Hydrology and Hydraulic Assessment of

Maumelle River

Hydraulics and Technical Services Branch

U.S. Army Corps of Engineers – Little Rock District

700 W. Capitol Ave

Little Rock, AR 72201

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CHAPTER I

Study Background and Introduction

1.1 Problem Statement

USACE is performing a cost-shared aquatic ecosystem restoration feasibility study on Maumelle River with Central Arkansas Water (CAW). This study falls under Section 206 of the Continuing Authorities Program. A major component of restoring the ecosystem of Maumelle River is removing three small dams that are used for river crossings. Removing a river crossing has the potential to destabilize the channel and incite erosion due to remobilization of sediment stored above it or incision below it. The stability of the channel post removal must be considered before any action occurs. Furthermore, there is interest in reconnecting two side channels. Of interest is the frequency of connectivity as well as the duration of connectivity between the main channel and the side channels.

1.2 Site Description

The study focuses on the portion of the Maumelle River, running through land owned by Central Arkansas Water just east of Lake Maumelle (Figure 1.1) in Pulaski County, Arkansas. Starting in the 1950's, the land to either side of the river has been largely deforested and leveled for agricultural purposes. Levees were also constructed adjacent to the channel to prevent flooding of agricultural fields that resulted in disconnected side channels. Historically, four river crossings, or small dams, were installed to provide water storage for irrigation. At the initiation of this study, it was noted that one river crossing, marked in a blue circle (Figure 1.2) had previously failed and was believed to be causing stream bank erosion. During the feasibility phase of the study, the most downstream river crossing, RC4, was completely removed and a new culvert crossing was installed (Figure 1.2).

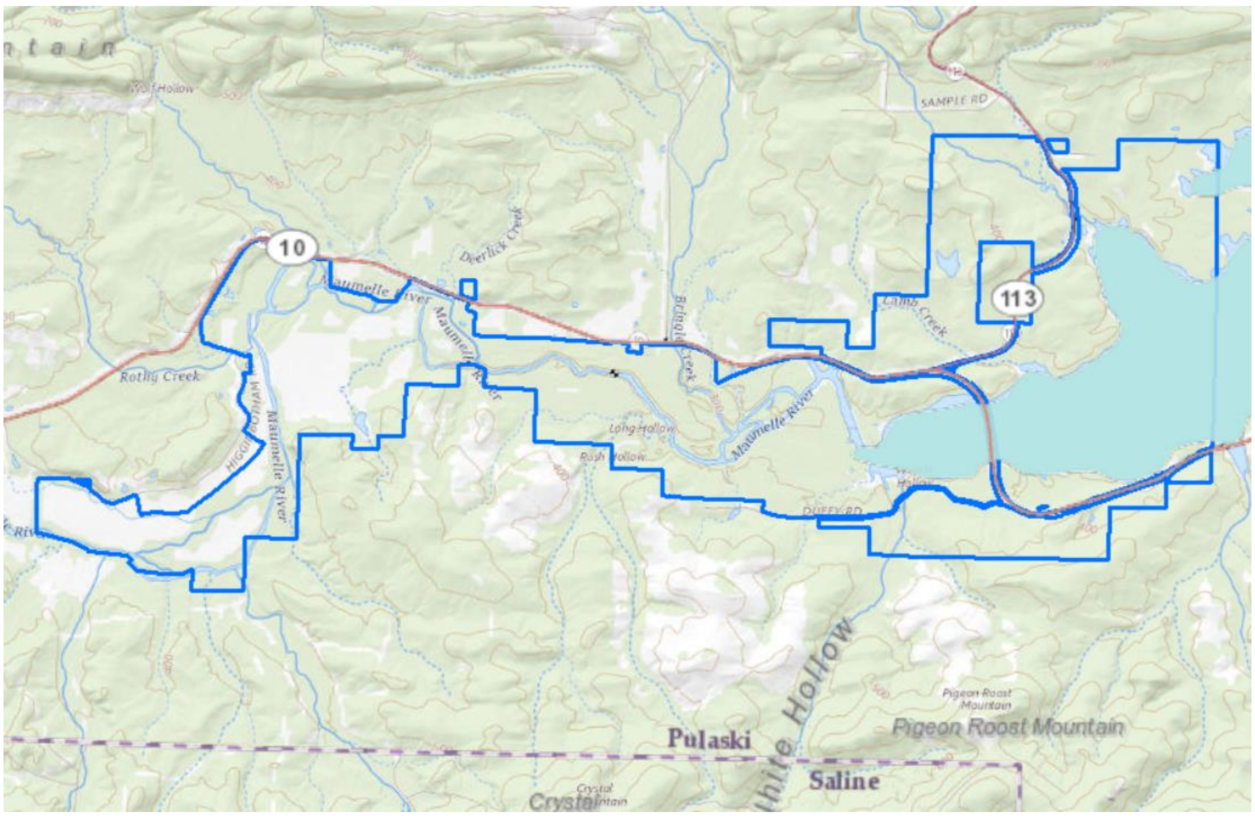

Figure 1.1 Location (Blue denotes Central Arkansas Water ownership)

Figure 1.2 River Crossings (Red denotes river crossings in place at the beginning of the study, blue denotes the failed river crossing).

1.3 Purpose

The Central Arkansas Water District has plans to restore the aquatic ecosystem of Maumelle River. Initially, the aquatic ecosystem restoration included the removal of three low head concrete dams, RC1, RC2 and RC4. During the beginning of the study, Central Arkansas Water removed and replaced RC4. All three structures were included in the hydraulic model efforts. The exact date of construction of the low concrete dams is unknown but is believed to be prior to 1950. Since these dams have been in place for over 70 years, Maumelle River has had time to adjust and reach dynamic equilibrium to its current hydrologic conditions. Removal of the dams has the potential to destabilize the channel, which will result in increased lateral stream migration, in-channel head cutting and increase the sediment load into the Maumelle River and Lake Maumelle. The Hydrologic Engineering Center Sediment Transport Capacity (HEC-STC) module within HEC River Analysis System (HEC-RAS), combined with engineering judgment, was used to determine if river crossing removal would increase the sediment transport capacity. An increase in sediment transport capacity with respect to existing conditions is an indication of channel destabilization.

CHAPTER II

2D HEC-RAS MODEL DEVELOPMENT

The Hydrologic Engineering Center

2.1 HEC-RAS Model Limits

The HEC-RAS upstream model limit is the gage Maumelle River at Williams Junction, AR. The downstream model limit is the gage at Lake Maumelle at state Hwy 10, near Wye, AR (Figure 2.1).

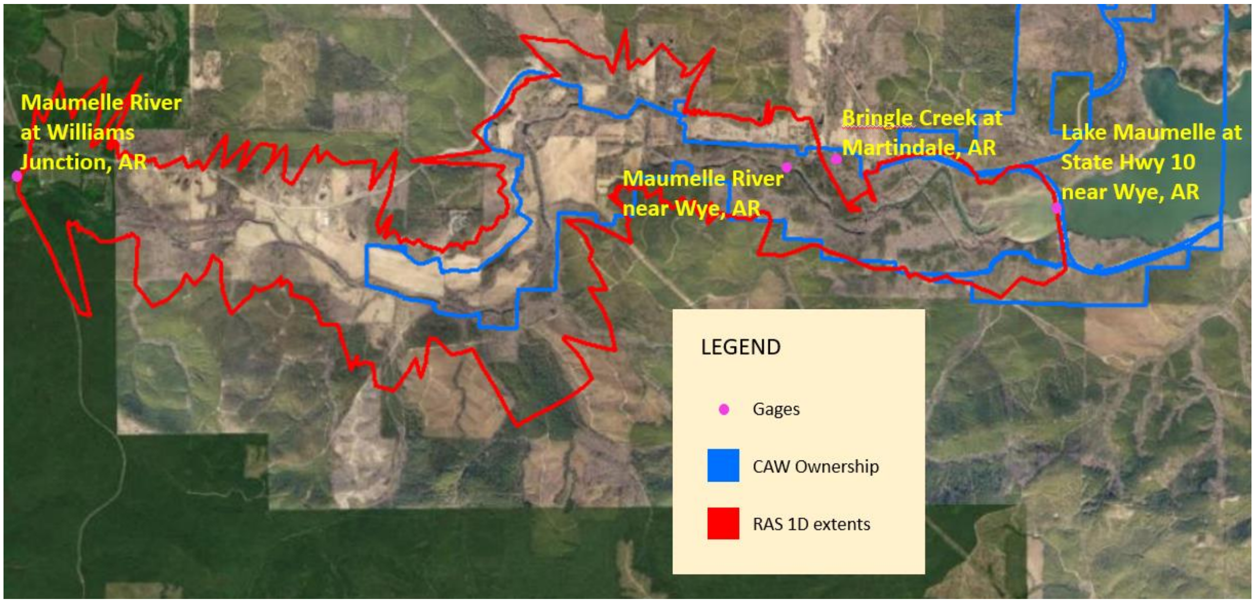

Figure 2.1 1D HEC RAS Model Limits and Gages

2.2 Gage Data

Rating curves were used for the upstream boundary conditions, Maumelle River at Williams Junction (USGS 07263295) and Bringle Creek at Martindale (USGS 072632962). The rating curve at Maumelle River near Wye (USGS 07263296) was used for the calibration. A known water surface was used for the downstream boundary condition State Hwy 10 Bridge over Lake Maumelle (USGS 072632966).

2.3 Terrain

2.3.1 LiDAR and Bathymetry

The spatial coordinate projection file is NAD83 Arkansas North, U.S. Feet and vertical projection is NAVD88. The terrestrial data is a combination of LiDAR data from 2017 and 2011. Water levels were higher during the 2017 survey, so the difference in the hydro-flattened areas between the 2011 and 2017 survey were stitched onto the 2017 terrain. Lake Maumelle bathymetry was provided by Central Arkansas Water. The

United States Geological Survey, USGS, was hired to survey thalweg data, the extents of which are shown in Figure 2.2. They were also tasked with surveying the crest of the river crossings and upstream and downstream channel cross sections. The thalweg, and channel cross section data were used to create a smooth interpolated bathymetry using a combination of Arc Map and RAS Mapper. All four rasters were combined to a single raster.

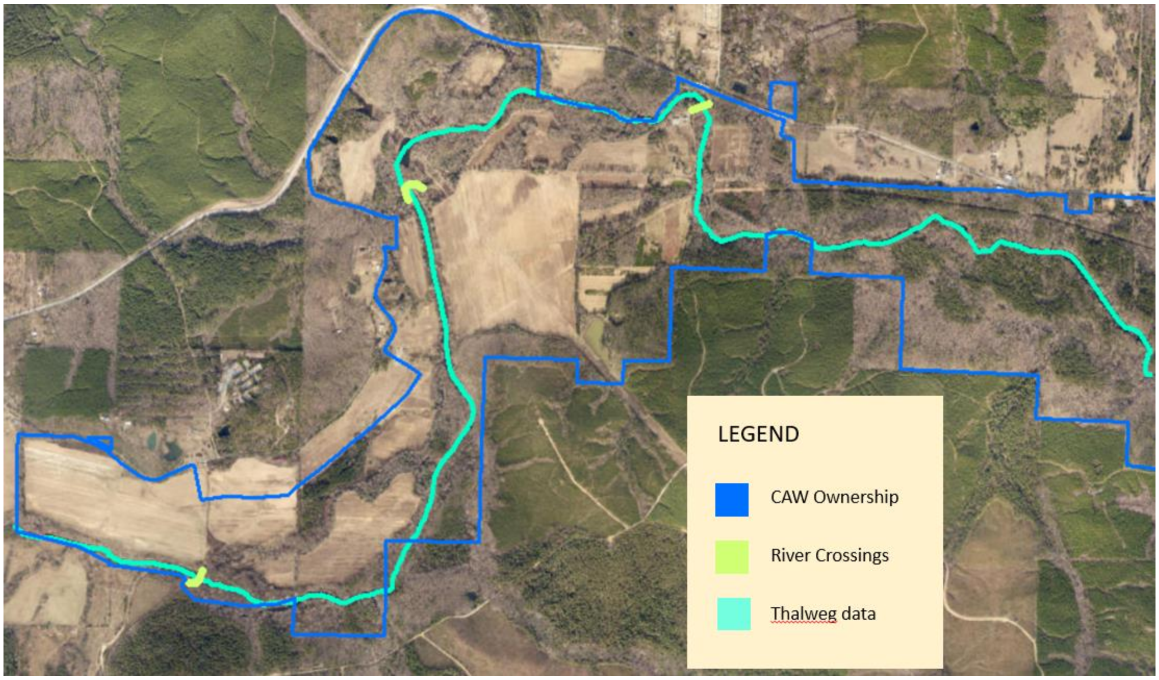

Figure 2.2	Thalweg Data Location and River Crossings.

2.4 Geometry

2.4.1 Cross-Sections

For the initial runs, the cross-sections were spaced close together to avoid large changes in slope between the cross-sections. (Figure 2.3). A large change in slope can contribute to a high transport capacity as high slope will result in higher shear stress. Cross-sectional spacing was adjusted as needed during the sediment transport calculations to ensure the results were not affected by too large of a cross-section spacing.

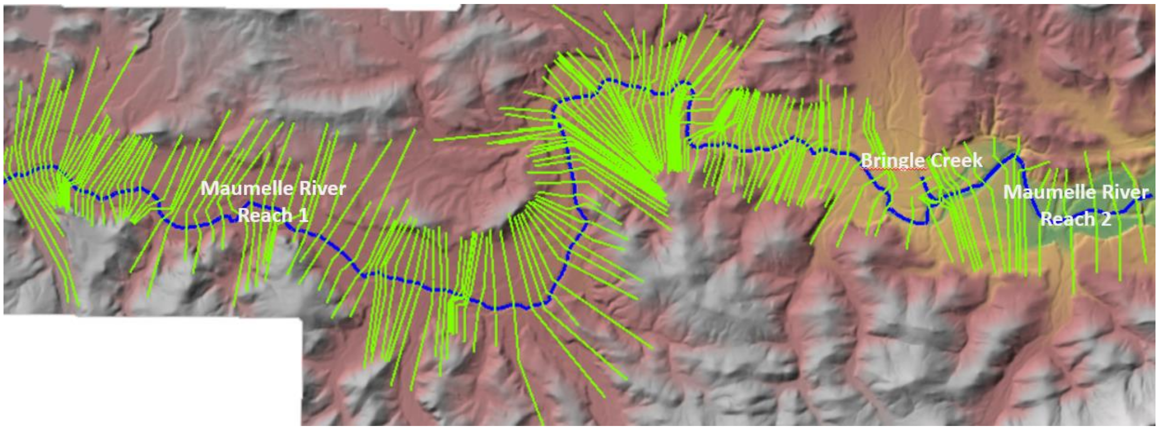

Figure 2.3 Cross-Sections for 1D HEC RAS Model

2.4.2 River Crossings

River crossings were included as inline structures with the weir elevation set to the lowest elevation on the physical structure. A weir coefficient of 2.6 was applied to all 3 dams. River crossing locations are shown in Figure 2.2.

2.5 Steady Flow Data

The 2-yr, 5-yr, 10-yr, 25-yr, and 50-yr flow rates were estimated using the methods developed by the USGS for estimating Annual Exceedance Probability (AEP) discharge for streams in Arkansas via StreamStats.gov (Wagner, 2016)(Table 2.1). Flows were introduced in three locations: 1) Maumelle River at Williams Junction and 2) below the junction of Bringle Creek at Martindale the Maumelle River reach. The most downstream cross-section corresponds to the gage on the State Hwy 10 Bridge over Lake Maumelle. The annual mean gage height for the 2019 water year was used at State Hwy 10 Bridge over Lake Maumelle, 289.53 feet, for all flows.

Table 2.1 Flow Rates

River Name	River Station	Annual Exceedance Probability				
		50%	20%	10%	4%	2%
	feet	cfs	cfs	cfs	cfs	cfs
Bringle Creek	958	1070	1910	2590	3570	4370
Maumelle River	42161	3460	6340	8690	12100	14800
Maumelle below Bringle	8868	5420	9480	12700	17200	20900

2.6 Calibration

Sediment Transport Capacity only needs a 1D steady flow model, so the model was calibrated to the rating curves at Maumelle River near Wye, AR, gage number 0723296. The modeled and observed rating curves fit closely for all flows with a root mean square error of 0.17 feet (Figure 2.4). The modeled rating curve at the calibration gage was not sensitive to roughness values further away from the gage, so the final overland n values outside of the area of influence for the gage were chosen in accordance with (Chow, 1959), and ranged from 0.04-0.12, with the lower values representing pasture/hay and the higher values representing forests. The model was calibrated for the channel n value and the overbank values near the gage, located in a woody wetland. The final n values for the overbanks in the area of the gage are 0.055 and the final channel n value is 0.073, an appropriate n value for a boulder lined channel (Benson, 1967)

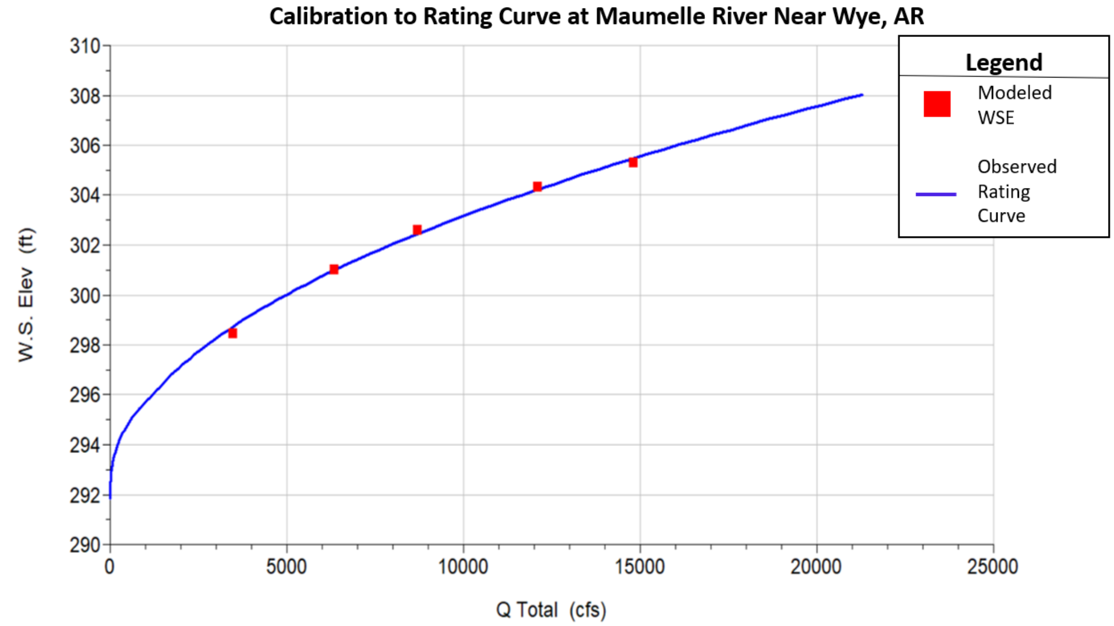

Figure 2.4 Calibration to Rating Curve at Maumelle River Near Wye, AR (07263296). Observed (blue) and Modeled (red) Rating Curve

2.7 Dam Removal Geometries

Two removal scenarios were developed. The first removal scenario will be referred to as dam removal, the second will be referred to as the modified channel. For the dam removal model, the inline structures were deleted to represent a complete removal of the dams with no alteration of the stream channel. The dams coincide with a rise in the channel elevation, perhaps a historic riffle. For the modified model, in addition to the dams being completely removed, the cross-sections at the inline structure, and a few hundred feet up and downstream from the structure were smoothed out to represent either natural or mechanical regrading (Figure 2.5).

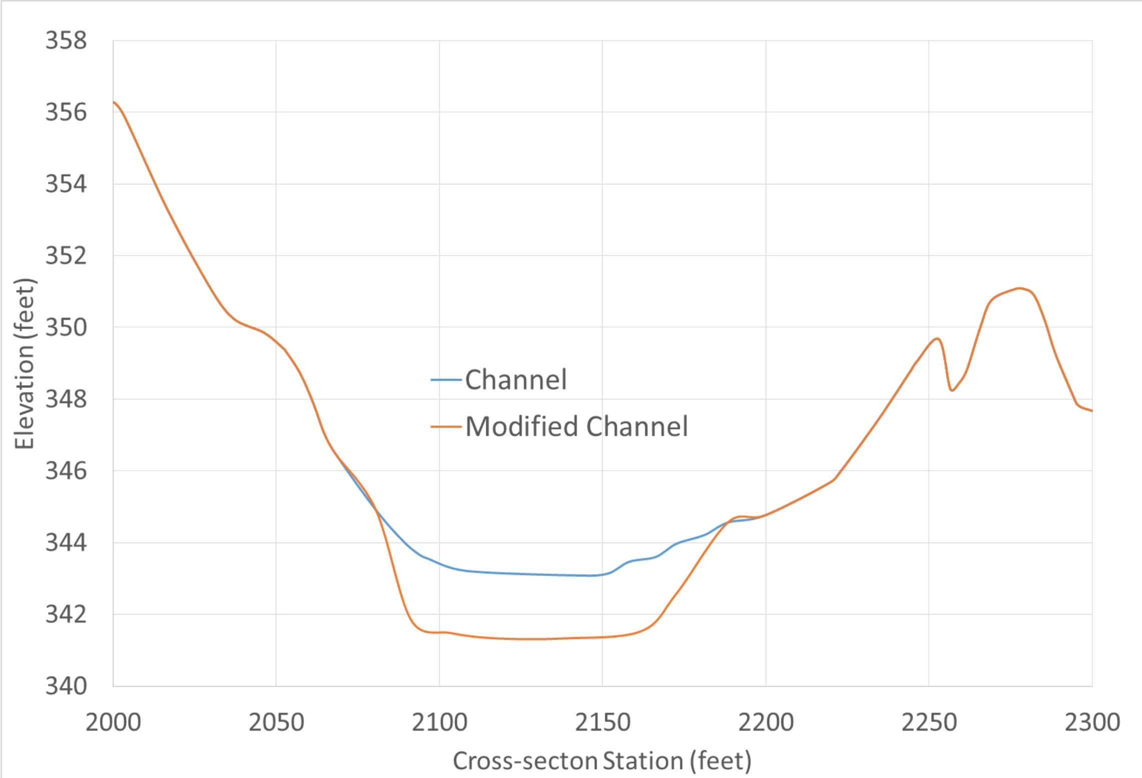

Figure 2.5 Channel in Removed Scenario and Modified Channel

CHAPTER III

Sediment Transport Capacity

3.1 Introduction

Sediment transport capacity is used to indicate stream stability. The grain size and shear stress of the river system determine the sediment transport capacity. USACE hydrologists employed the Meyer-Peter Muller sediment transport calculations via the Hydraulic Design-Sediment Transport Capacity (STC) Module in HEC RAS to determine the relative STC of the system if. The STC module calculates the transport capacity for every grain size class. The final total transport capacity is a weighted sum of all the results. However, armoring, a coarse layer overlying smaller gravels and sands, typical in gravel, cobble, and boulder channels, like the Maumelle River, can make the channel resistant to erosion regardless of the sediment transport capacity. Here we discuss the formulation of the STC, and the results of the various scenarios described in Section 2.7. Because the Maumelle River is considered stable in its current state, the STC results of the AS IS scenario are used to establish a threshold of acceptable STC values for the dam removal scenarios when considering the stability of the Maumelle River under future conditions, though it is possible to have localized higher STC results. It should be noted that these results were not calibrated and do not necessarily represent absolute sediment transport capacity values.

3.2 Grain Size Distribution

The sediment transport capacity is largely dependent on grain size as a larger grain requires a higher shear stress to mobilize. An initial site visit was undertaken on September 24, 2019. The investigation was limited to accessible portions of the river. At this time, the most downstream river crossing, RC4, had just been removed. Of note were the large percentage of boulder and cobble grain sizes present in the system as well as the presence of bedrock (Figure 3.1 and Figure 3.2). Finer grained gravel was visible in a riffle downstream from the Dam 4 location (Figure 3.3). At the time, a sediment analysis was requested from CAW, but it was noted by the CAW Watershed Protection Manager, that a sediment study had been attempted, but was not complete due to the lack of fines in the system.

The cobble count was performed on December 30, 2019. Water was too high to get into the channel. However, a cobble count was performed on the right bank of the river just upstream from the previous RC4. The location was chosen based on accessibility and representation of the system. On a visual inspection, it is apparent that the material is dominated by cobbles and boulders at this location. Conversations with the CAW natural resource specialist indicated that the gradation of the material on the bank was indicative of the material in the channel at that location. Furthermore, the previous site visit and discussion with the natural resource specialist indicate that the grain size distribution coarsens up further upstream. This is consistent with what USACE hydrologists and engineers witnessed on a previous site visit during dry conditions. Sediment transport capacity is sensitive to smaller grain sizes, so a bias towards a smaller grain size distribution results in a more conservative sediment transport capacity estimate.

Figure 3.1 Picture for Scale of Grain Size Analysis

Figure 3.2 Boulders Downstream from River Crossing 1

Figure 3.3 Fine Gravels Present in Riffle Downstream from River Crossing 4

The cobble count was performed by the hydrologist crisscrossing back and forth in the accessible area, taking one heel-to-toe step and with closed eyes reaching down and touching the rock immediately in front of the toe. If conditions allow, a more representative sample should be taken in the future. It is believed that this analysis skewed to the finer grain sizes due to the difficulty of heel toeing over boulders. The resulting count and grain size analysis can be viewed in Figure 3.4

The pebble counts shows that 2% of the grains at this location fall in the boulder category. 49% fall in the cobble size range, and the rest fall in the gravel size category (Figure 3.5). It is likely that some sand size particles are present in the system in areas like the riffle in Figure 3.3, but the surficial system is dominated by larger particle sizes whether due to armoring or a decreased sediment load from upstream, though the lack of fines behind the river crossing indicates the former.

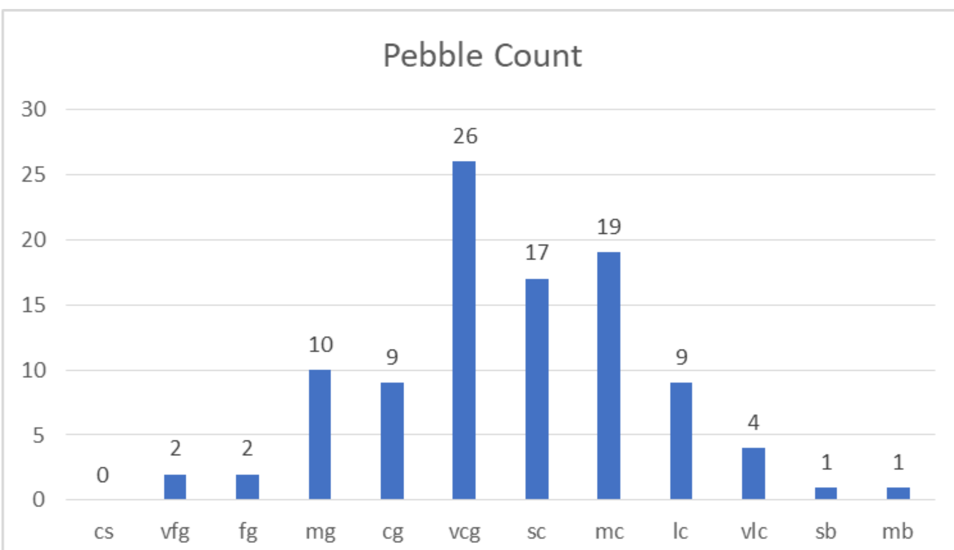

Figure 3.4 Pebble Count

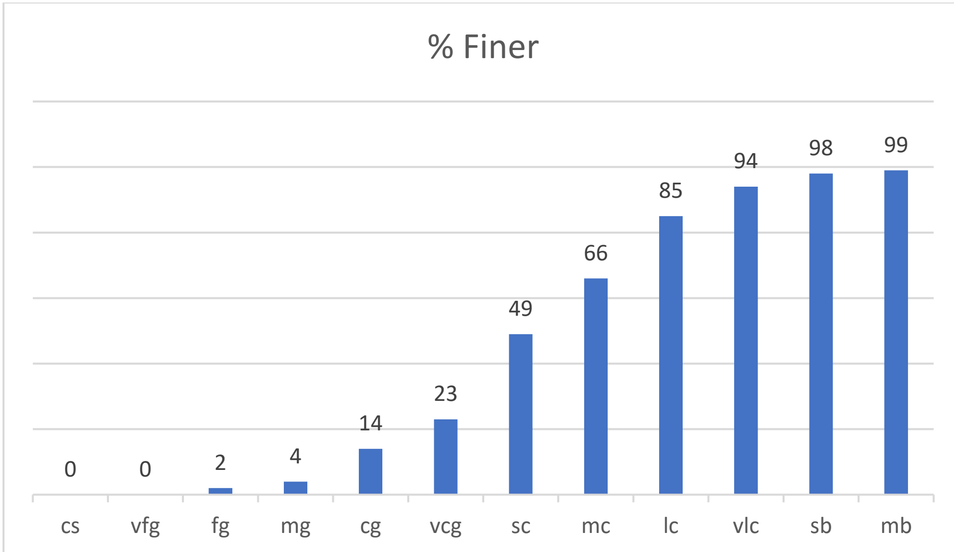

Figure 3.5 Grain Size Distribution of Maumelle River

3.3 Sediment Transport Model Development

The entire Maumelle River Reach 1 was modeled as one sediment reach in the STC module. This allowed for comparison of the modeled STC in areas around the removed dams to other areas in the river that are considered stable. The grain size distribution (Figure 3.5) was applied to the entire reach. Temperature and specific gravity were kept to defaults of 55°F and 2.65 g/cm^3. Six functions are available in the HEC-RAS STC module. Between information available in the HEC-RAS 5.0 User's Manual, and personal correspondence with the subject matter expert (SME) at USACE Engineering Research and Development Center, the list of possible functions for the Maumelle River were narrowed down to two; the Laursen and the Meyer-Peter Müller (MPM) transport functions. The SME indicated that if only one were chosen, the MPM would be more appropriate. Both MPM and Laursen functions rely on excess critical shear stress to determine sediment transport capacity. The STC was performed with both functions for comparison, though we should note that none of the functions available in the HEC-RAS STC were designed for a cobble stream though they do account for the cobble and boulder contribution to the sediment transport capacity.

Upon the initial run of the STC module, high STC values were calculated in areas that are known to be stable. This was attributed to large changes in slope across high cross-section spacing. Cross-sections were added near STC highs until the STC results no longer changed. Lowering the cross-section spacing did not always reduce the STC results, but it did increase confidence.

50% annual exceedance probability (AEP) discharge is considered the channel forming discharge, so it was used for the STC computations on each scenario; the AS IS, Dam Removal, and Modified Channel scenarios.

3.4 STC Results

The STC module calculates the transport capacity for every grain size class. The final total transport capacity is a weighted sum of all the results. Stream stability is determined by comparing transport capacity at the dam removal locations in relation to the rest of the stream. Since the stream is considered stable in its current state, the STC was performed on the entire reach where channel data was available to determine permissible transport capacity ranges for each function. The MPM STC function was compared to the Laursen STC to ensure that for the given stream system, the comparable results would not be sensitive to the chosen function.

3.4.1 Maumelle River from Williams Junction to Bringle Creek

The transport capacity for every cross-section with channel data in the reach from Williams Junction to Bringle Creek is shown in Figure 3.6. Results are reported by cross-section increasing from left to right, downstream to upstream. Transport capacity is reported in tons/day. The results of the two functions are on different orders of magnitude, however, the transport capacity of the cross-sections in relation to one another is similar for both functions. Besides the large sediment transport capacity at RC2, two large spikes in the sediment transport capacity stand out at river station 7000. This is upwards of 30,000 tons/day for Laursen, and near 5000 tons/day for MPM. As noted earlier, cross-sections were added until the transport capacity results stabilized. Maumelle River is considered stable, so a sensitivity analysis to the grain size distribution was performed by shifting the grain size distribution curve (Figure 3.7) so that the system is dominated by fine to coarse gravels. Only the MPM results are reported. As expected, the sediment transport capacity is sensitive to smaller grain sizes (Figure 3.8) as they require a lower shear stress in order to be displaced. Because the calculated high transport capacity is attributable to the smaller grain sizes in the system, the stability of the system is attributed to armoring. The rest of the discussion will focus on the results of the MPM function for transport capacity. Any values below the highest values in the AS IS scenario, 5050 tons/day, that are not at a river crossing, will be considered stable.

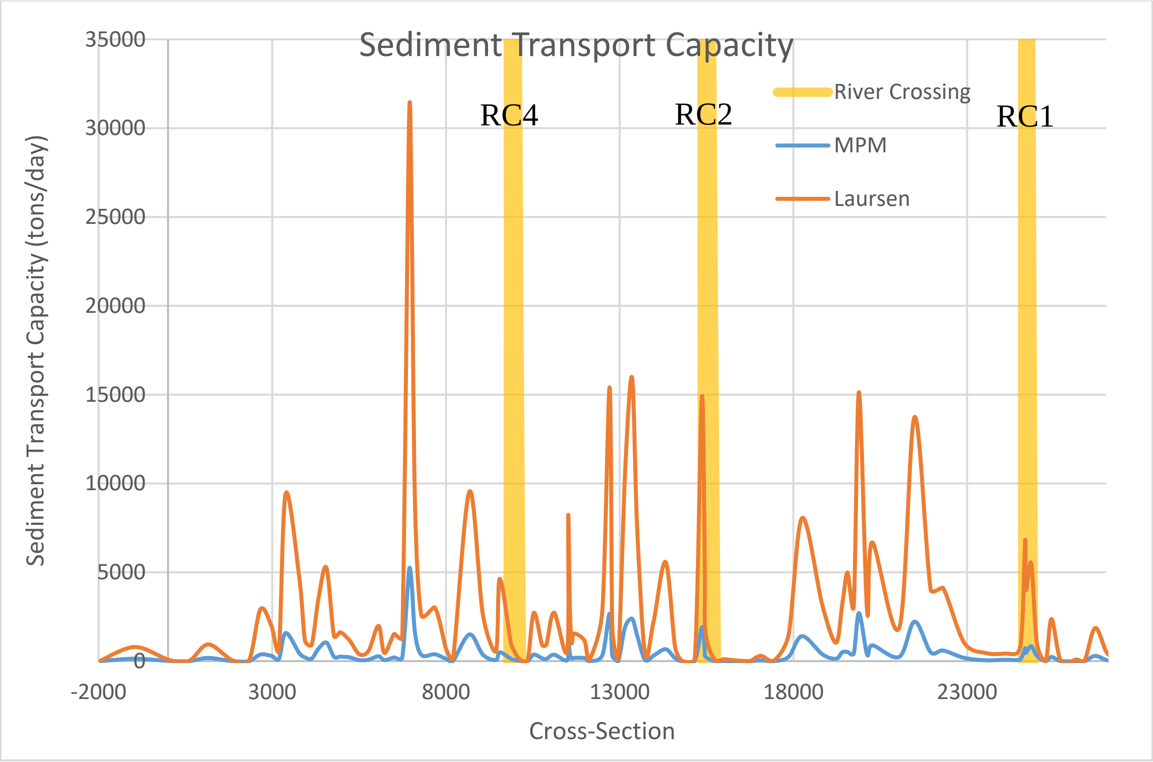

Figure 3.6 MPM and Laursen Sediment Transport Capacity for the system AS IS

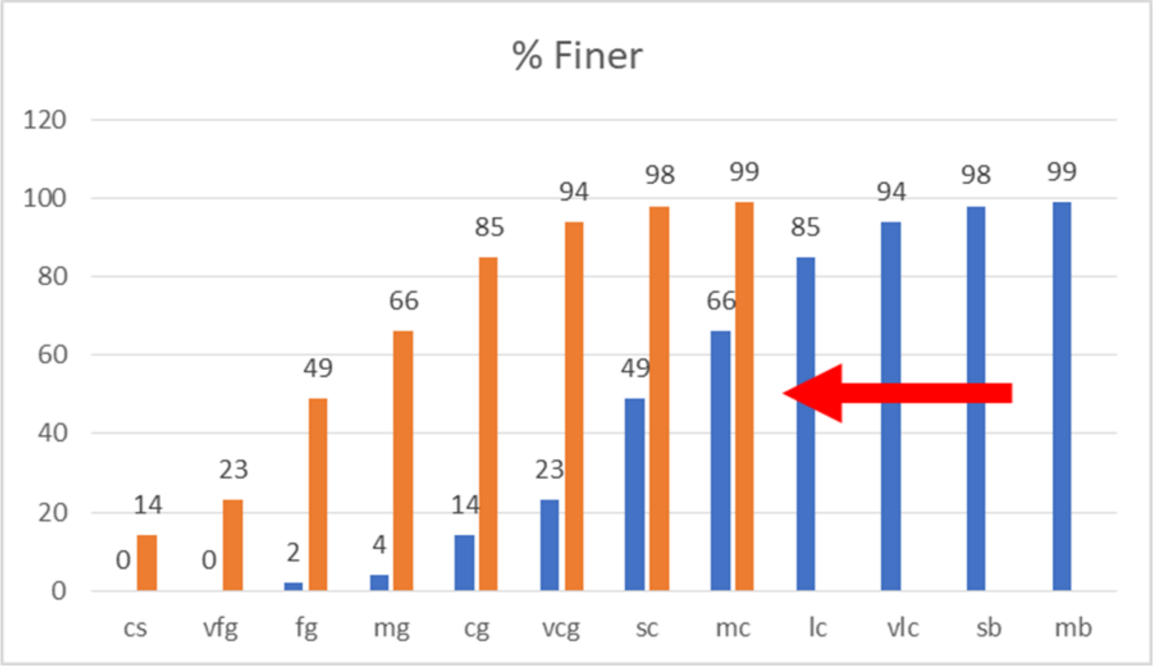

Figure 3.7 Shifted Grain Size Distribution for Sensitivity Analysis

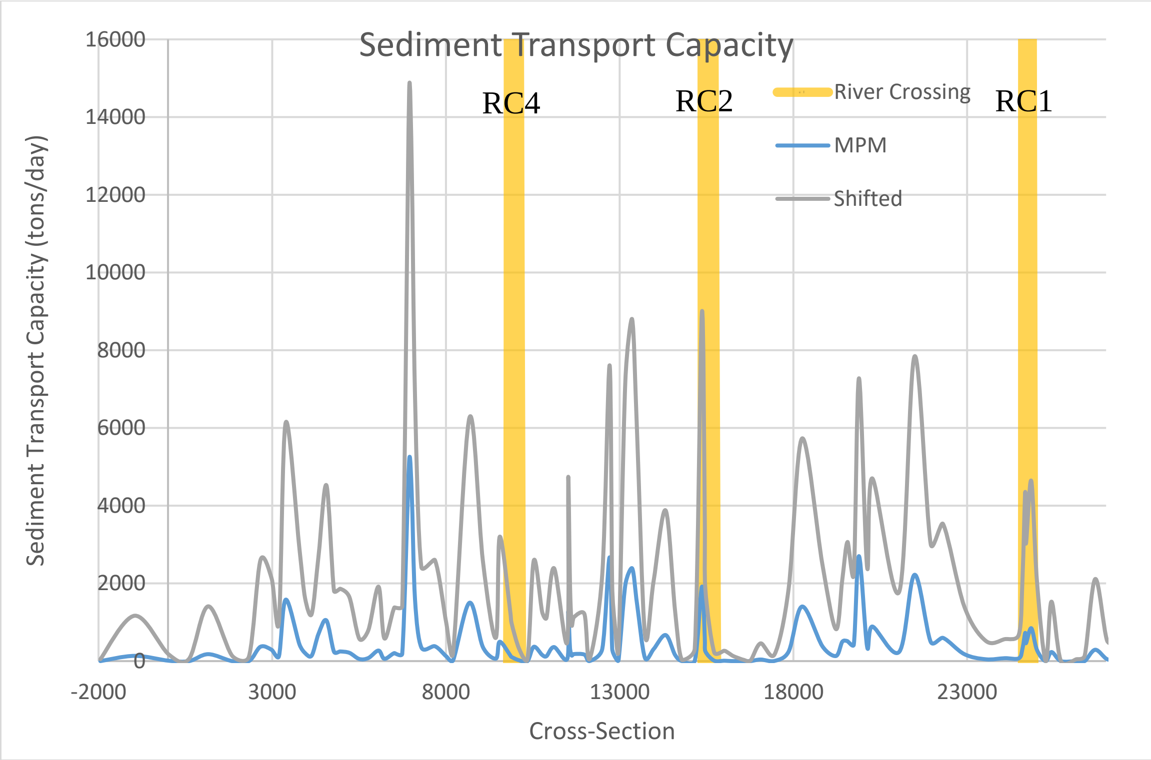

Figure 3.8 Comparison of Shifted Grain Size Distribution Curve to Grain Size Distribution

For the AS IS condition, the STC at the river crossing is very low, with a spike in tons/day just after each river crossing (Figure 3.9). After the river crossing is removed, at RC1, the high STC increases from 850 tons/day to 1480 tons/day (Figure 3.10). After channel modification, the high STC stays at 1480 tons/day (Figure 3.11). At RC2, the STC does not change after removal of RC2 (Figure 3.10). STC lowers to 90 tons/day after channel modifications (Figure 3.11). At RC4, the STC does not change after the RC4 removal. After channel modification, the STC does increase from 500 tons/day to 820 tons/day (Figure 3.11).

None of the final sediment transport capacities increased above the 5050tons/day threshold for the system. As expected, the modified channels results are highly dependent on the geometry of the final channel.

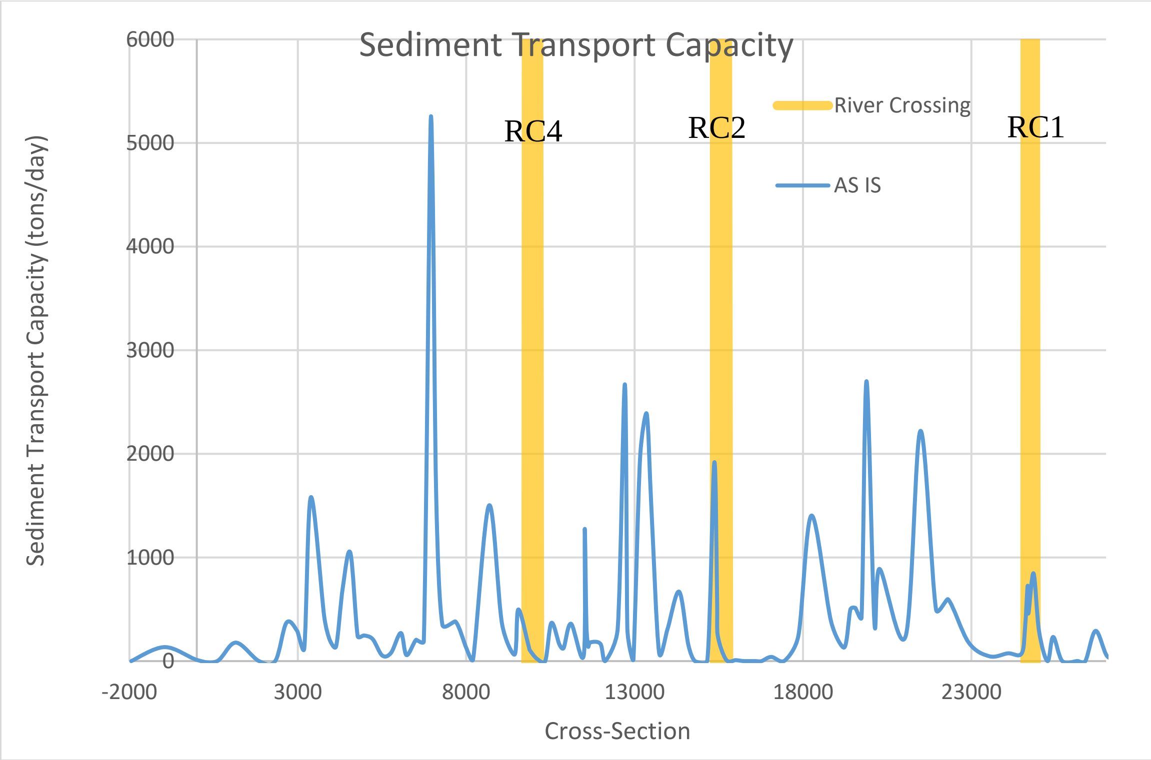

Figure 3.9 Sediment Transport Capacity for AS IS condition

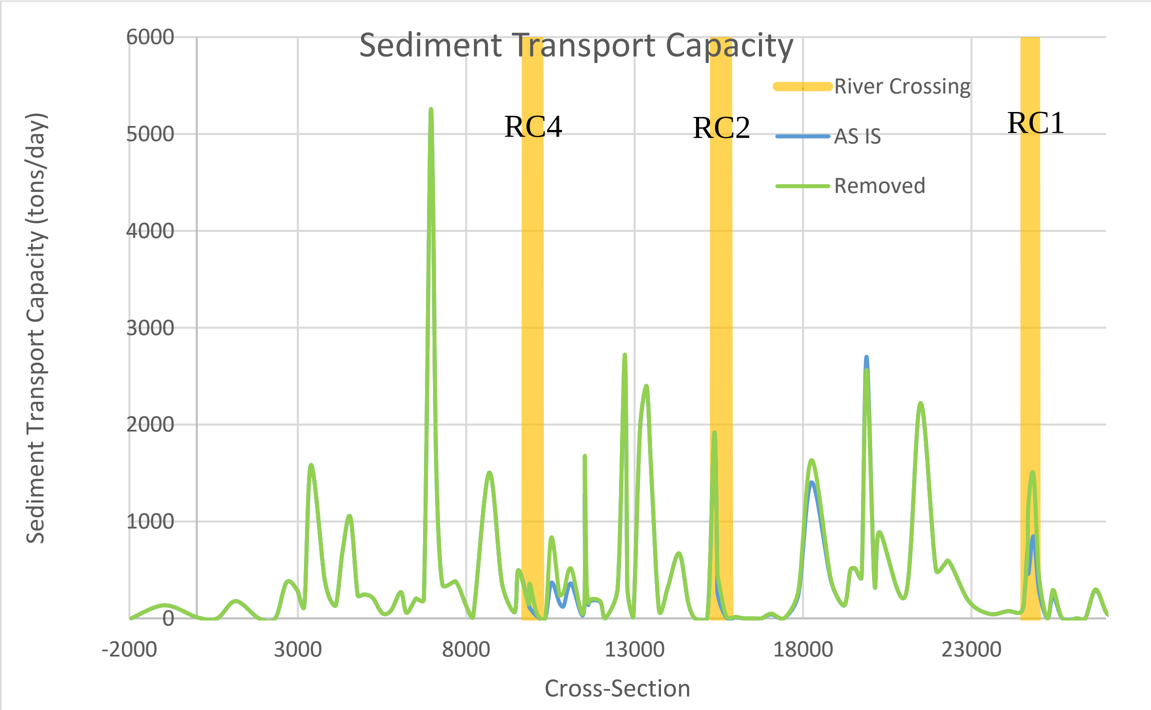

Figure 3.10 Sediment Transport Capacity for AS IS and after river crossing removal

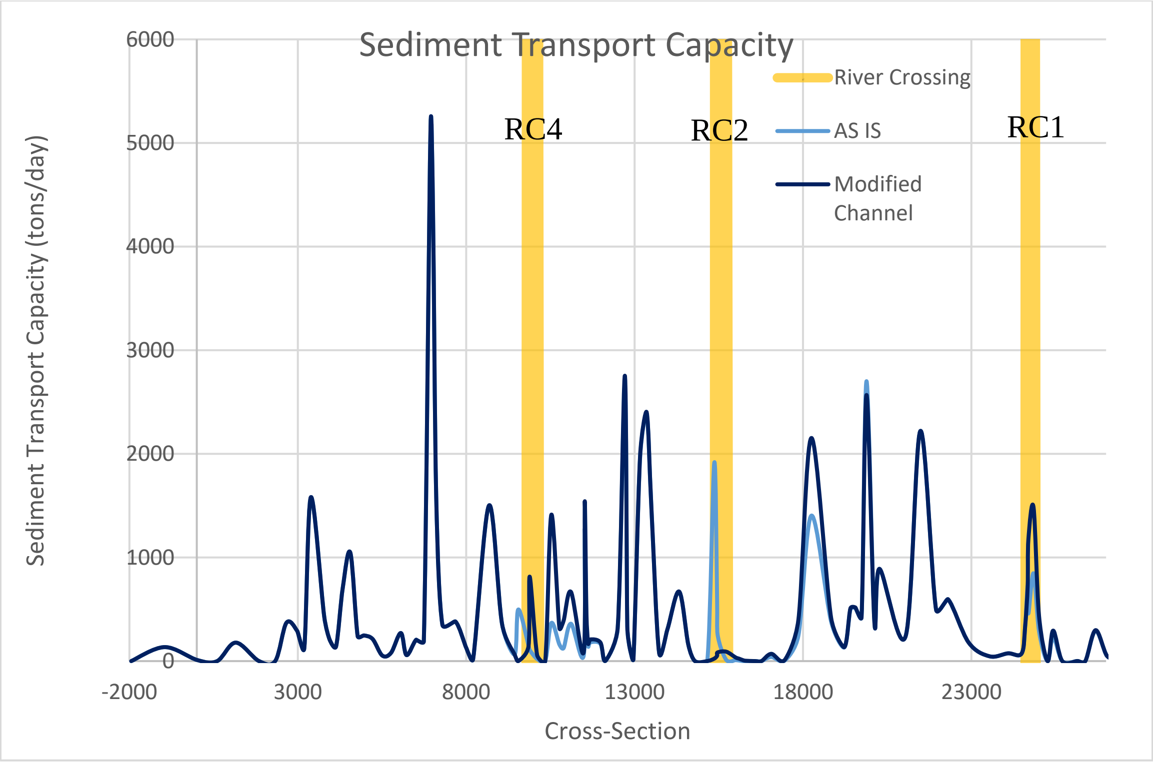

Figure 3.11 Sediment Transport Capacity After River Crossing Removal and Channel Modification

CHAPTER IV

Climate Change Considerations

To reduce vulnerabilities and enhance the resilience of communities, all current and future USACE studies require consideration of climate change in accordance with ECB 2018-14 (2020). With regards to sediment transport capacity, the Maumelle River is going to be most vulnerable to an increase in streamflow or a change in the 50% AEP, though this is a cobble bed river, the increase in the 50% AEP would have to be significant.

The Central Arkansas Water project area is located within the Hydrologic Unit HUC-4 1111-Lower Arkansas. Literature compiled by the USACE asserts that there is "general consensus amongst recent peer-reviewed literature indicating an upward trend for average streamflow" for Water Resources Region 11 (White, 2015). The gage Maumelle River at Williams Junction, AR shows an upward trend in the maximum annual streamflow (Figure 4.1).

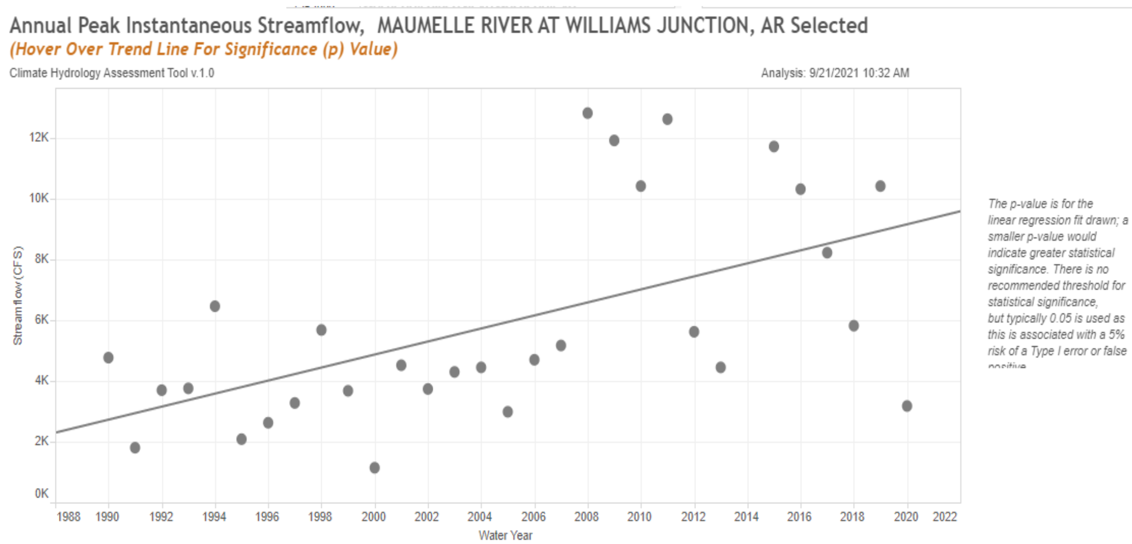

Figure 4.1 Trend in Annual Maximum Flow at Maumelle River at Williams Junction, AR

Abrupt non-stationarities were also detected at this gage, resulting in an increase in the mean maximum annual flow from 3700 cfs to 8700 cfs as well as a shift in the distribution (Figure 4.2). There is no known land use change that resulted in the shift.

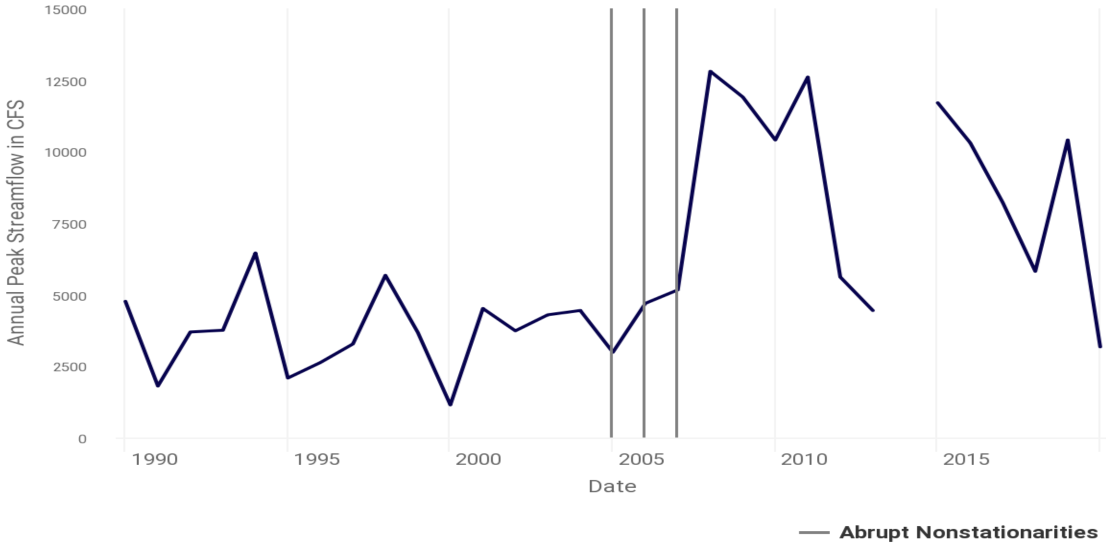

Figure 4.2 Abrupt Nonstationarities in Annual Peak Streamflow for Maumelle River at Williams Junction, AR

The mean of 93 models for the projected annual maximum monthly streamflow for HUC 1111 shows an upward trend now but indicates a downward trend through the later part of the century. The p-value is 0.0549, above the typical recommended threshold for statistical significance of 0.05 (USACE, 2018).

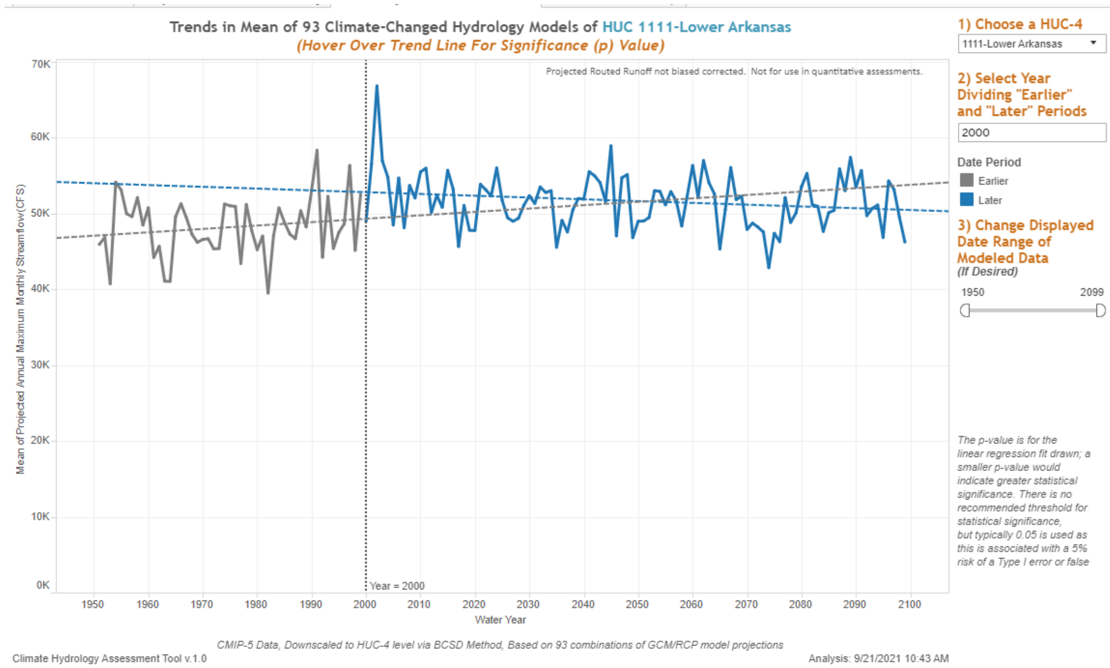

Figure 4.3 Trends in Mean of 93 Climate-Changed Hydrology Models of HUC 1111-Lower Arkansas

Historically, there has been an upward trend in streamflow in this region. However, future climate projections indicate a downward, though statistically insignificant, trend in streamflow for HUC 1111, likely due to increasing temperatures resulting in longer period. If future streamflow follows the current trend, an increase in streamflow in the future is possible, but increasing temperatures may contribute to drought. Should there be an increase, restoring the riparian zones will help to reduce peak streamflow levels in the Maumelle River. Furthermore, this is a cobble river and could likely withstand slightly increased flows in the 50% AEP.

CHAPTER V

Side Channel Connectivity

The feasibility study will determine the benefits of reconnecting two side-channels. The most upstream side channel, SC1, will be reconnected with the full removal of RC1. The lower side channel, SC2, can be reconnected by levelling a small earthen dam. The duration of connectivity to the side channels is determined by the elevation to which the connecting structure is levelled. The percent of time a flow is exceeded is calculated using HEC Statistical Software Package (HEC-SSP). The flows are tied to an elevation at the upstream end of the side channels by routing the various flows through the 1D steady-state HEC-RAS model and extracting a water surface elevation from the given location.

5.1 Elevations from Flows at Side Channels

To determine the elevations for a given flow, the 1D steady model was run with flows ranging from 500 cfs to 3000 cfs in increments of 500 cfs, all under the 50% AEP for the Williams Junction gage, 3460 cfs. The water surface elevation profiles for each flow were pulled from each side channel connection location (Table 5.1).

Table 5.1 Water Surface Elevations at Side Channel Connection Locations

Flow (cfs)	SC1 WSE (ft)	SC2 WSE (ft)
500	344.80	322.10
1000	345.90	323.50
1500	346.70	324.30
2000	347.50	324.90
2500	348.10	325.50
3000	348.60	326.00

5.2 Duration Analysis at Williams Junction

A duration analysis was performed on daily mean data from Williams Junction which has a drainage area of 46 mi^2. The data was scaled to account for the larger drainage area at each of the upstream ends of the side channels (Table 5.2).

Table 5.2 Scaling for Duration Analysis

Location	Drainage Area (mi^2)	Multiplier
SC1	59.3	1.29
SC2	68.7	1.49

The resulting flow duration analyses are given in Table 5.3 and 0. The percent of time a given elevation will be exceeded is given in Table 5.5 and Table 5.6.

Table 5.3 SC1 Flow Duration Analysis

Percent of Time Exceeded	Flow (CFS)
99.0	0.0
95.0	0.0
90.0	0.0
80.0	0.4
50.0	15.6
25.0	69.7
15.0	132.9
10.0	198.7
5.0	370.2
4.0	451.5
3.0	564.4
2.0	779.2
1.0	1270.7
0.1	3620.8

Table 5.4 SC2 Flow Duration Analysis

Percent of Time Exceeded	Flow (CFS)
99.0	0.0
95.0	0.0
90.0	0.0
80.0	0.4
50.0	18.0
25.0	80.5
15.0	153.5
10.0	229.5
5.0	427.6
4.0	521.5
3.0	651.9
2.0	900.0
1.0	1467.7
0.1	4182.2

Table 5.5 SC1 Elevation Duration Analysis

Percent of Time Exceeded	Elevation (ft)
3%	344.80
1%	345.90
<1%	346.70
<1%	347.50
<1%	348.10
<1%	348.60

Table 5.6 SC2 Elevation Duration Analysis

Percent of Time Exceeded	Elevation (ft)
4%	322.10
1%	323.50
<1%	324.30
<1%	324.90
<1%	325.50
<1%	326.00

CHAPTER VI

Discussion

Sediment transport capacity of the Maumelle River was calculated under 3 conditions: 1) AS IS - the current conditions, 2) Removed - after the removal of the river crossings, and 3) Modified Channel - after regrading of the river near the river crossing sites. Sediment transport capacity is dependent on grain size. With no indication of clay or sand size sediment in the system, a pebble count was performed at a representative location in the river. This grain size analysis was applied to the entire river reach during the sediment transport capacity analysis. Because the Maumelle River is considered stable in its current condition, results of the AS IS model indicate that a threshold of 4958 tons/day is an acceptable sediment transport capacity for this river. The smaller gravels contribute to the higher sediment transport capacity values in the system, but the armoring, which is common in a gravel/cobble/boulder river, likely prevents the smaller constituents from mobilizing. Removal of the river crossing always resulted in an increased sediment transport capacity, and at RC1. At RC4, the sediment transport capacity increased after modifying the channel, but this is likely due to not properly grading the channels via cross-section manipulation. However, it is important to note that none of the results of the two removal scenarios resulted in sediment transport capacities approaching the upper threshold established for this system indicating that the Maumelle River will not suffer significant channel instabilities after the removal of the river crossings.

The pebble count was performed during conditions that did not allow for an in-channel count. Though it is thought that the count skewed to the left, resulting in a more conservative sediment transport capacity estimate, if future conditions allow, another pebble count should be performed.

The duration of connectivity with the side channels is dependent on the elevation to which the connection is excavated. Assuming the elevations pulled from LiDAR are representative of the side channel inverts, a connectivity duration of 3% and 4% can be achieved for side channels 1 and 2 respectively.

It should be noted that the study area lies in a floodway as indicated in FEMA map numbers 05119C0090G and 05119C0255G. A potential rise in flood levels should be considered during the design phase.

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