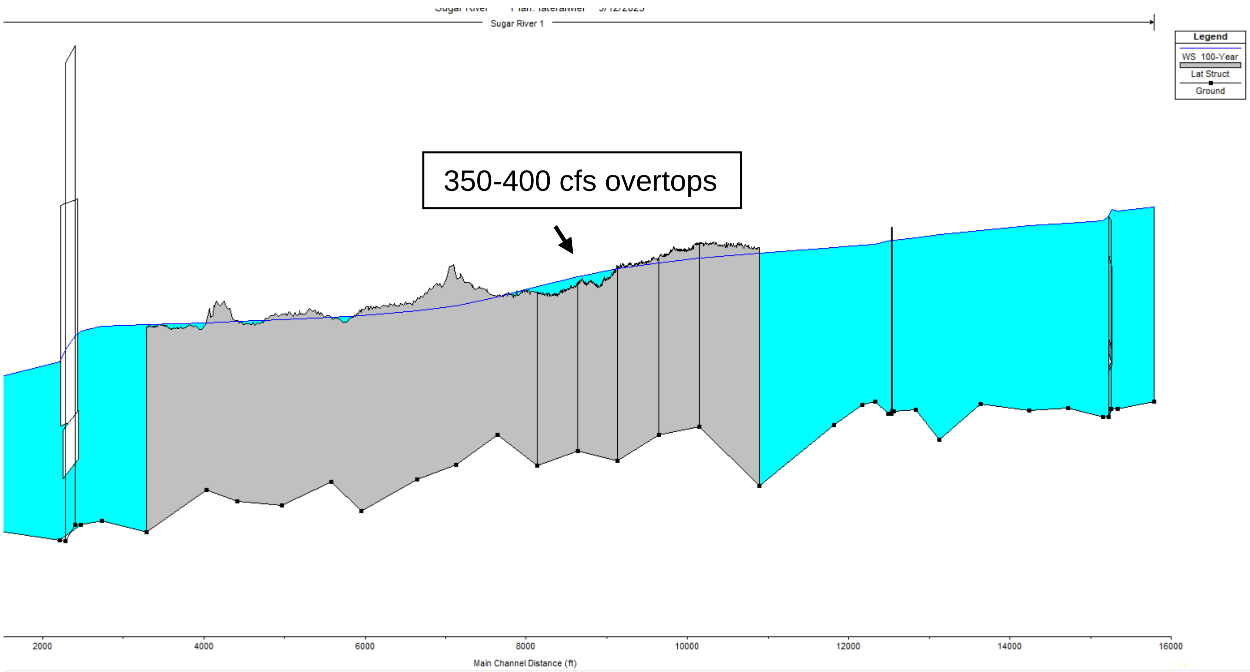

Figure 17. Profile of lateral weir placed in HEC-RAS

4.8. Downstream Boundary Conditions

The downstream boundary conditions for the 10, 50, 100, and 500-yr return intervals within the Existing Conditions model are set to the downstream effective model water surface elevations at cross section 108021 as run in HEC-RAS version 3.1.3. The 2-yr return interval was not analyzed in the effective model as previously discussed in the hydrology section of this report. The boundary condition was set to normal depth to analyze the 2-yr flow and water surface elevation for erosion control computations. The downstream boundary condition for each profile is shown in Table 4.

Table 4. Existing Conditions Model Downstream Boundary Conditions

Return Interval	Normal Depth (bed slope)
02-yr	0.003
Return Interval	**Known WS El (ft) NAVD88**
10-yr	923.19
50-yr	924.30
100-yr	925.08
500-yr	926.45

5. Proposed Hydraulic Conditions

The proposed design incorporates the addition of a crossing over the Sugar River as well as a stream restoration design. To model the proposed design, changes were made to the existing conditions model (see section 4). Adjustments were made only between cross sections 117655 and 113599.

5.1. Proposed West Road Design

The Proposed west road crossing (River Station 116900) is a newly added structure. The proposed bridge crossing (see Figure 18) includes 12 precast openings (BEBO Concrete Arch) with each opening 54 feet (wide) by 16 feet (high). The far east opening is centered on the MRST trail with each additional opening centered 57.33 ft to the west. All openings are placed hydraulically perpendicular to the 100 year floodplain flow direction.

Only the internal bridge cross sections for the proposed structure (cross section 116900) were added for the areas between the precast bridge openings. Due to the length of the structure, impacts to the vegetation will occur due limiting the density and limited vegetative growth through the structure. Due to this a Manning's n of 0.05 was selected. This corresponds to scattered brush and heavy weeds.

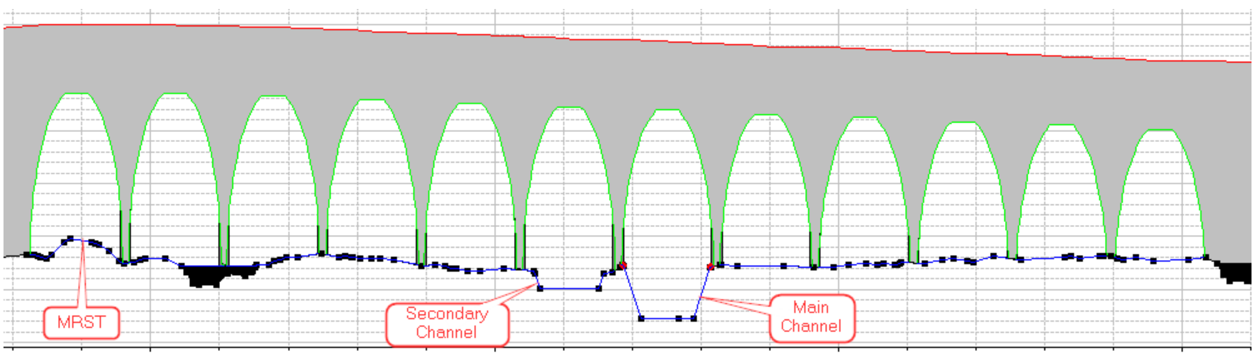

Figure 18. Proposed West Road Bridge Looking Downstream

5.2. Proposed Stream Alignment and Restoration Design

A widened channel (flowthrough wetland) is proposed upstream and downstream of the proposed west road crossing to provide additional conveyance through the structure. The widened channel is a combined channel (main and secondary channel) between cross sections 117655 and 116148. Through the proposed bridge crossing, the main and secondary channels are separated through two precast openings.

The widened channel ends between cross sections 116657 and 116148 and is where the proposed stream restoration begins and continues downstream until tying into the existing channel at cross section 113599. The stream restoration consists of returning the channelized stream into a stream that approximates pre-disturbance conditions and establishes conditions to support natural processes. These changes as pertaining to the model includes an updated stream channel geometry, lengthened stream channel alignment (due to the meandering channel), decreased channel slope, and manning's n adjustments (see section 5.4.2) for the channel. See Figure 19 to see a comparison of the existing and proposed stream alignment.

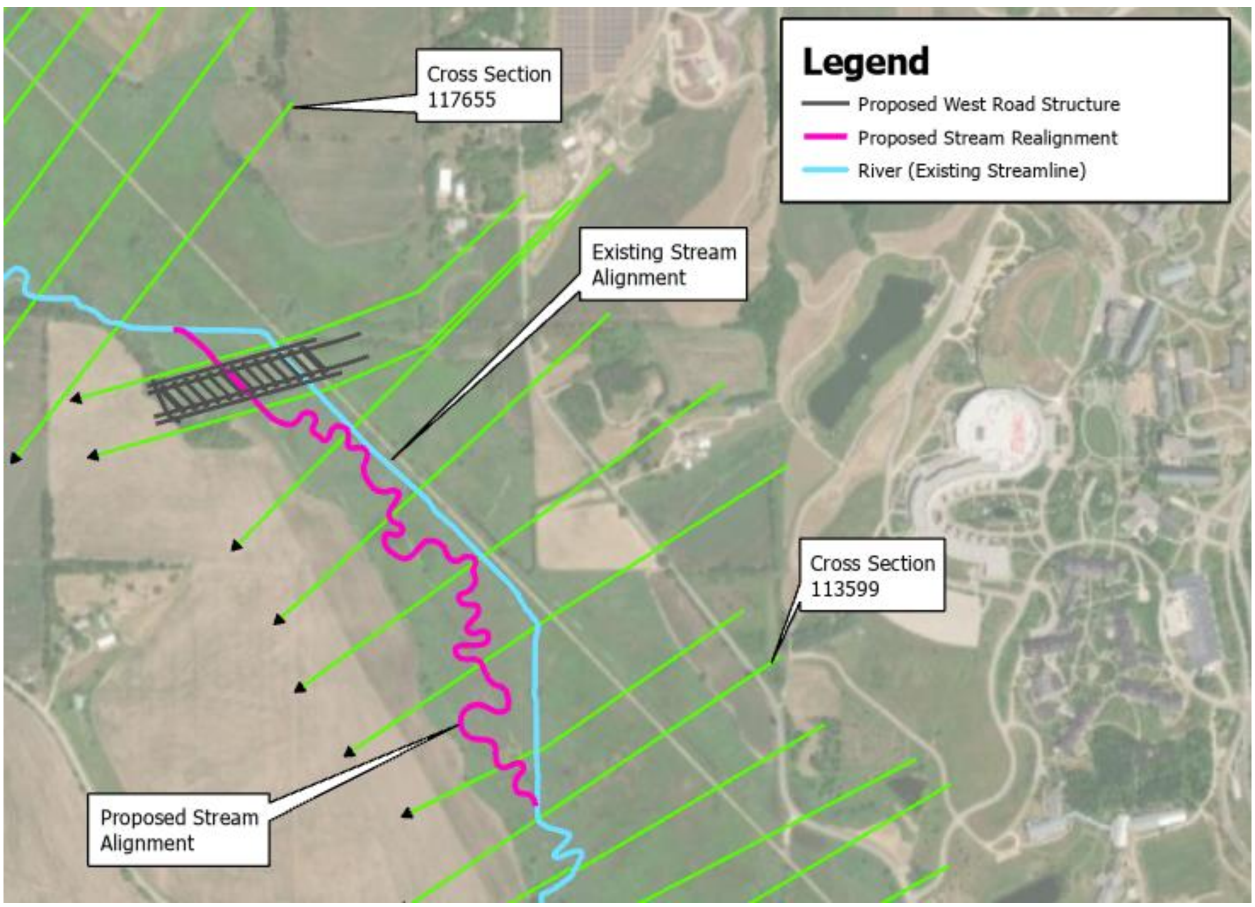

Figure 19. Comparison of Existing and Proposed Stream Alignment

5.3. Cross sections

Cross sections are at the same locations for both existing and proposed to allow for an easy comparison of WSELs. Flow paths were manually refined in RASmapper and updated from the existing conditions from cross section 177655 to 113970 (to account for the proposed stream alignment). Cross section geometry was updated in the proposed conditions to account for the proposed project impacting cross sections 117655 through 133599.

To model contraction and expansion at hydraulic structures, two cross sections upstream and one cross section downstream of the hydraulic structure were updated to have a contraction ratio of 0.3 and an expansion ratio of 0.5.

5.4. Manning's n Values

5.4.1. Overbank

No change to manning's n overbank values from the existing conditions.

5.4.2. Channel

The channel manning's n for the main channel were not updated for the proposed conditions except in areas of the proposed channel work. This is split into two sections: the widened channel with a secondary channel (from cross sections 117655 – 116657) and the stream restoration section (from cross sections 116148 – 113970). The proposed widened section is straight channel with a manning's n of 0.03 selected. This corresponds to a channel that is clean, straight, full, and no rifts or deep pools. The stream restoration section selected a manning's n of 0.033 for the area within the inner berm (corresponding to the minimum n value for a natural stream that is clean, winding, some pools and shoals) and 0.04 for the area from the inner berm to the right overbank (corresponding to a natural stream that is clean, winding, some pools and shoals).

5.5. Blocked Obstructions

Blocked obstructions were added between cross sections 117145 and 113970 to remove the old channel sections that are replaced with the widened channel and stream restoration. Additionally blocked obstructions were added to block small ditches within that area that are proposed to filled in.

6. Results

Water Surface Elevations (WSELs) for the Existing Conditions and Proposed Conditions Model are provided below in

Table 5. At cross sections 110230, 109332, and 108021, which overlap with the downstream effective model, a comparison between models is shown.

Between the effective and existing conditions shows an increase in WSELs at cross sections 110230 and 109332. This increase is due to modeling the USH 18/151 bridge and updating the cross-section topography. This increase is not due to the proposed design.

The Proposed Conditions Model was compared to the Existing Conditions Model and shows no rise in WSEL outside of Epic's Property (upstream of cross section 118904). However, there are increases in the 100-Year WSELs (limited within Epic's Property) as a result of the proposed design. The increases occur between cross sections 117145 and 115147. There was a maximum increase of 0.16 ft and maximum decrease 0.14 ft between the Existing and Proposed Conditions. The maximum increase occurs at cross section 117145 and is due to the proposed bridge downstream of the cross section. This increase does not impact any insurable structures. A maximum decrease is exhibited at cross section 117655. As a result of the project, a Conditional Letter of Map Revision (CLOMR) will be required and followed up with a Letter of Map Revision (LOMR) after the project is constructed.

Table 5. Sugar River 100-Year Water Surface Elevation Comparison (ft NAVD88)

FEMA XS	**FEMA BFE**	Cross Section	Effective WSEL v 3.1.3	Existing Conditions WSEL	Proposed Conditions WSEL	Difference (Existing Conditions – Effective)	Difference (Proposed Conditions – Existing)
		123802		932.71	932.70		-0.01
		123346		932.57	932.57		0.00
	White Crossing Road						
		123166		931.86	931.85		-0.01
		122736		931.74	931.73		-0.01
		122254		931.6	931.59		-0.01
		121655		931.43	931.40		-0.03
		121136		931.28	931.25		-0.03
		120841		931.17	931.14		-0.03
		120579		931.09	931.06		-0.03
	Metal Footbridge						
		120509		931.05	931.01		-0.04
		120345		930.89	930.85		-0.04
		120178		930.82	930.77		-0.05
		119825		930.72	930.67		-0.05
		118904		930.53	930.47		-0.06
		118158		930.35	930.27		-0.08
		117655		930.08	929.94		-0.14
		117145		929.56	929.72		0.16
	Proposed Crossing (West Road)						
		116657		929.35	929.32		-0.03
		116148		929.13	929.17		0.04
		115653		928.84	928.87		0.03
		115147		928.65	928.67		0.02
		114661		928.51	928.51		0.00
		113970		928.37	928.37		0.00
		113599		928.31	928.31		0.00
		112985		928.25	928.25		0.00
		112428		928.17	928.17		0.00
		112045		928.13	928.13		0.00
		111303		928.07	928.07		0.00
		110750		928.03	928.03		0.00
		110489		927.74	927.74		0.00
	USH18/151 Crossing						
CF	**926.2**	110230	926.23	926.53	926.53	0.24	0.00
		110050.*	925.85	N/A	N/A	N/A	N/A

FEMA XS	**FEMA BFE**	Cross Section	Effective WSEL v 3.1.3	Existing Conditions WSEL	Proposed Conditions WSEL	Difference (Existing Conditions – Effective)	Difference (Proposed Conditions – Existing)
		109870.*	925.54	N/A	N/A	N/A	N/A
		109691.*	925.32	N/A	N/A	N/A	N/A
		109511.*	925.23	N/A	N/A	N/A	N/A
		109332	925.19	925.53	925.53	0.34	0.00
CE	**925.1**	108021	925.08	925.08	925.08	0.00	0.00

*** Interpolated cross sections**