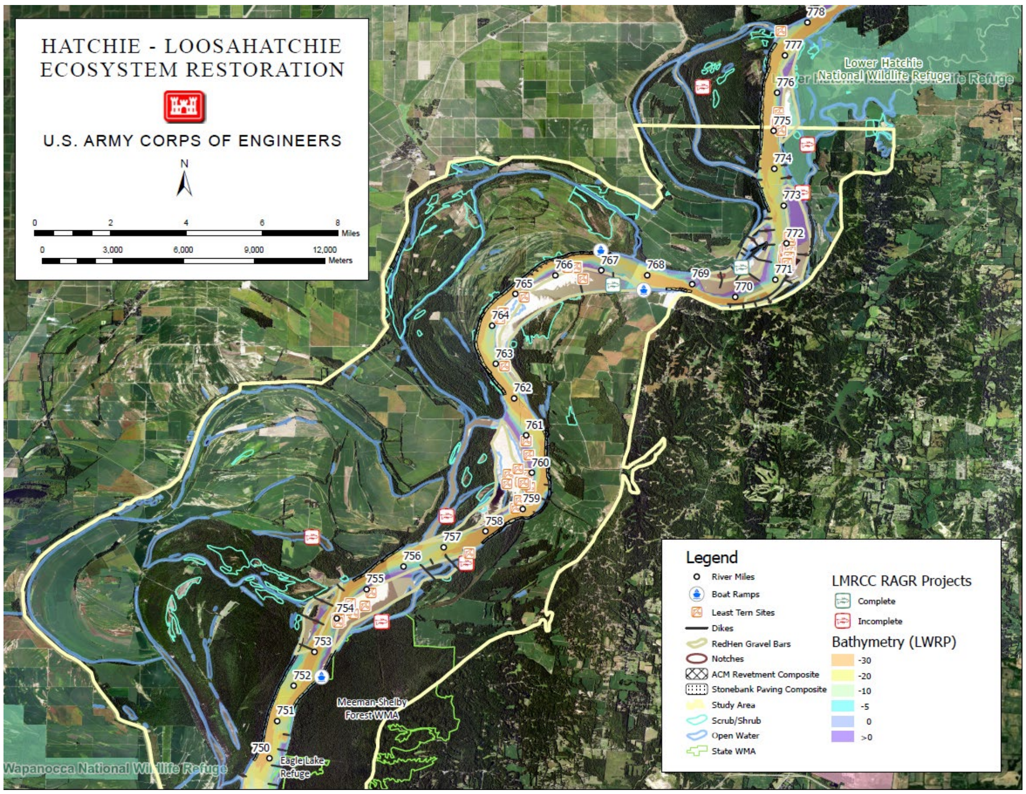
Mississippi Valley Division,
Regional Planning and Environment Division South

Mississippi River Hatchie/Loosahatchie Mississippi River Mile 775-736, Tennessee and Arkansas



Appendix 3 - Engineering Appendix

February 2023

Contents

LIST OF TABLES

LIST OF FIGURES

Section 1
General Overview

1.1 BASIN DESCRIPTION

The project area encompasses a 39-mile reach of the Mississippi River beginning at the mouth of the Hatchie River and extending south to the mouth of the Wolf River Harbor (River Mile 775-736) in Memphis, TN. The study area is bounded on the east by the West Tennessee bluffs and on the west by the Mississippi River Levee System and is in Lauderdale, Tipton, and Shelby Counties, Tennessee and Mississippi and Crittenden Counties, Arkansas. In addition, there are three tributaries to the Mississippi River in the reach (i.e., Hatchie, Loosahatchie, and Wolf Rivers). Numerous State and Federal Lands, including Meeman Shelby State Park, Fort Pillow State Park, the Lower Hatchie National Wildlife Refuge and JM Tulley Wildlife Management Area fall within the project area.

The USACE is responsible for maintaining a navigation channel as well as flood risk management features within the project reach. Numerous river training structures and revetments have been constructed in this reach to promote a self-scouring channel in order maintain a navigable waterway. Levees and floodwalls have been constructed in the area as flood risk management measures. These construction activities have altered the hydraulics of the area and constricted the floodplain.

1.1.1 Existing Conditions

Commerce, MO to St. Francis Levee system bounds the study area to the west. This levee system was constructed as part of the Mississippi River and Tributaries Project as authorized by the Flood Control Act of 1928. The levee system has reduced the natural floodplain of the Mississippi River and provided protection to acres/miles of productive farmland and communities in the region and prevented millions of dollars in flood damages. However, this has restricted the channel from forming natural cutoffs and new meander bends. River training structures, such as dikes, and revetments were constructed to maintain a navigation channel and reduce the need for dredging. Approximately 150 different river training structures, and 33 miles of revetment have been constructed in this reach since the early 1930s.

While this has provided huge benefits to the navigation industry, it has reduced the number of backwater and side-channel connections to the river and resulted in the loss of wetlands negative impacts to the aquatic, semi-aquatic, terrestrial, and areal species. In recent years, the USACE Memphis District has partnered with the Non-Federal sponsor to incorporate environmentally friendly designs into the channel improvement program. Within this reach, approximately 40 dike notches have been constructed to promote flow in secondary channels.

In addition to the impacts from the levee and river training structures, this reach has been undergoing large scale geomorphic change due to the channel cutoff program in reaches further downstream (Biedenharn et al., 2017). The reach of river around Memphis has shown a decreasing trend in the specific gage records, indicating a state of degradation (i.e., the lowering of the channel bed). This has likely exacerbated the disconnection of secondary channels and floodplain water bodies from the main channel.

1.2 ENGINEERING PROBLEM STATEMENT

Restore the ecological structure and function along the Mississippi River including secondary channels and other aquatic habitat; floodplain forests; and several scarce vegetative communities such as wetlands, canebrakes, riverfront forests, and BLH Forests without adverse impacts to navigation or flood risk management features.

1.3 HYDRAULIC DESIGN CONSIDERATIONS

The primary hydraulic concern for this study was to avoid impact to the performance of flood control features (i.e., levees and floodwalls). The measures and alternatives proposed in this study were primarily concerned with diverting water into secondary channels and holding water for fish habitat during river stages lower than flood stage. Therefore, no impact to flood risk management is expected.

1.4 RIVER ENGINEERING CONSIDERATIONS

The 39-mile stretch of the Mississippi River that encompasses the Hatchie/Loosahatchie Feasibility study area contains approximately 150 different River Training Structures and 33 miles of Revetment. Of the 150 River Training Structures, there are approximately 90 dikes, 2 round points, 1 chevron, 9 bendway weirs and 48 hardpoints. The Memphis District has incorporated a variety of environmentally friendly designs within the reach. Hardpoints were constructed in lieu of riprap bank paving from the mouth of the Hatchie River downstream for approximately one mile. A chevron and two round points were constructed in the secondary channel between Loosahatchie Bar and Robinson Crusoe Island to form a split channel and promote more diverse aquatic habitat. As part of the Cedar Point Densford revetment project, the Memphis District utilized the cleared debris to place two woody debris piles, promoting diverse aquatic habitat for fish and macroinvertebrates. In partnership with the Lower Mississippi River Conservation Committee (LMRCC), the Non-Federal Sponsor for this study, the Memphis District has incorporated approximately 40 dike notches, promoting flow in various secondary channels throughout the reach.

Most of the study reach has historically been plagued with navigation issues, primarily caused by increasingly large point bars, channel crossings and a long straight stretch of the channel. Several point bars have continued to grow over the years, necessitating the construction on numerous dikes, primarily the Lookout Bar/Randolph Dikes at River Mile

771, the Cedar Point Dikes at River Mile 759 and the Corona Bar Dikes at River Mile 754. By 2010, the point bar at River Mile 766 had restricted channel dimensions to a level that required the construction of the Reverie Bendway Weirs. At River Mile 757, the Mississippi River changes course, shifting the high velocities from the left descending bank to the right descending bank, creating a channel crossing where the channel widens, velocities slow down and aggradation occurs. The Densford Dikes were constructed on the left descending bank to address this concern, with additional dike work proposed for the future. Beginning at Brandywine Island and Meeman-Shelby Forest State Park, through the remaining portion of the study reach downstream to the City of Memphis, the Mississippi River remains predominantly straight. Given the River's natural inclination to meander, a straight River results in lower velocities due to channel geometry, causing sediment aggradation. Much of this portion of the study reach has river training structures on both side of the channel and has required dredging eight times in the last five years.

When developing the ecosystem restoration alternatives throughout the course of the study, it was imperative to consider all the existing navigation concerns. This resulted in the exclusion of several measures.

1.5 GEOTECHNICAL CONSIDERATIONS

There is currently no historical geotechnical boring data available in the areas of proposed work. Throughout the study process, multiple borrow pits deepening proposals were discussed and evaluated. Due to the nature of the areas the borrow pits occurred (within proximity of mainline levee footprints) it was determined that borrow pits were not to be excavated beyond the previous borrow pit excavation design plan. This was to ensure that this study did not create new or recreate seepage issues in areas where work for seepage remediation had been performed. If this proposal was to be further evaluated, the only allowable work to be done that was agreed upon, was for the borrow pits to be resurveyed and to compare how much depository material had settled in the borrow pits since their construction. If borrow pits had accumulated excess depository material, it would be valid to excavate the borrow pits back to the original excavation design grade.

It has been assumed, at this time, that geotechnical recommendations are not expected for measures that include replacing culverts or lowering culvert inverts. In many areas the study team does not have adequate data to determine the culvert sizes and borings have been indicated as not feasible to obtain. If Geotechnical recommendations are required for these alternatives, a boring or sub surface investigation of some type will be required, and design requirements set forth by of EM 1110-1-1904 Settlement Analysis and EM 1110-1-1905 Bearing Capacity of Soils will need to be met.

1.6 AVAILABLE DATA

Engineering analysis for this report is based on the most comprehensive data that can be acquired within the defined, relatively compressed schedule and budget. A significant data mining and compilation effort was completed during the initial phases of this project. Satellite imagery, main channel bathymetry, LiDAR, location of existing river training structures and revetments, land cover data, soil data, historic maps, and inundation layers were compiled in a GIS portal to be used for the evaluation of proposed measures.

1.6.1 Data quality and interpretation

Elevations were taken from a 1m Digital Elevation Model (DEM) derived from LiDAR data. The error in this class of data averages over a wide area, making it appropriate for modeling watersheds but can be inaccurate when determining the elevation of any one discreet point. Algorithms that process LiDAR point clouds into DEMs remove building and vegetation data points but can produce local error in the dataset based on how it interprets the adjacent ground level. In addition, LiDAR datasets do not include any bathymetry data in locations where water was ponded during data collection. This introduces significant uncertainty when using LiDAR for this study where many of the proposed measures are in areas that are permanently inundated. Information on the depth of water or channel bottom elevation was unavailable for most of the proposed measures. Survey data will need to be collected during the planning, engineering, and design phase to accurately determine quantities and channel inverts.

Information on the size, location, and number of existing water control, drainage, and other structures was not available. This study also relied heavily on satellite imagery. Imagery from multiple dates and conditions (i.e., low water, high water, leaf off) were used to evaluated measures. However, the resolution of the imagery was not always sufficient to evaluate the measure or existing conditions and several proposed measures were within forested areas, making the use of satellite imagery limited.

1.6.2 Quantity calculations

Volume calculations are based on LiDAR elevations, which introduces a significant source of error in quantities. During PED, topographical surveys will allow increased accuracy to less than ± 10% of actual values.

Section 2
Measures and Alternatives

2.1 OVERVIEW

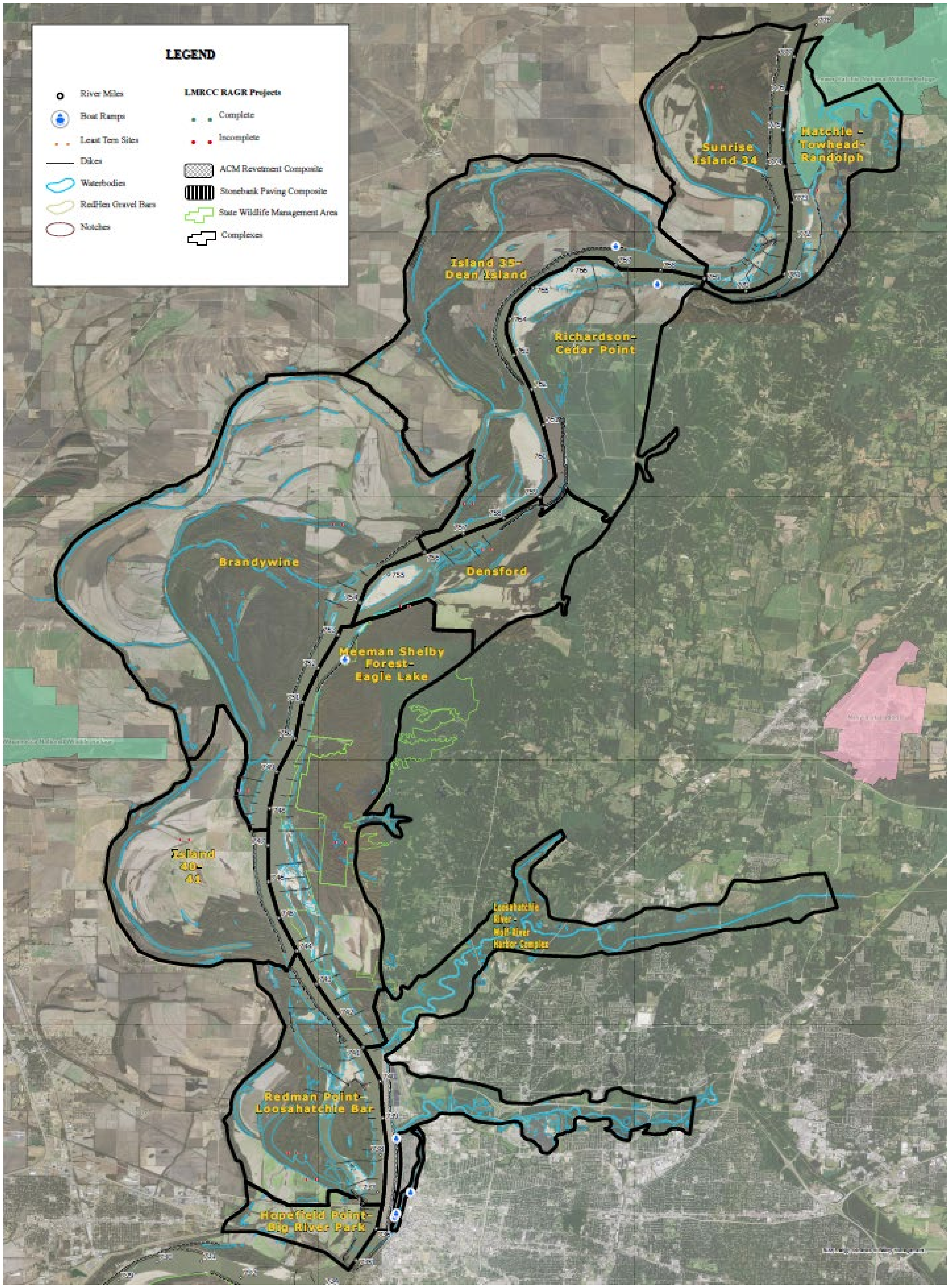
2.1.1 Geographic Complexes

The study area was further delineated into 11 separate ecological complexes based on the geomorphic and/or hydrologic evolution of the floodplain using historical maps and existing elevation data. Land ownership and/or management considerations were also factored into the delineation of the complexes (e.g., Meeman Shelby Forest State Park – Eagle Lake State WMA). Table 1 lists the geographic complexes and abbreviations used in this study. See Figure 1 for map of complexes.

Table 1. Geographic Complex Names and Locations

Geographic Complex Name	Code	River Miles	Bank
Sunrise-Island 34	S	776-769	Right
Hatchie Towhead	HT	776-769	Left
Island 35	I35	769-756	Right
Richardson-Cedar Point	RCP	769-758	Left
Brandywine	Br	756-747	Right
Densford	D	759-753	Left
Meeman-Shelby Forest	M	753-741	Left
Island 40-41	I40	747-744	Right
Loosahatchie River- Wolf River	LW	741-736	Left
Redman Point-Loosahatchie Bar	RL	744-737	Right
Hopefield Point-Big River Park	HB	737-735	Right

Figure 1. Geographic Complex Names and Locations



In each complex, numerous potential restoration measures were identified to be evaluated in this study. A total of 225 measures were initially identified.

2.2 METHODOLOGY

The methodology used for this study followed the USACE six-step planning process. This is an iterative process conducted to formulate and evaluate an efficient, effective and reasonable array of alternatives. The study area was delineated into 11 separate geographic complexes based on the geomorphic/hydrologic evolution of the floodplain, using historical maps and existing elevation data and incorporating practical land ownership/management considerations (private and public lands).

Project objectives were established, and management measures were developed using these objectives. The management measures address the identified problems, opportunities, objectives, and constraints. Each of the retained management measure activities were then applied to the developed geographic complexes through a series of expert election and complex specific planning meetings with the PDT, NFS, and cooperating agencies. A total of 225 site specific measures were identified. Those site-specific measures were then evaluated and grouped into unique measures. Measures were screened if they did not meet objectives and/or engineering feasibility.

Multiple iterations of the IWR Planning Suite cost effective and incremental cost analysis (CE/ICA) were used to identify efficient measures and combinations of measures to form the final array of alternatives and ultimately TSP selection. Costs and benefits were developed for 83 management measures across all complexes. Benefits for each ecological measure were determined by the associated model. The final array of alternatives were consolidated into the following categories: Alternative A, Alternative B, and Alternatives C. Alternative A incorporated measures characterized as best buys for habitat diversity from all objectives and all model runs. Alternative B incorporated measures within public lands where real estate acquisition was minimal and only required for construction mobilization and demobilization. Alternative C constituted a range of combinable groupings of measures throughout the geographic complexes where benefit areas were consistent. The measures in the final array of alternatives were evaluated against specified criteria, as stated in Section 2 of the main Integrated Feasibility Report and Environmental Assessment.

The Recommended Plan (TSP) was selected as Alternative C3. The selected TSP is a comprehensive plan to address historically significant and ecologically important habitats across the 11 geographic complexes. The TSP (Alternative C3) includes 38 measures with ecological output and 2 recreational feature measures. Designs and parametric cost estimates were developed for each of the 38 measures and the 2 recreational measures, as follows.

Comprehensive documentation on measure descriptions can also be found in the Habitats Evaluation Appendix.

2.3 LIMITATIONS

The primary limitations are project scope and existing data. The study area is comprised of 39 river miles and thousands of acres of batture land. The proposed features are designed based primarily on aerial imagery and LiDAR, due to time, funding and Right of Entry restrictions required to obtain design level data. This severely limits the accuracy of the quantities and costs. To achieve construction level design, additional time, funding and access will be required to collect the existing data required for a level of confidence acceptable for construction plans and specifications.

2.4 ASSUMPTIONS

Key assumptions made by the technical team for this report include:

- Disposal of excess fill can be made within the project footprint, thus no hauling costs.
- LiDAR and aerial imagery are acceptable for reconnaissance-level design.
- Existing utilities, if any, should be avoided. Detailed survey data was not available to determine the location of utilities. Relocations of sewer and gas lines are prohibitively expensive and shall be minimized or avoided.
- Demolition of existing structures is typically not justified for the anticipated benefits and should be avoided.

2.5 MEASURES CONSIDERED; NOT CARRIED FORWARD

Brainstorming produced approximately 207 possible measures. These were evaluated based on potential performance, costs, environmental considerations, and suitability to the project sponsor. Many proposals dropped out due to navigation concerns, connectivity, poor performance, or ecological objectives. At the end of this exercise, the Team identified 85 measures that would be assigned parametric costs and ran through the IWR Planning Suite. After multiple rounds of CE/ICA, additional measures were removed, resulting in 60 possible measures, combined into Alternatives A, B and C. The Tentatively Selected Plan of C3 contains 40 measures for further design and analysis.

2.6 MEASURES SELECTED

The measures presented below were selected as part of Alternative C3. The geographic location of each measure can be found in the complex specific maps located in Appendix A-1-A Hatchie Loosahatchie Measures by Complex.

2.6.1 Dike Notching

The primary purpose of dike notching, both pile and stone dikes, is to increase connectivity in secondary channels by allowing flow through the dikes at lower river stages. The TSP proposed a total of 11 dike notches, including 8 pile dike notches (Measures Br_01b, I35_7a, S_4d and S_6a) and 3 stone dike notches (Measures Br_01a, Br_01c and RL_3a). Table 2 below provides Measure details.

Table 2. Dike Notching Measures

Measure #	Item #	Complex Name	Long Notes
Br_1	Br_01a	Brandywine	Within Poker Point secondary channel, lower existing stone dike notch.
Br_1	Br_01b	Brandywine	Within Poker Point secondary channel, create notch in pile dike.
Br_1	Br_01c	Brandywine	Within Poker Point secondary channel, lower existing stone dike notch (at +8 LWRP TW 150' BW 50').
I35_7a	I35_7a	Island35_DeanIsland	Notch Pile Dike at Deans Island Secondary Channel. Assume 200-ft width and to depth of riverbed.
I35_7a	I35_7b	Island35_DeanIsland	Notch Pile Dike at Deans Island Secondary Channel. Assume 200-ft width and to depth of riverbed.
I35_7a	I35_7c	Island35_DeanIsland	Notch Pile Dike at Deans Island Secondary Channel. Assume 200-ft width and to depth of riverbed.
I35_7a	I35_7d	Island35_DeanIsland	Notch Pile Dike at Deans Island Secondary Channel. Assume 200-ft width and to depth of riverbed.
I35_7a	I35_7e	Island35_DeanIsland	Notch Pile Dike at Deans Island Secondary Channel - Low priority since it is already notched. Assume 200-ft width and to depth of riverbed.
RL_3	RL_3a	RedmanPoint_LoosahatchieBar	Notch stone dike in secondary channel.
S_4	S_4d	Sunrise_Island34	Increase connectivity of meander scarp by notching old pile dike. Low Flow channel downstream is functioning so not included with S_4
S_6	S_6a	Sunrise_Island34	Increase secondary channel connectivity by notching old pile dike.

The pile dike notches vary in width and will be constructed to an assumed depth equal to the channel bed. Pile dike notch construction would typically consist of a barge mounted excavator that will either push the piles over if possible or cut the piles off at the deepest practicable depth. Stone dike notch construction also consists of barge mounted equipment with the possibility of offloading equipment onto the dike depending on the width of the dike crown. A typical stone dike notch will be constructed to a zero Low Water Reference Plane (LWRP) with a 50-foot bottom width, 150-foot top width and 1V:2.5H side slopes. The stone shall be excavated from the dike in such a fashion as to form an apron of stone on the downstream side of the dike to provide scour protection. Construction costs for stone pile dikes was based on a previous contract for similar work performed in the St. Louis District. A contingency of 30% was assumed to account for varying channel conditions and additional towing costs. Construction costs for stone dike notching was based on the most recent Memphis District Stone Structures MATOC bid for similar work. Geotechnical recommendations are not required for these measures. See Figure 3 below for dike notch locations and Figure 4 for a typical stone dike notch detail.

Figure 2. Typical Stone Dike Notch Detail

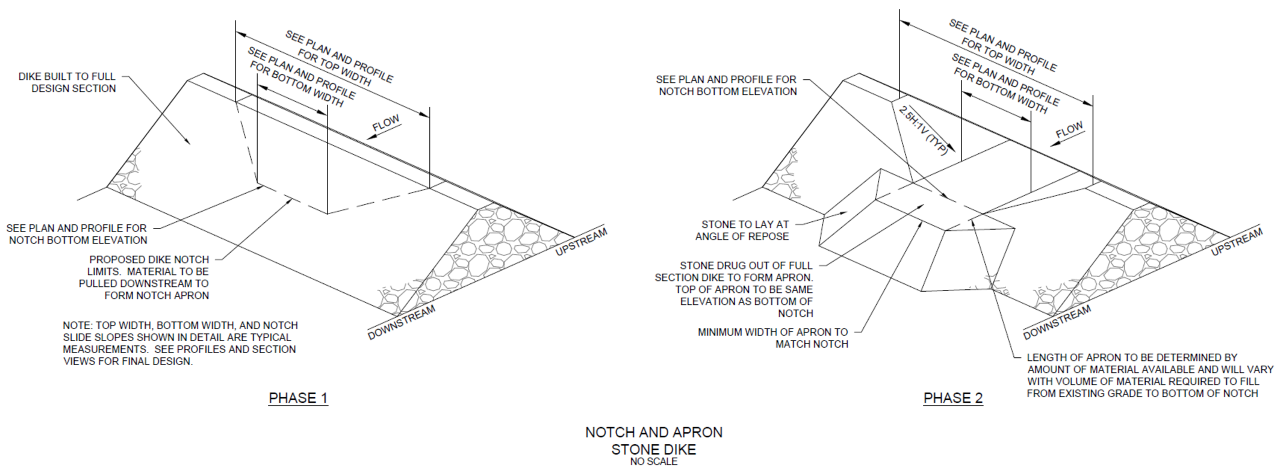
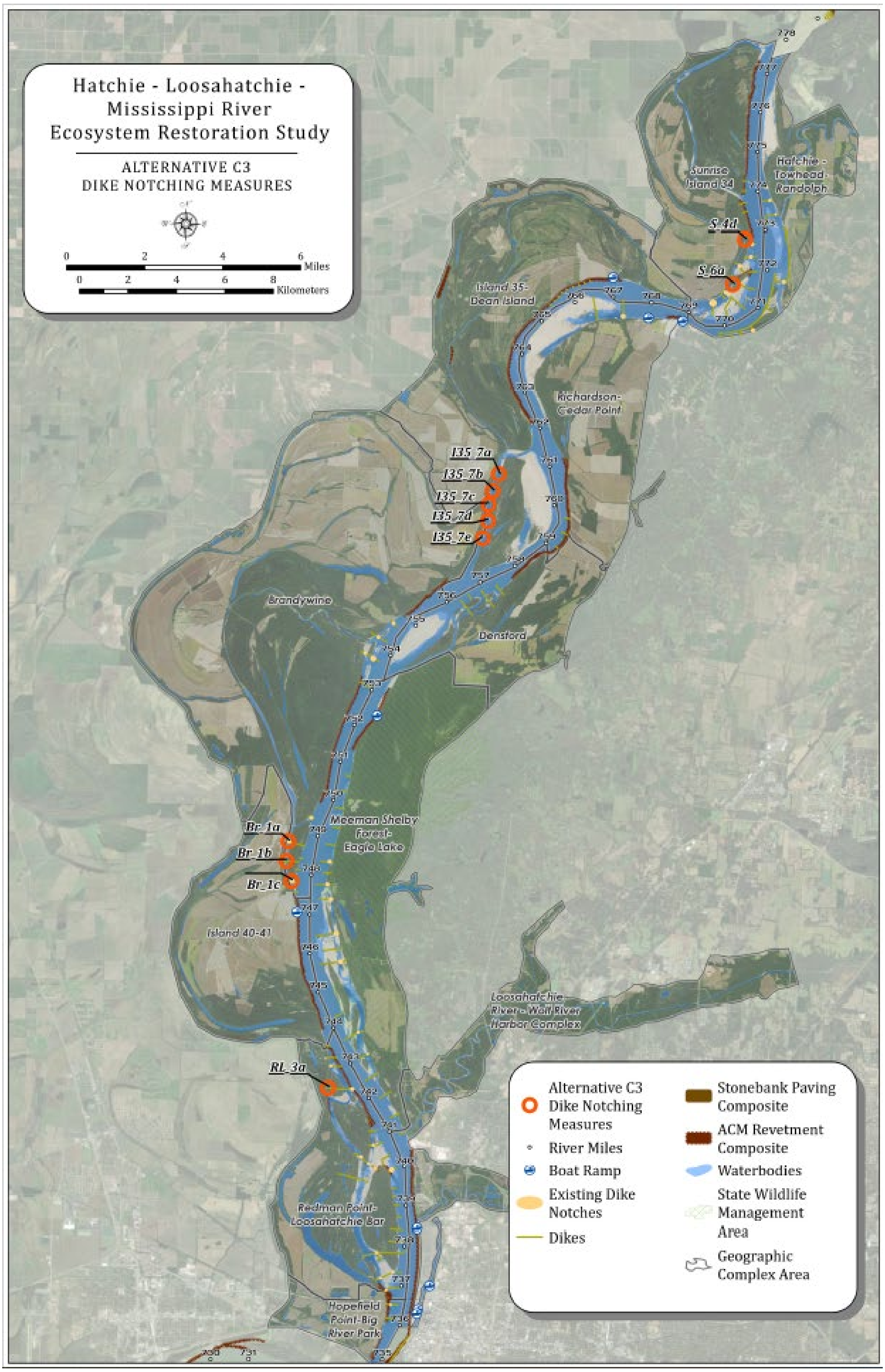


Figure 3. Dike Notch Locations



2.6.2 Woody Debris Traps

The primary purpose of a woody debris trap is to collect drifting wood as it floats downstream. The trapped debris creates a diverse habitat for fish and macroinvertebrates. The TSP proposed a total of 5 woody debris traps (Measures Br_02a, D_3, M_14, RL_6a and S_7a). Table 3 below provides Measure details.

Table 3. Woody Debris Trap Measures

Measure #	Item #	Complex Name	Long Notes
Br_2	Br_02a	Brandywine	Install woody debris traps to enhance invertebrate diversity in secondary channel.
D_3	D_3	Densford	Install wood traps to enhance aquatic invertebrate diversity.
M_14	M_14	MeemanShelbyForest_EagleLake	Install woody debris traps for aquatic invertebrates.
RL_6	RL_6a	RedmanPoint_LoosahatchieBar	Install large woody debris traps in Loosahatchie Bar secondary channel along erosional outside bend without causing bank scour.
S_7	S_7a	Sunrise_Island34	Install large woody debris traps to promote aquatic macroinvertebrates in secondary channels.

Woody debris traps would be constructed from barge mounted equipment. Wooden piles are driven in strategic locations utilizing three, 40-50 foot wood pilings, driven in a “V” shape, approximately 3-5 meters apart. The traps are placed in permanently or near-permanently flowing water in proximity of the island side of secondary channels. The top elevation of the piles shall be no higher than the controlling dike elevation of the secondary channel. Safety signage and/or buoys will be utilized for navigational safety. Woody Debris Trap construction procedures and costs are based on the assumed procedures and costs associated with the pilot project at Prairie Point, which were developed by Engineering, in conjunction with specialists from ERDC and LMRCC. Safety signage is considered incidental to construction. Geotechnical recommendations are not required for these measures. See Figure 4 below for a woody debris trap detail and Figure 5 for trap locations.

Figure 4. Typical Woody Debris Trap Detail

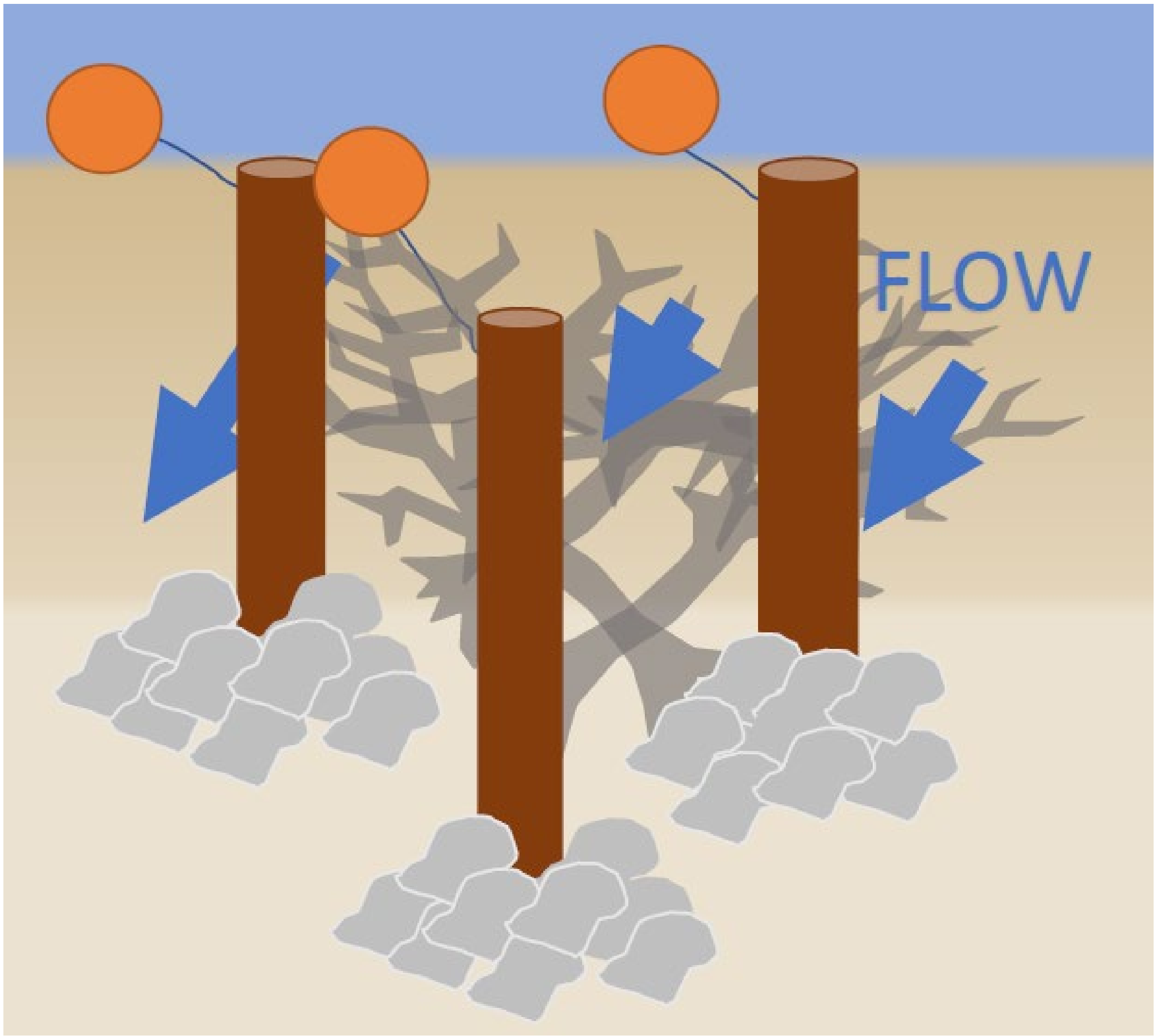
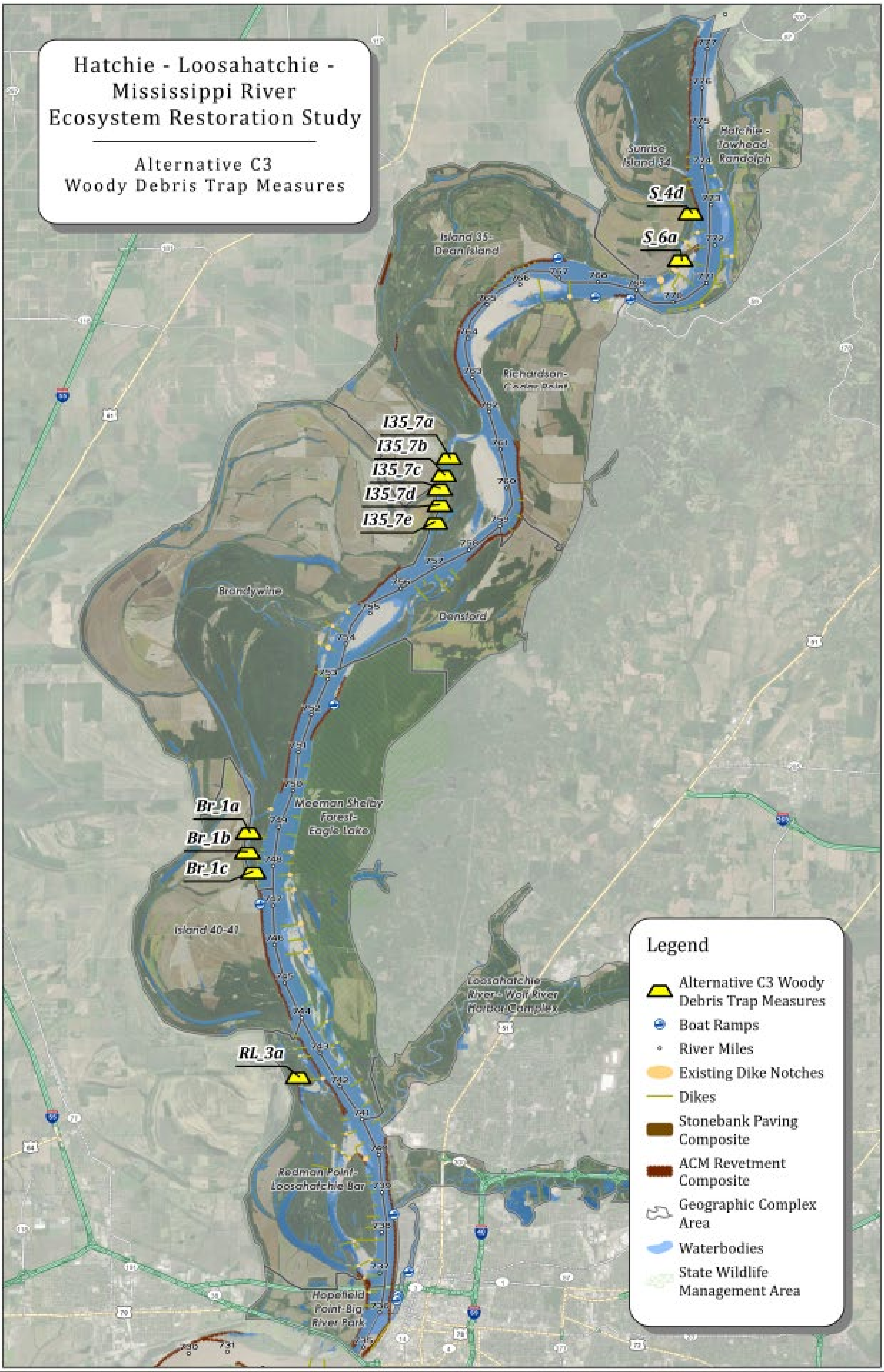


Figure 5. Woody Debris Trap Locations



2.6.3 Riprap Bank Protection

The primary purpose of riprap bank protection is to prevent future bank line erosion and forested buffer degradation. The TSP proposed a total of two bank protection measures, one riprap bank paving (Measure Br_05a) and one set of riprap hardpoints (Measure I35_7g). Table 4 below provides Measure details.

Table 4. Riprap Bank Protection Measures

Measure #	Item #	Complex Name	Long Notes
Br_5	Br_05a	Brandywine	Install riprap bank paving to reduce bank erosion within Brandywine Chute; qualitative benefits help to preserve the scarce oak dominated high ridge bankline (important for Neotropical migrants such as Swainson's Warblers).
I35_7g	I35_7g	Island35_DeanIsland	Add 10 hardpoints for 2000 linear feet to protect eroding bankline and adjacent forested buffer. Bankline has eroded over 200' since 2007 adding sediment to Deans 2nd channel and reducing forest buffer.

For both measures, it is assumed work can be completed from the channel. The riprap bank paving measure shall be constructed in the Brandywine chute to prevent bank line erosion and preserve the scarce oak dominated high ridge, which is important for neotropical migrants such as Swainson's Warblers. Mature oak stands are very limited within the batture of the Mississippi River. Due to cost effectiveness and velocities, riprap bank paving was selected over riprap hard points for this measure. The construction consists of 2,200 linear feet of bank paving, 50 feet wide from top bank riverward at a thickness of 2'. A stone gradation of R200 (200-pound riprap) will be utilized. It is assumed that 2 acres of clearing may be required to access the site or place equipment at top bank. Geotechnical recommendations may be required during PED for slope stability analysis. See Figure 6 and Figure 7 below for construction details.

Figure 6. Plan View of Riprap Bank Protection for Measure Br_05a

Figure 7. Typical Section of Riprap Bank Protection for Measure Br_05a

The riprap hard point measure shall be constructed in the Island 35 chute to prevent bank line erosion and preserve the forested buffer. The construction consists of 10 hard points, covering approximately 2,000 linear feet. The hard points shall be constructed utilizing a 6-foot crown, with 1V:2.5H side slopes and 30-foot top length at 200 foot spacing. Assume 1,600 tons of 250-pound riprap per hard point. Geotechnical recommendations are not required for this measure. See Figure 8 and Figure 9 below for construction details.

Figure 8. Plan View of Riprap Hardpoints for Measure I35_7g

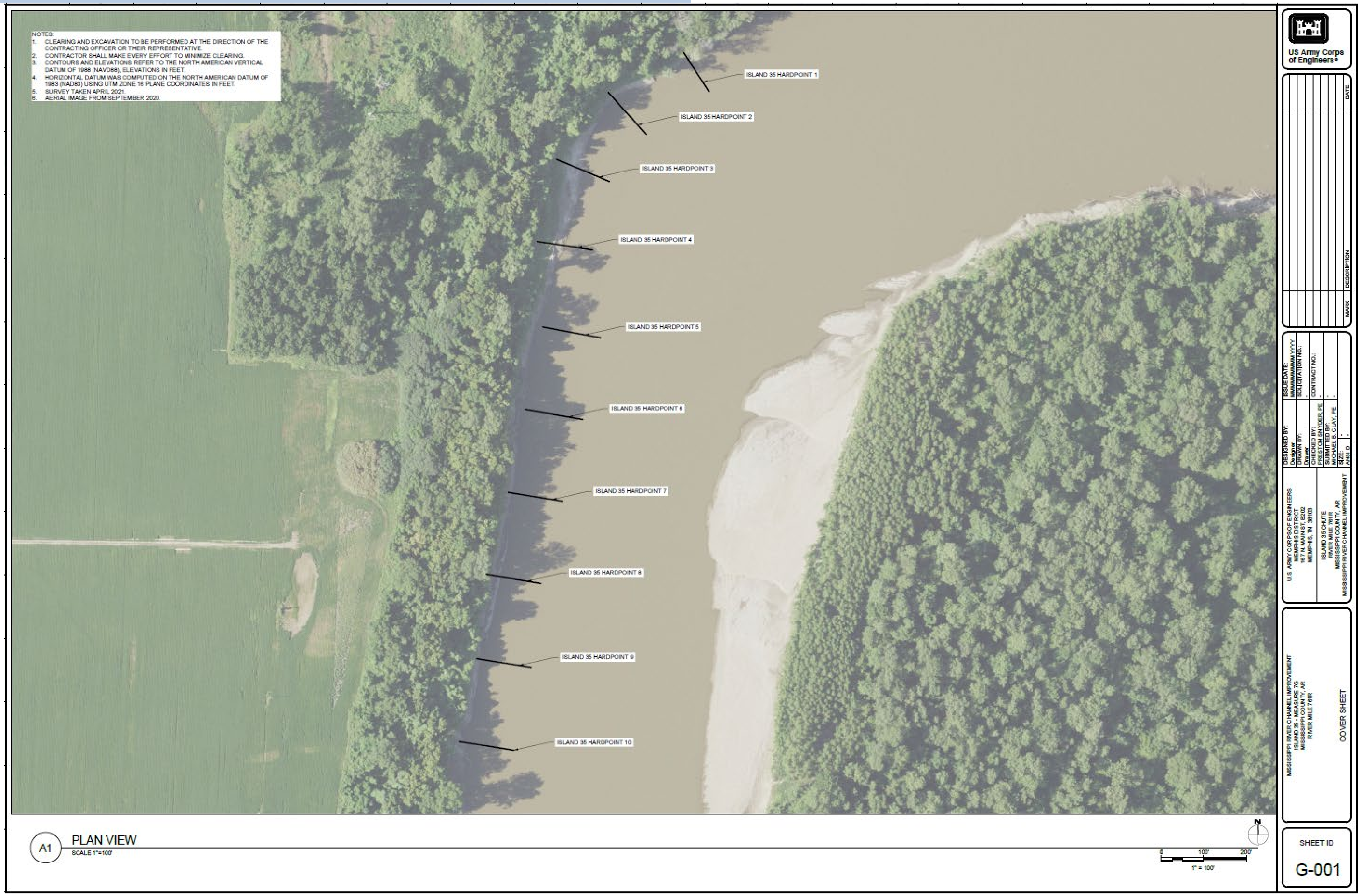
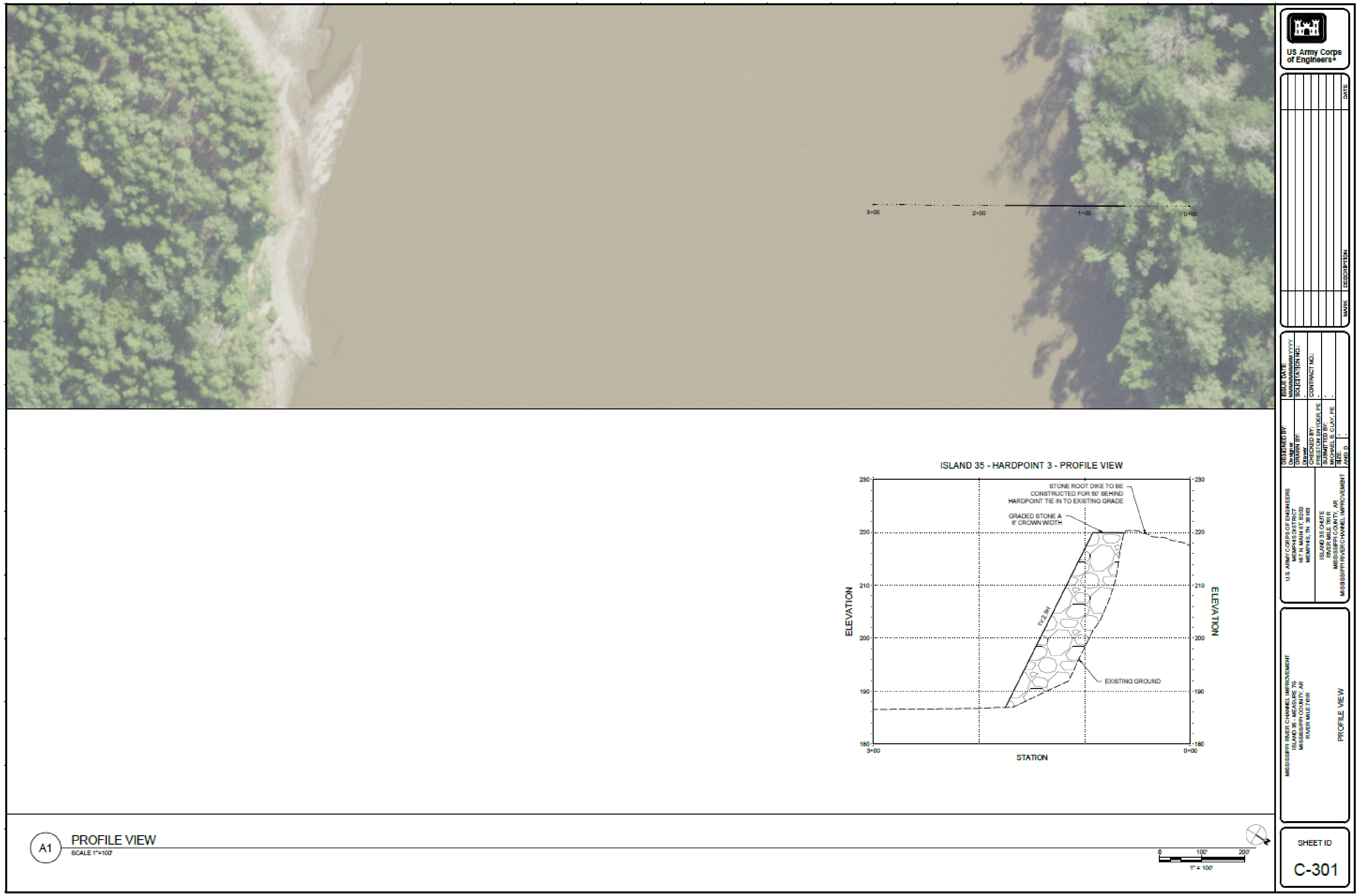


Figure 9. Typical Section of Riprap Hardpoints for Measure I35_7g



2.6.4 River Training Structures

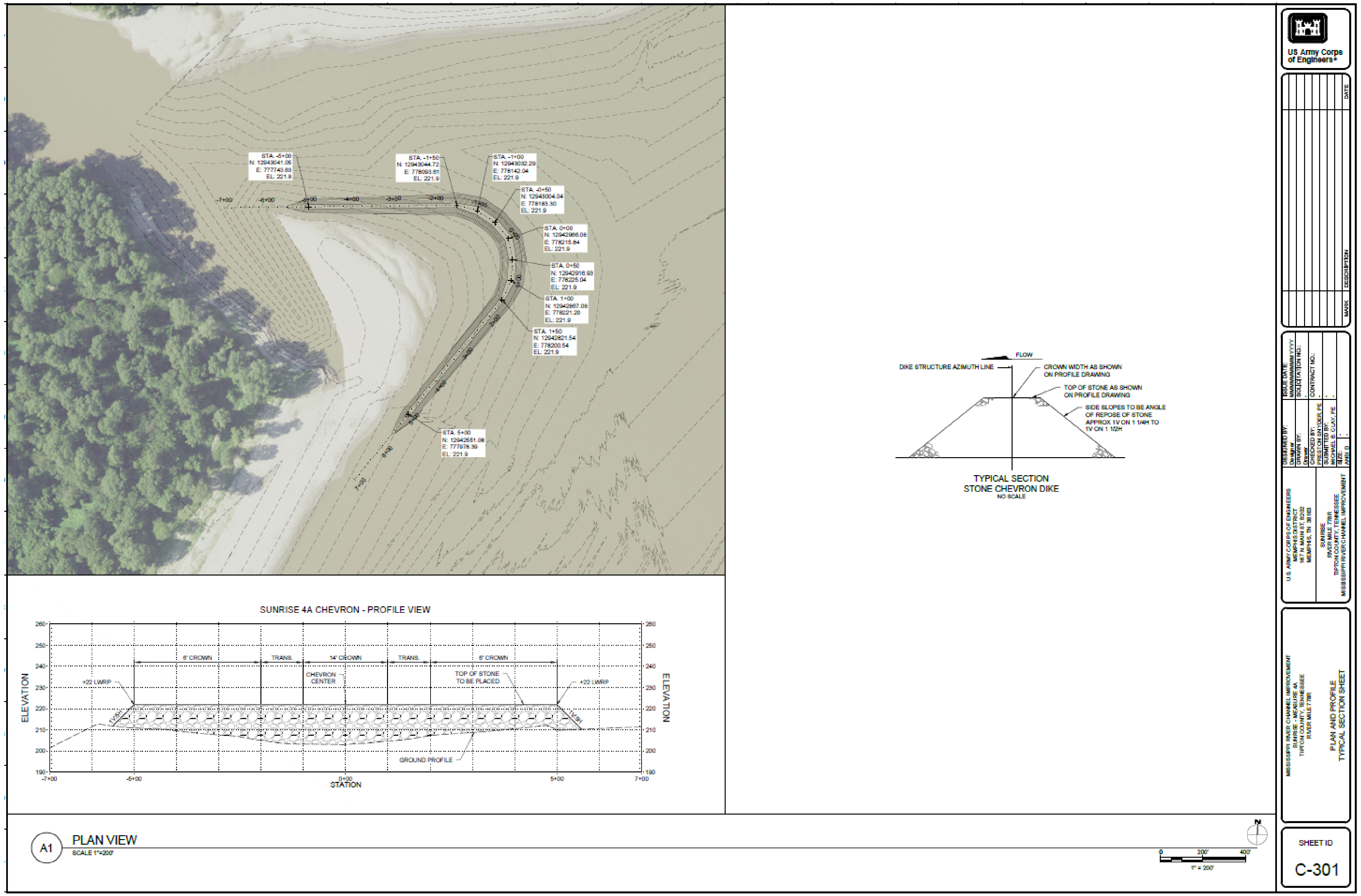
The primary purpose of river training structures is to maintain a navigation channel by directing flow and altering channel geomorphology. However, there are ancillary environmental benefits of certain types of structures, such as redirecting flow into secondary channels and creating diverse fish habitat. The TSP proposed a total of one river training structure measures (Measure S_4a). Table 5 below provides Measure details.

Table 5. River Training Structure Measures

Measure #	Item #	Complex Name	Long Notes
S_4	S_4a	Sunrise_Island34	Install RTS (chevron) to divert flow into Meander Scarp to increase connectivity.

The river training structure measure shall be a chevron constructed at the upstream entrance to the Sunrise chute to divert additional water into the chute at various river stages. The construction consists of 1 stone chevron. The chevron shall be constructed utilizing a varying crown width from 6 to 14 feet, with 1V:1.25H side slopes, and 1V: 5H end slopes for approximately 1,000 linear feet. Assume 24,800 tons of Graded Stone C riprap. Geotechnical recommendations are not required for this measure. See Figure 10 below for construction details.

Figure 10. Chevron Layout for Measure S_4a



2.6.5 Weirs and Stoplog structures

Weirs can be used regulate water elevations by controlling the energy and velocity of the water as it passes over or through the structure. The TSP proposed a total four water control structures (Measure Br_4b, HB_2a, M_5 and M_6), including 3 rock weirs and 1 stoplog structure. It is currently assumed that geotechnical exploration is not required for grade control measures. Table 6 below provides Measure details.

Table 6. Weir and Stoplog structures

Measure #	Item #	Complex Name	Long Notes
Br_4	Br_04b	Brandywine	Install weir at the mouth of McKenzie Chute to prevent water levels from falling below existing lows (i.e., maintain this floodplain waterbody while restoring downstream meander scarp activities in Item BR_04a).
HB_2ab	HB_2a	HopefieldPoint_BigRiverPark	Degrade rock weir to connect to non-forested permanent water and non-forested wetland to HB_1. Downstream Floodplain waterbody is 8 acres (A. gar habitat is 47 acres). HB_2a, b, and c will be merged for TSP selection.
M_5	M_5	MeemanShelbyForest_EagleLake	Install weir 2-ft higher to back up water onto upstream depression to promote cypress tupelo by controlling of unwanted species included with adaptative management (qualitative - while maintain Alligator gar access).
M_6	M_6	MeemanShelbyForest_EagleLake	Stop log structure and groundwater well to control water on fallow field for waterfowl and shorebirds (qualitative-potential benefits to Alligator gar).

The proposed rock weir for Measure Br_04b shall be constructed at the mouth if McKenzie Chute to regulate water levels between McKenzie Chute and the Brandywine Channel. The weir shall be constructed approximately 80 feet long of a minimum 4-foot thickness of R400 riprap with a 10-foot crown width and 1V:1.5H side slopes. See Figure 11 below for construction details.

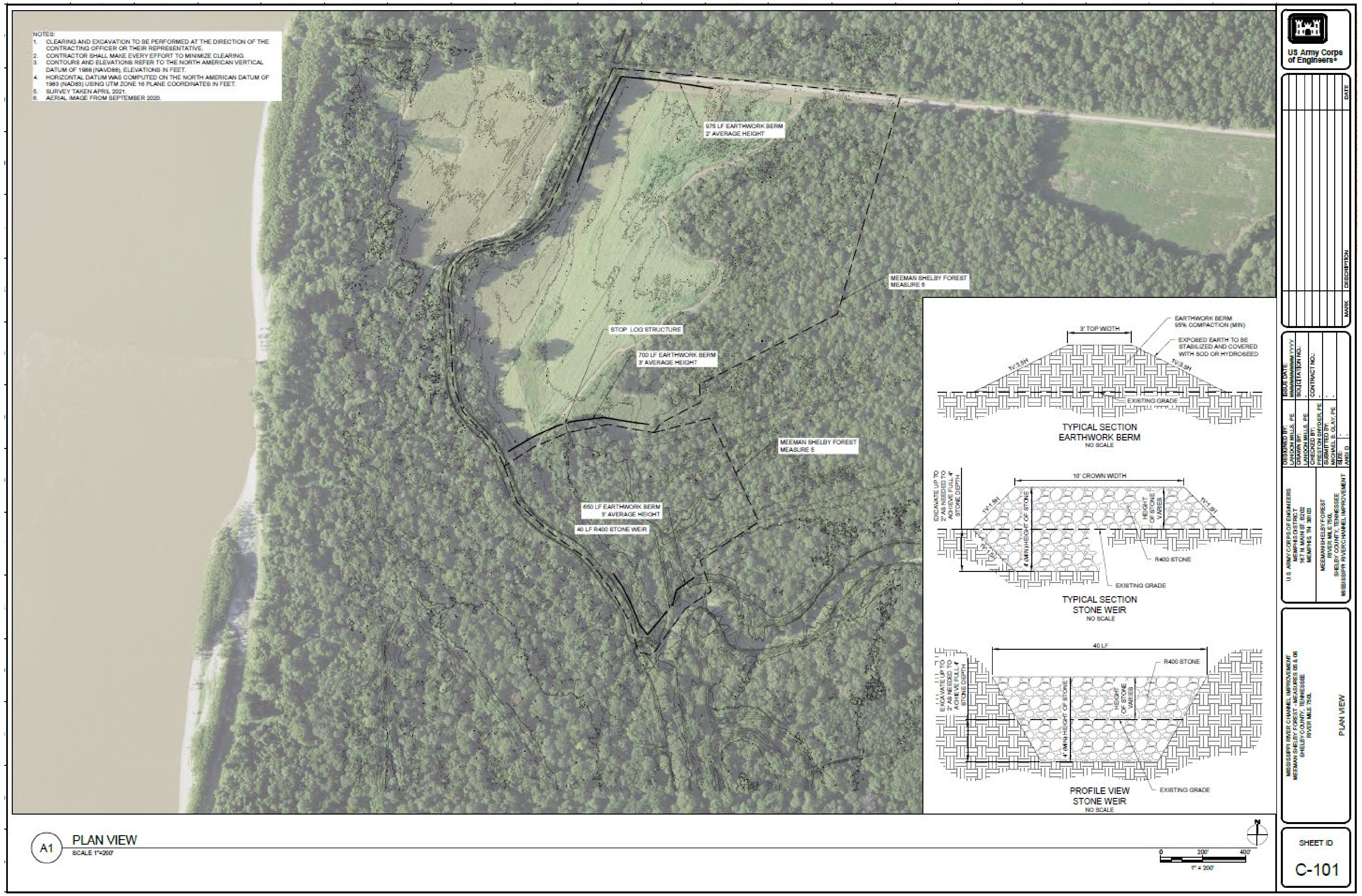
Figure 11. Weir Design for Measure Br_04b

The proposed rock weir for Measure HB_2a shall be degraded to connect non-forested permanent water and non-forested wetland to Measure HB_1. The weir shall be degraded for approximately 200 feet long and 8 feet deep (assuming the existing rock weir is at elevation 212 feet). The remaining riprap shall be reshaped with R400 riprap ensuring a 20-foot crown width and 1V:1.5H side slopes remain. See Figure 12 below for construction details.

Figure 12. Weir Design for Measure HB_2a

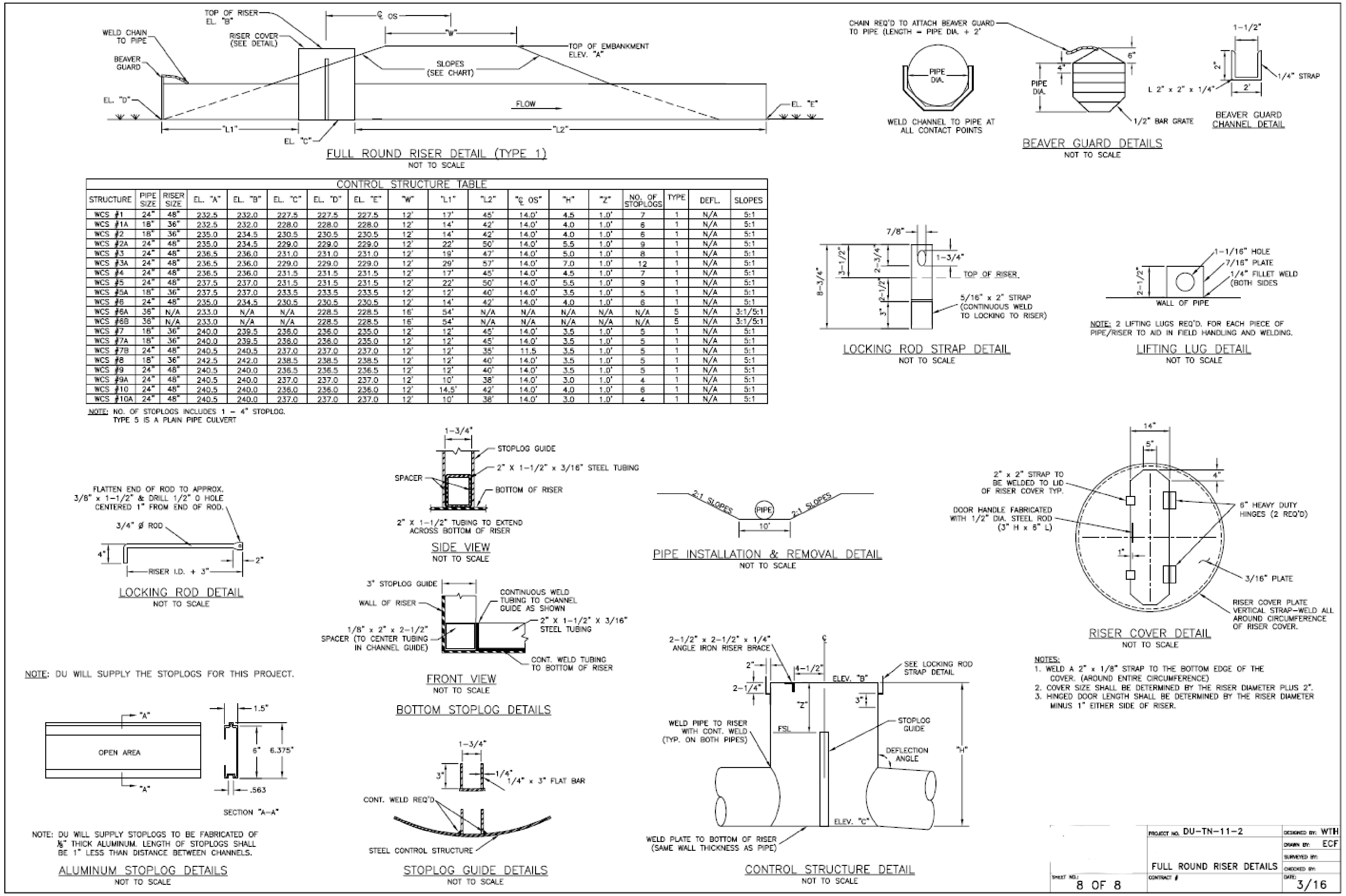
The proposed rock weir for Measure M_5 shall be constructed to a higher elevation to back up water higher onto upstream depression, promoting cypress tupelo, while maintaining alligator gar access. The weir addition shall be constructed approximately 40 feet long and 4 feet deep of R400 riprap with a 10-foot crown width and 1V:1.5H side slopes. The existing weir will be degraded by 2 feet to get a full grade and section of R400 stone. See Figure 13 below for construction details.

Figure 13. Weir Design for Measure M_5



The proposed stop log structure for Measure M_6 shall be constructed to control water on fallow field for waterfowl and shorebirds. Site managers indicated that water moves onto the fields adjacent to M_6 and M_7 around +30 to +32 feet on the Memphis gage. Due to the high inundation elevation, the field adjacent to M_6 would be suitable for Alligator Gar in high water years or if site managers maintain water on the site using water control structures. For this reason, a stop log structure, utilizing wooded timbers, in conjunction with a groundwater well, shall be constructed to pond water to height of 4 feet allowing the existing herbaceous site to be managed as a wetland. See Figure 14 below for standard West TN stop log structure construction details.

Figure 14. Typical Stop Log Structure Design for Measure M_6



CONTROL STRUCTURE TABLE

STRUCTURE	PIPE SIZE	RISER SIZE	EL. "A"	EL. "B"	EL. "C"	EL. "D"	EL. "E"	"W"	"L1"	"L2"	"℄ OS"	"H"	"Z"	NO. OF STOPLOGS	TYPE	DEFL.	SLOPES
WCS #1	24"	48"	232.5	232.0	227.5	227.5	227.5	12'	17'	45'	14.0'	4.5	1.0'	7	1	N/A	5:1
WCS #1A	18"	36"	232.5	232.0	228.0	228.0	228.0	12'	14'	42'	14.0'	4.0	1.0'	6	1	N/A	5:1
WCS #2	18"	36"	235.0	234.5	230.5	230.5	230.5	12'	14'	42'	14.0'	4.0	1.0'	6	1	N/A	5:1
WCS #2A	24"	48"	235.0	234.5	229.0	229.0	229.0	12'	22'	50'	14.0'	5.5	1.0'	9	1	N/A	5:1
WCS #3	24"	48"	236.5	236.0	231.0	231.0	231.0	12'	19'	47'	14.0'	5.0	1.0'	8	1	N/A	5:1
WCS #3A	24"	48"	236.5	236.0	229.0	229.0	229.0	12'	29'	57'	14.0'	7.0	1.0'	12	1	N/A	5:1
WCS #4	24"	48"	236.5	236.0	231.5	231.5	231.5	12'	17'	45'	14.0'	4.5	1.0'	7	1	N/A	5:1
WCS #5	24"	48"	237.5	237.0	231.5	231.5	231.5	12'	22'	50'	14.0'	5.5	1.0'	9	1	N/A	5:1
WCS #5A	18"	36"	237.5	237.0	233.5	233.5	233.5	12'	12'	40'	14.0'	3.5	1.0'	5	1	N/A	5:1
WCS #6	24"	48"	235.0	234.5	230.5	230.5	230.5	12'	14'	42'	14.0'	4.0	1.0'	6	1	N/A	5:1
WCS #6A	36"	N/A	233.0	N/A	N/A	228.5	228.5	16'	54'	N/A	N/A	N/A	N/A	N/A	5	N/A	3:1/5:1
WCS #6B	36"	N/A	233.0	N/A	N/A	228.5	228.5	16'	54'	N/A	N/A	N/A	N/A	N/A	5	N/A	3:1/5:1
WCS #7	18"	36"	240.0	239.5	236.0	236.0	235.0	12'	12'	45'	14.0'	3.5	1.0'	5	1	N/A	5:1
WCS #7A	18"	36"	240.0	239.5	236.0	236.0	235.0	12'	12'	45'	14.0'	3.5	1.0'	5	1	N/A	5:1
WCS #7B	24"	48"	240.5	240.5	237.0	237.0	237.0	12'	12'	35'	11.5	3.5	1.0'	5	1	N/A	5:1
WCS #8	18"	36"	242.5	242.0	238.5	238.5	238.5	12'	12'	40'	14.0'	3.5	1.0'	5	1	N/A	5:1
WCS #9	24"	48"	240.5	240.0	236.5	236.5	236.5	12'	12'	40'	14.0'	3.5	1.0'	5	1	N/A	5:1
WCS #9A	24"	48"	240.5	240.0	237.0	237.0	237.0	12'	10'	38'	14.0'	3.0	1.0'	4	1	N/A	5:1
WCS #10	24"	48"	240.5	240.0	236.0	236.0	236.0	12'	14.5'	42'	14.0'	4.0	1.0'	6	1	N/A	5:1
WCS #10A	24"	48"	240.5	240.0	237.0	237.0	237.0	12'	10'	38'	14.0'	3.0	1.0'	4	1	N/A	5:1

NOTE: NO. OF STOPLOGS INCLUDES 1 – 4" STOPLOG.
TYPE 5 IS A PLAIN PIPE CULVERT

2.6.6 Culverts

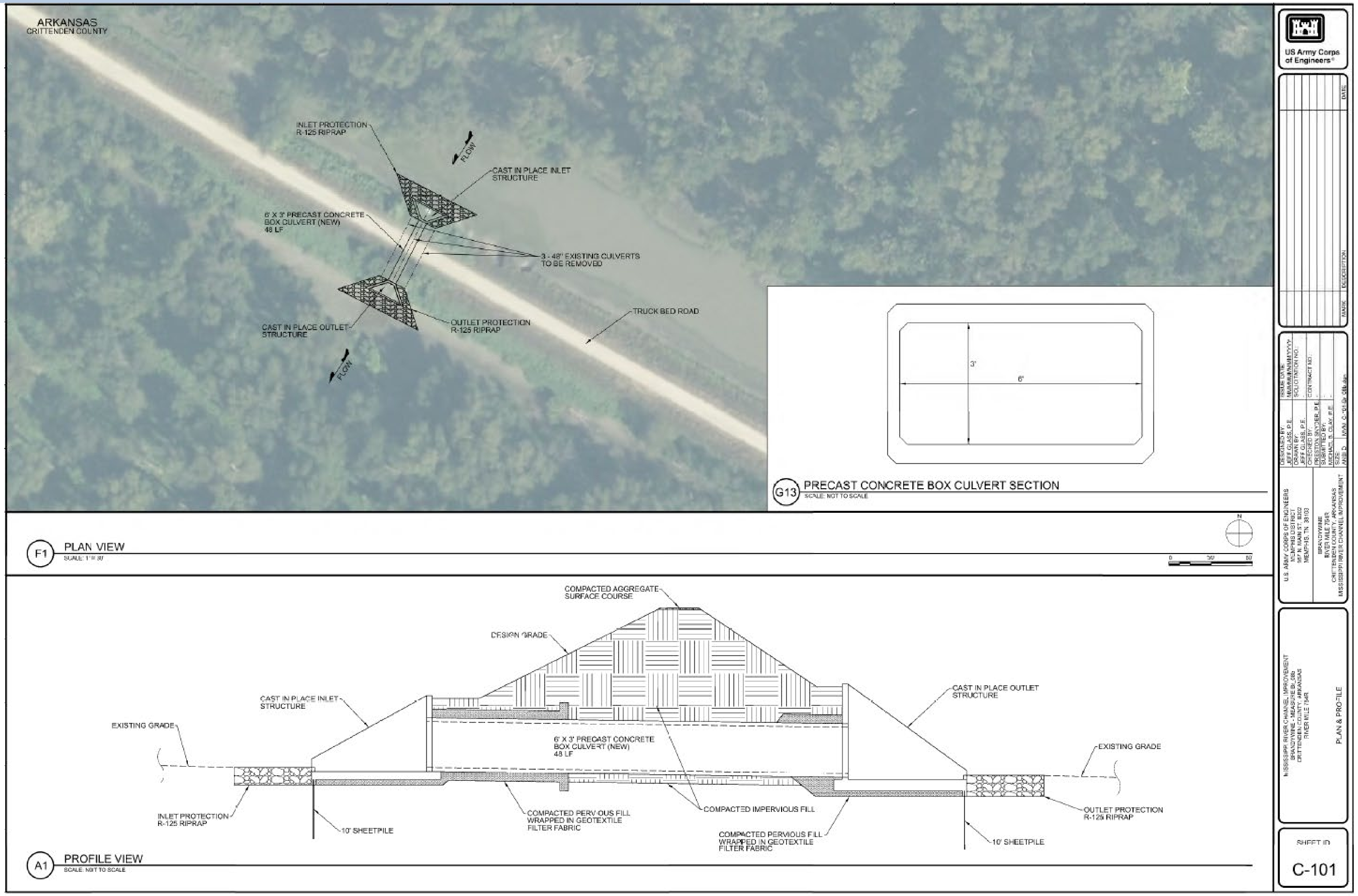
The primary purpose of culverts is to serve as hydraulic conduits, conveying water from one location to another, generally through an embankment that ponds water. The TSP proposed a total of five culvert measures (Measure Br_8b, Br_11a, HB_2b, I40_1b1 and RCP_2a), including 1 concrete box culvert, 3 corrugated metal pipe (CMP) culverts and 1 aluminum flap gate replacement. Culverts were sized to utilize the largest feasible culvert diameter based on LiDAR elevations to allow for the largest amount of connectivity and fish passage. It is currently assumed that geotechnical recommendations are not expected for culvert measures. In many areas the study team does not have adequate data to determine the culvert sizes and borings have been indicated as not feasible to obtain. If Geotechnical recommendations are required for these alternatives, a boring or sub surface investigation of will be required, and design requirements set forth by of EM 1110-1-1904 Settlement Analysis and EM 1110-1-1905 Bearing Capacity of Soils will need to be met. Table 7 below provides Measure details.

Table 7. Culvert Measures

Measure #	Item #	Complex Name	Long Notes
Br_8	Br_08b	Brandywine	Replace 3-48" culverts with 1-6x3 box culvert to facilitate debris passage to reduce ponding in upstream forest; includes additional plantings to promote mast producing trees and neotropical migrants (41 acres planting ~ 20% of total benefit acreage).
Br_11	Br_11a	Brandywine	Install flap gate on existing thick steel culvert (5ft diam.) which drains the southeastern 1/3 of Brandywine Island to reduce forest inundation frequency and promote mast producing trees; includes additional plantings to promote mast producing trees and neotropical migrants (120 acres planting ~ 20% of total benefit acreage).
HB_2ab	HB_2b	HopefieldPoint_BigRiverPark	Install larger culverts to improve connectivity to HB_1 for A Gar et al. Downstream Floodplain waterbody is 8 acres (A. gar habitat is 47 acres). HB_2a, b, and c will be merged for TSP selection.
I40_1b	I40_1b1	Island40_41	Improve upstream connectivity to increase fish access, enhance habitat, and reduce sediment and nutrient inputs. Lower culvert invert to increase connectivity.
RCP_2	RCP_2a	Richardson_CedarPoint	Purchase 115 acres and seed wetlands with an emergent seed mix; (allowing for 25 acres of LMVJV forest through natural succession and 90 Acres alligator Gar HSI-non- Forest marsh); lower invert of culvert 3' and cleanout channel (for alligator gar).

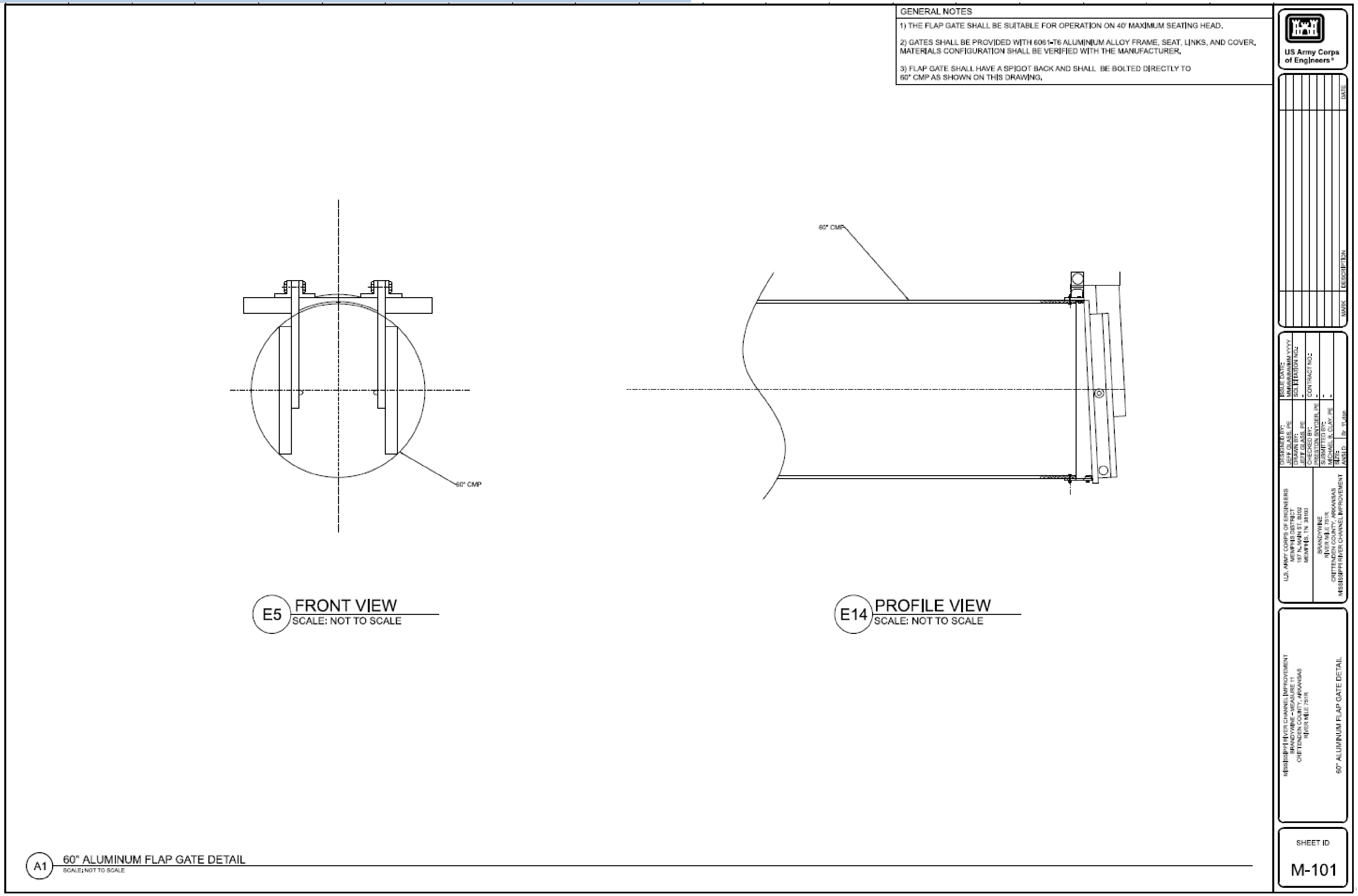
The proposed work for Measure Br_08b shall be the demolition and replacement of 3 existing 48” CMPs with a single 6x3 concrete box culvert to facilitate debris passage to reduce ponding in the upstream forest, promoting mast producing trees and neotropical migrants. The concrete box culvert shall be 48 linear feet with inlet and outlet R125 riprap protection. Once the culvert has been replaced, compacted impervious fill and aggregate road surface shall be replaced in kind. See Figure 15 below for construction details.

Figure 15. Concrete Box Culvert Design for Measure Br_08b



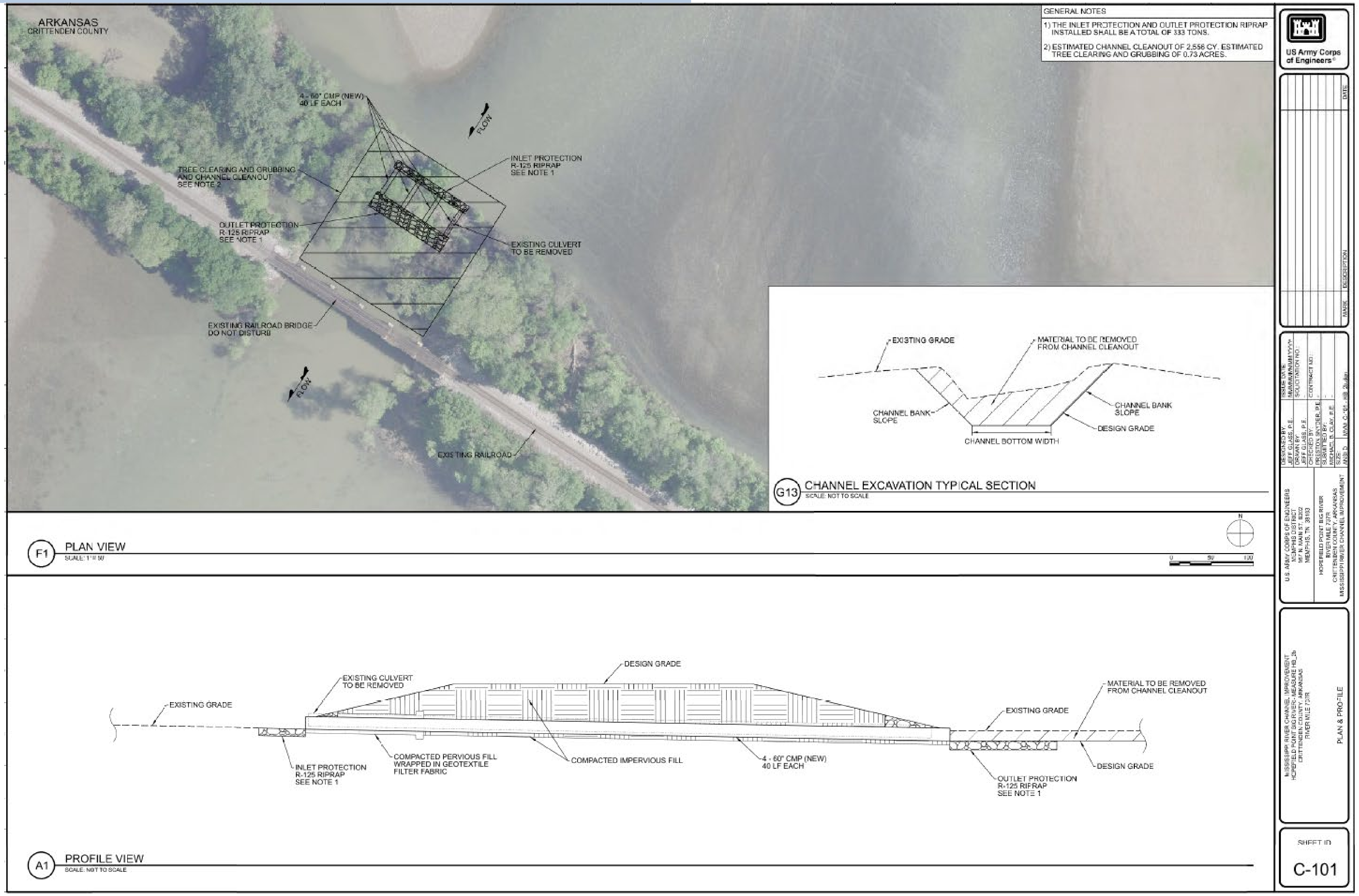
The proposed work for Measure Br_11a shall be the replacement of an existing steel culvert flap gate with a new aluminum flap gate. The culvert is assumed to be 60 inches with an existing malfunctioning flap gate. This culvert drains nearly one third of the southeastern portion of Brandywine Island; therefore, this measure will reduce forest inundation frequency and promote mast producing trees. See Figure 16 below for construction details.

Figure 16. Typical Flap Gate Detail for Measure Br_11a



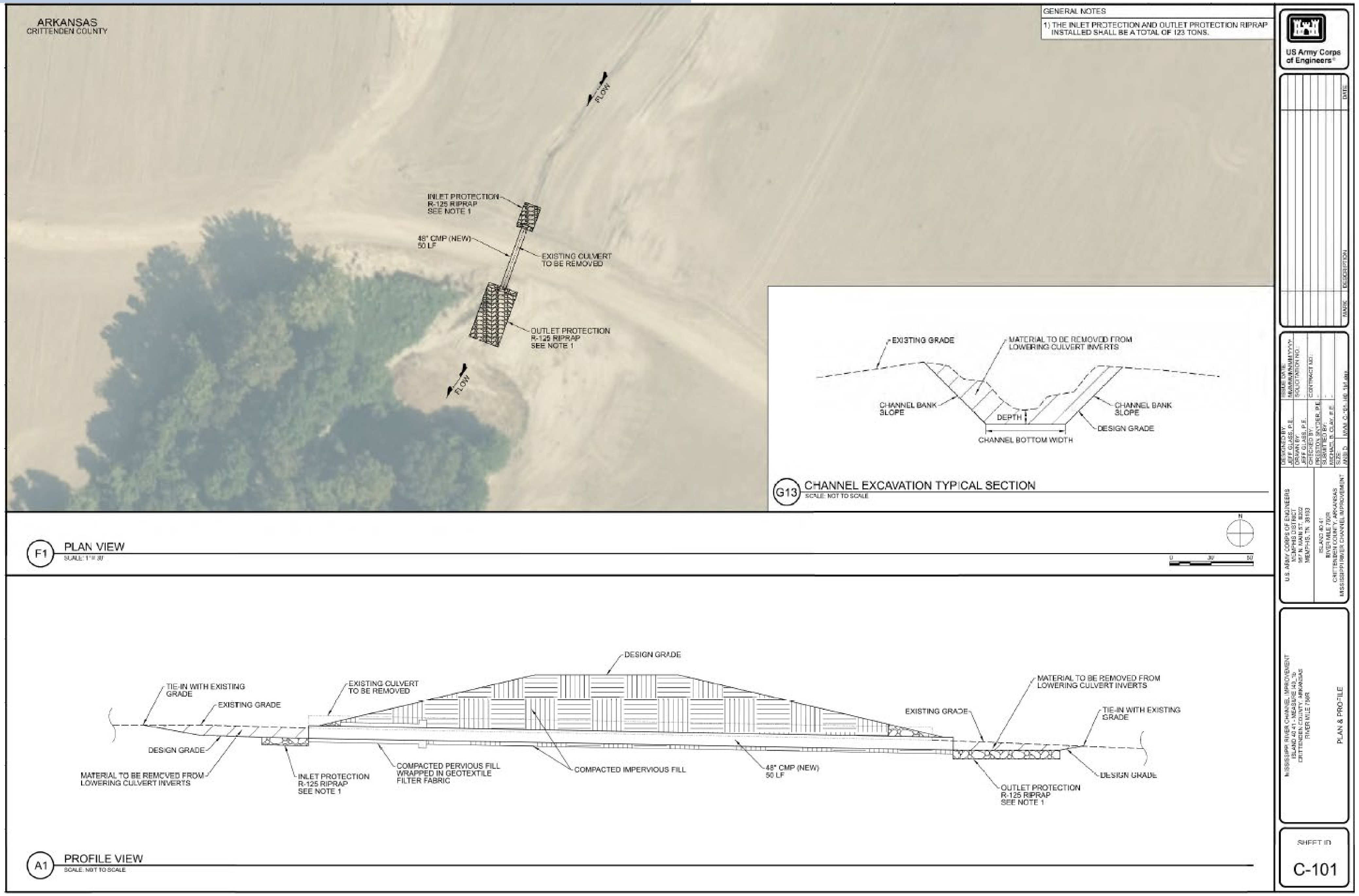
The proposed work for Measure HB_2b shall be the installation of 4 new culverts to improve connectivity to Measure HB_1 for alligator gar and other fish species. The new culverts shall be 40 linear feet each of 60" CMPs with 333 tons of R-125 riprap inlet and outlet protection. Approximately 2,500 cubic yards of excavation will be required downstream of the culverts, connecting the flow path under the railroad bridge. See Figure 18 below for construction details.

Figure 17. CMP Design for Measure HB_2b



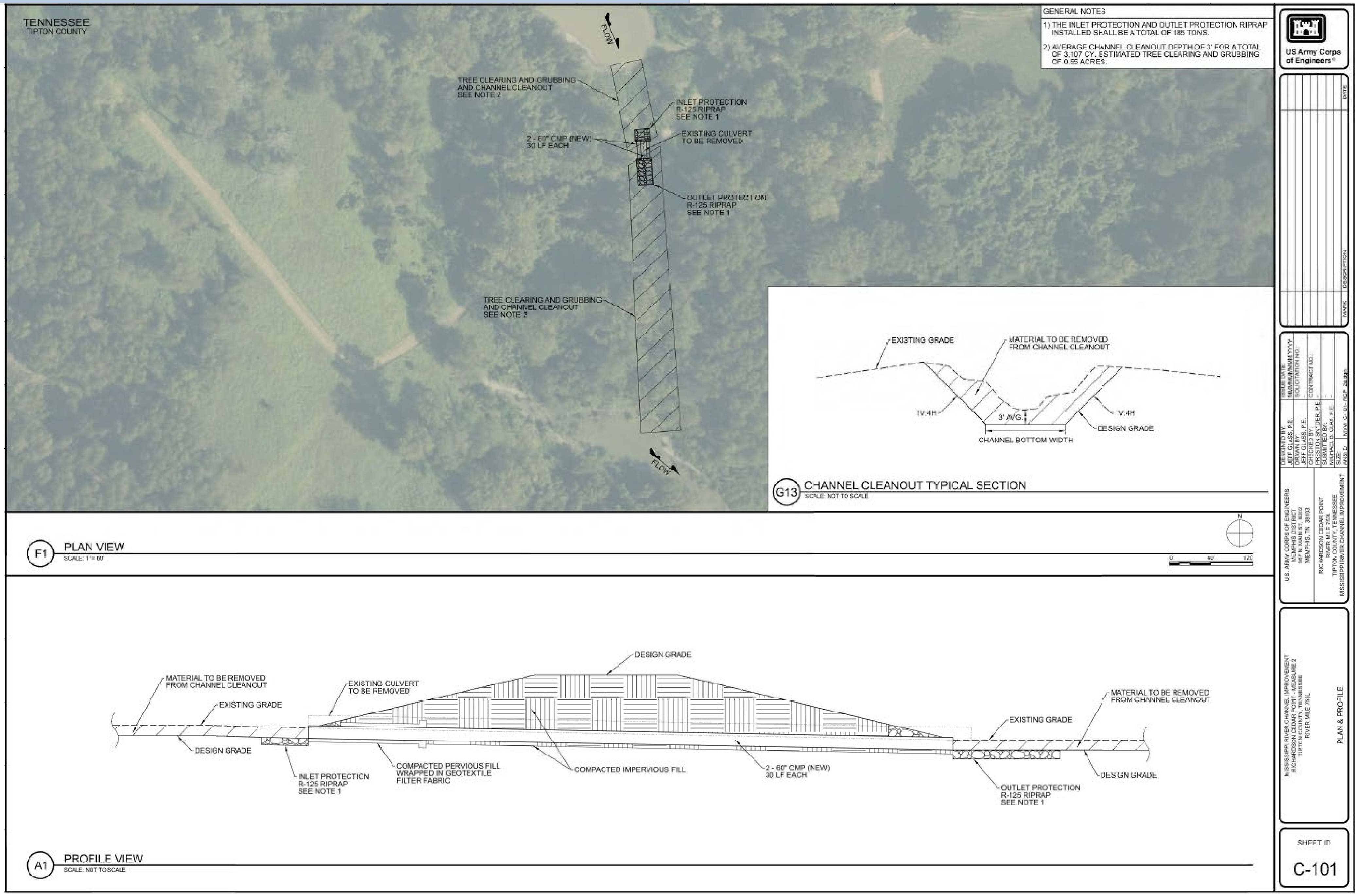
The proposed work for Measure I40_1b1 shall be the installation of a new culvert to improve upstream connectivity increasing fish access, enhancing habitat, and reducing nutrient inputs. The new culvert shall be 50 linear feet of a single 48" CMP with 123 tons of R-125 riprap inlet and outlet protection. See Figure 19 below for construction details.

Figure 18. CMP Design for Measure I40-1b1



The proposed work for Measure RCP_2a shall be the demolition of an existing culvert and the installation of 2 new culverts to improve connectivity for alligator gar and other fish species habitat. The new culverts shall be 30 linear feet each of 60" CMPs with 185 tons of R-125 riprap inlet and outlet protection. Approximately 3,100 cubic yards of excavation and an acre of clearing will be required downstream of the culverts to connect the flow paths. See Figure 20 below for construction details.

Figure 19. CMP Design for Measure RCP_2a



2.6.7 Earthwork

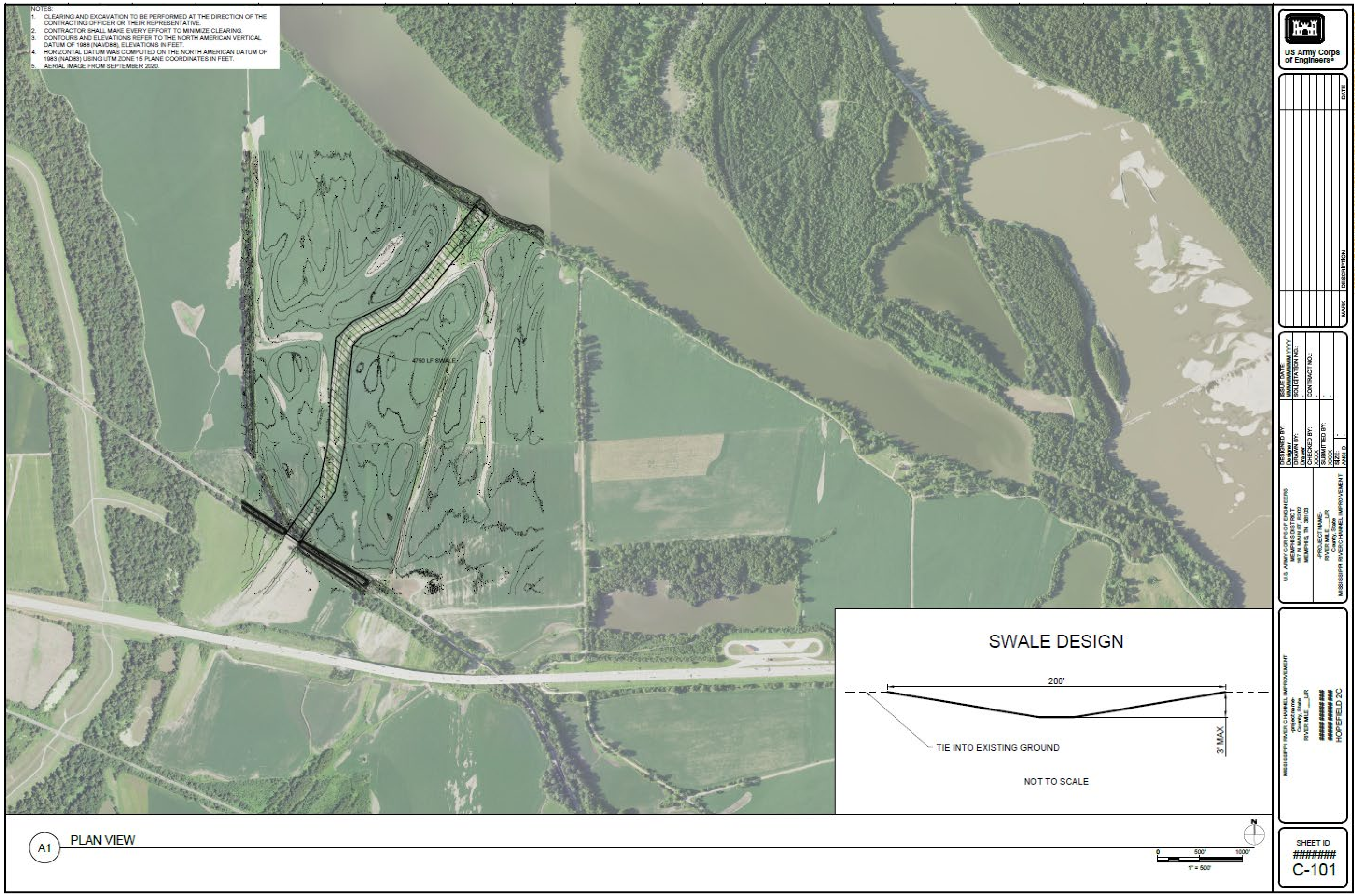
Earthwork generally consists of channel excavation, berm construction and miscellaneous excavation associated with other measures. Numerous measures throughout the study area have a minimal amount of excavation required to construct the measure. This excavation would be completed with standard excavation equipment. The primary purpose of channel excavation is to remove sedimentation, increasing connectivity. The primary purpose of the berm construction is ponding of water for certain moist soil management practices. The TSP proposed a total of five earthwork measures (Measures HB_2c, I40_1b2, M_5, M_6 and S_4c), including 2 swales, 1 channel cleanout and 2 earthen berms. Table 8 below provides Measure details.

Table 8. Earthwork Measures

Measure #	Item #	Complex Name	Long Notes
HB_2c	HB_2c	HopefieldPoint_BigRiverPark	Establish swale/acquire non-productive farmland (22 acres = dimensions of ~4750 ft length x ~210 ft.avg. width) to connect non-forested downstream area to HB_1 for A Gar. HB_2a, b, and c will be merged for TSP selection.
I40_1b	I40_1b2	Island40_41	Improve upstream connectivity to increase fish access, enhance habitat, and reduce sediment and nutrient inputs. Excavate swale.
M_5	M_5	MeemanShelbyForest_EagleLake	Install weir 2-ft higher to back up water onto upstream depression to promote cypress tupelo by controlling of unwanted species included with adaptative management (qualitative - while maintain Alligator gar access).
M_6	M_6	MeemanShelbyForest_EagleLake	Stop log structure and groundwater well to control water on fallow field for waterfowl and shorebirds (qualitative- potential benefits to Alligator gar).
S_4	S_4c	Sunrise_Island34	Increase meander scarp connectivity by establishing a low flow channel but using excavated material in place.

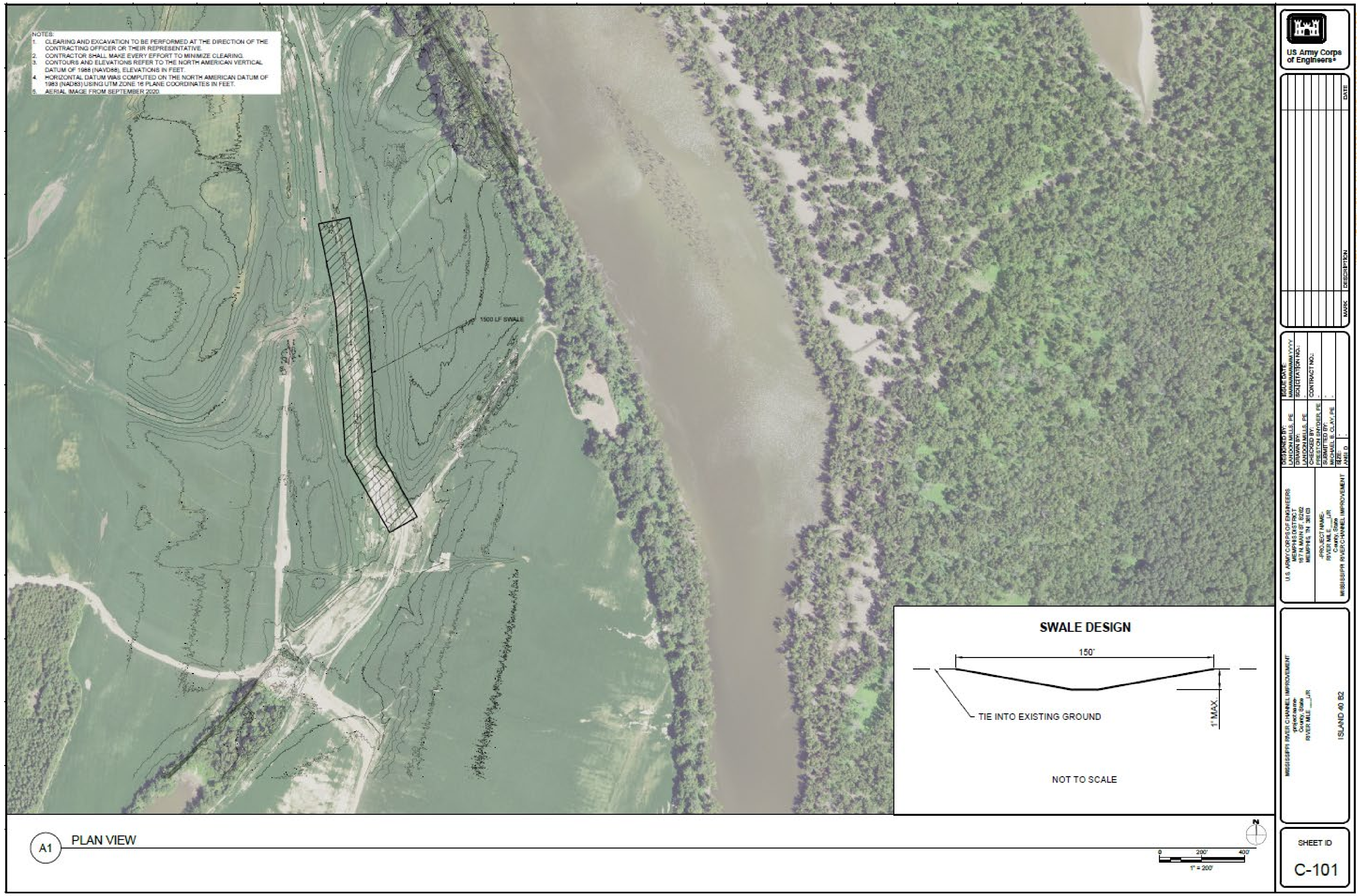
The proposed work for Measure HB_2c shall be the construction of a swale to connect the non-forested downstream area to Measure HB_1 for alligator gar habitat. The swale shall be constructed approximately 4,750 feet long and 200 feet wide and no deeper than 3 feet at the center. The excavation will result in approximately 90,000 cubic yards of material. It is assumed that no hauling will be required and can be used onsite for either a ditch berm or spread throughout the field. It is currently assumed that geotechnical recommendations are not required for this measure. See Figure 21 below for construction details.

Figure 20. Swale Construction Details for Measure HB_2c



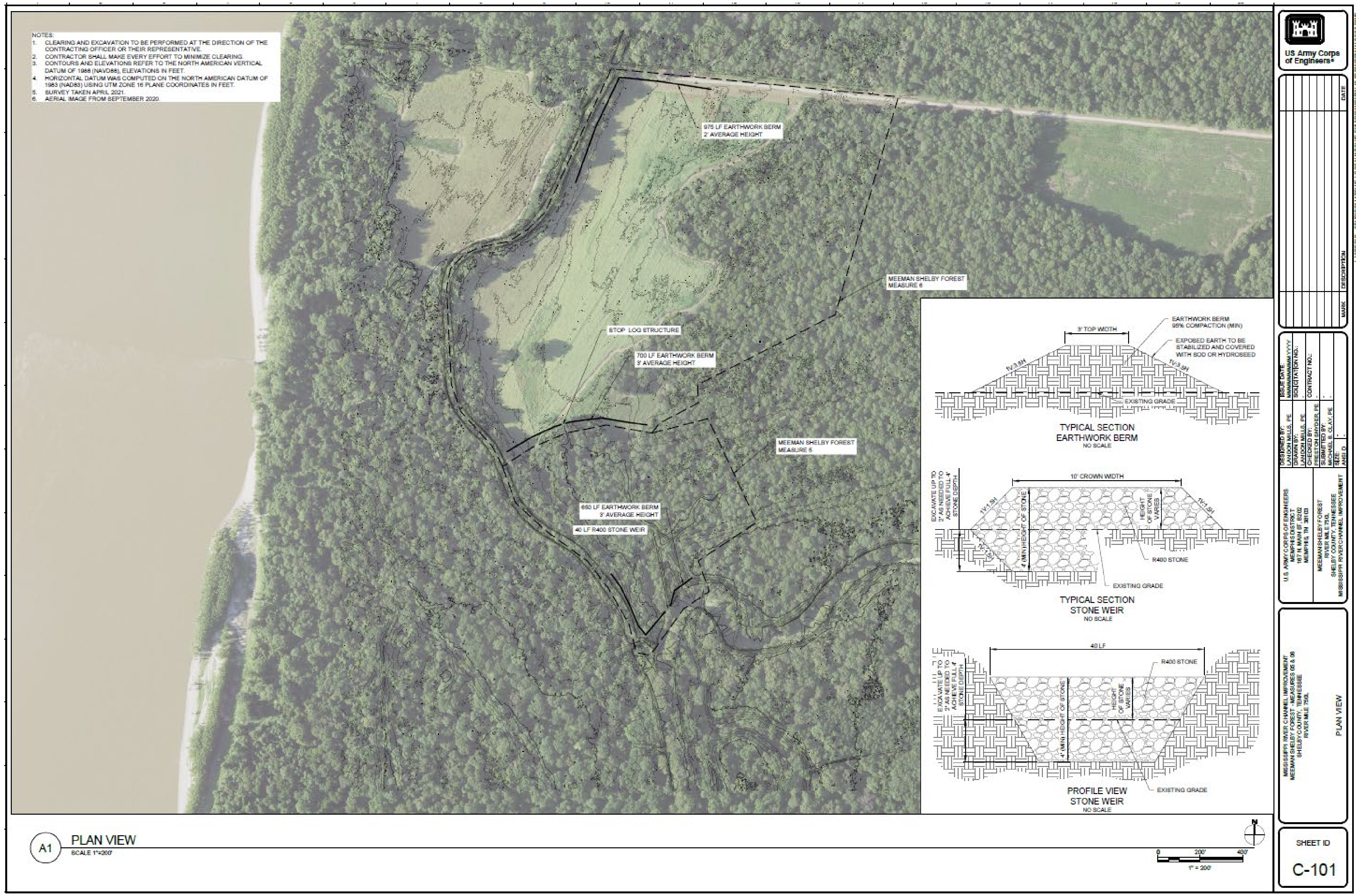
The proposed work for Measure I40_1b2 shall be the construction of a swale to improve upstream connectivity to increase fish access, enhance habitat, and reduce sediment and nutrient inputs. The swale construction will complement the culvert installation in Measure I40_1b1, increasing the connectivity between the Brandywine Chute upstream and Danner Lake downstream. The swale shall be constructed approximately 1,500 feet long and 150 feet wide and no deeper than 1 foot at the center. The excavation will result in approximately 9,000 cubic yards of material. It is assumed that no hauling will be required and can be used onsite for either a ditch berm or spread throughout the field. It is currently assumed that geotechnical recommendations are not required for this measure. See Figure 22 below for construction details.

Figure 21. Swale Construction Details for Measure I40-1b2



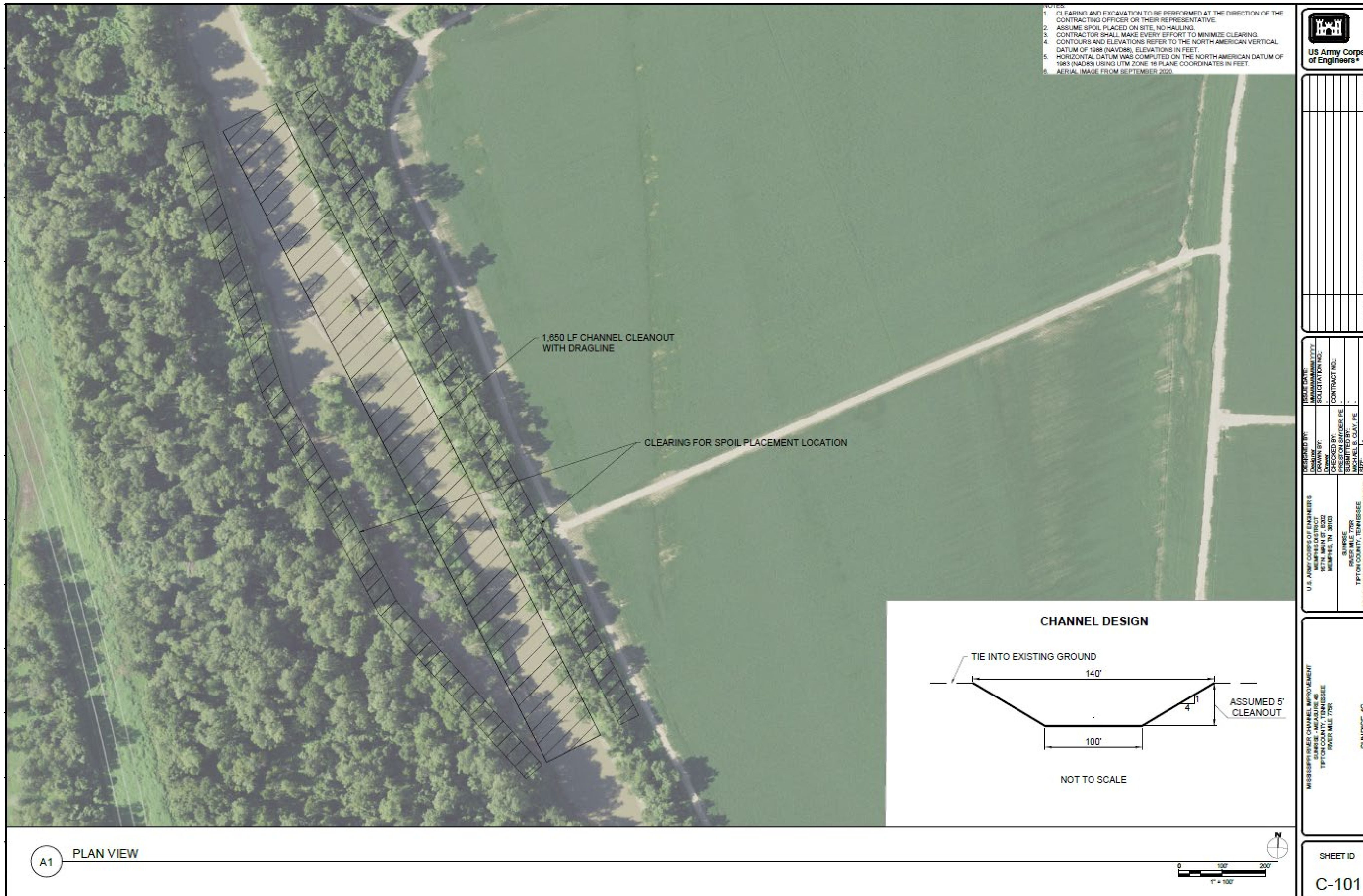
The proposed earthwork for Measures M_5 and M_6 shall be the construction of three berms to back up water onto an upstream depression to promote cypress tupelo and to control water on fallow field for waterfowl and shorebirds. The berms will work in tandem with the grade control structures previously discussed for Measure M-5 (rock weir) and Measure M-6 (stoplog structure). The berm for Measure M_5 shall be constructed approximately 650 feet long with a maximum height of no more than 3 feet. Measure M_6 shall have two berms constructed, one 700 linear feet with an assumed 3-foot maximum height and one 975 linear feet with an assumed 2-foot maximum height. The maximum side slopes shall be 1V:3H, per Geotechnical recommendations. See Figure 23 below for construction details.

Figure 22. Earthen Berm Construction Details for Measures M_5 and M_6



The proposed work for Measure S_4c shall be a 1,650 linear foot channel cleanout to increase meander scarp connectivity by establishing a low flow channel. It is assumed that the channel cleanout for Measure S_4c will be constructed utilizing a dragline due to the width of the cleanout. Clearing will be required to for the dragline to track along both banks. It is assumed the excavated material will be placed as spoil on site, with no hauling. Per Geotechnical recommendations, A 5-foot depth is being assumed for this cleanout. USACE does not have any existing data (survey or subsurface) for the areas of this proposed alternative. Due to data availability, generic and conservative side slopes were requested. For this recommendation, due to the shallow nature of the cleanout, side slopes that do not exceed 1V:4H should suffice in maintaining general slope stability of the channel. This recommendation does not meet slope stability EM requirements and is very general in nature. If more data is obtained about the cleanout areas, it is recommended that this be revisited so a more informed recommendation can be provided. The excavation will result in approximately 60,000 cubic yards of material. See Figure 24 below for construction details.

Figure 23. Channel Cleanout Design for Measure S_4c



2.6.8 Bridge Replacements

The primary purpose of the bridge replacements is to increase connectivity within the meander scarp by enhancing debris passage. The TSP proposed a total of two bridge replacement measures (Measures Br_4a and S_4b). Table 9 below provides Measure details.

Table 9. Bridge Replacement Measures

Measure #	Item #	Complex Name	Long Notes
Br_4	Br_04a	Brandywine	Lower bridge invert at the apex of Brandywine Chute to increase connectivity in Meander Scarp.
S_4	S_4b	Sunrise_Island34	Increase Meander Scarp connectivity by enhancing debris passage underneath an existing bridge and/or remove accumulated sediment. Assumed Bridge replacement.

Bridge replacements will be designed, constructed and maintained by the Arkansas Highway Department of Transportation as County Road bridges. Design plans and specifications can be made available through ArDOT. Construction costs associated with the bridge replacements as part of this study were based off a previous ArDOT bridge replacement contract.

2.6.9 Recreational Measures

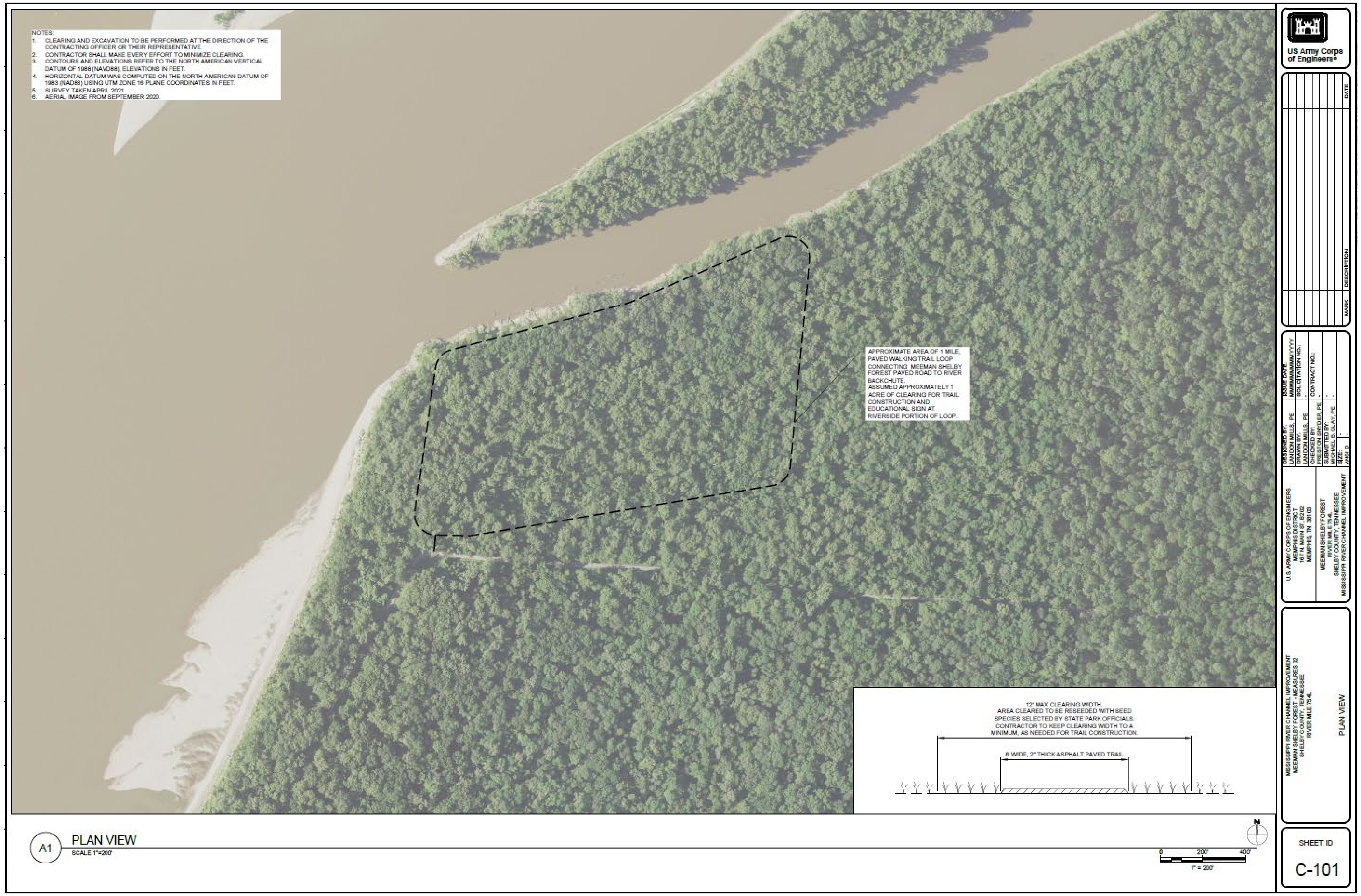
Two recreational features are proposed as part of this study. Trail access improvements (M_2) consists of constructing a new/refurbishing an existing walking trail and adding educational signage for the surrounding ER measures, which would include hazard signage for the proposed woody debris trap. The proposed trail will be constructed as a 1-mile asphalt loop approximately 6 feet wide. One acre of clearing is assumed for trail construction. All signage costs are considered incidental to trail construction. Interpretive media and a woody debris trap demonstration (LW_1a) will be constructed in the Wolf River Harbor for educational purposes. Figure 4 above for a woody debris trap detail and Figure 25 below for proposed cautionary signage. See Figure 26 below for recreational trail details. Table 10 below provides Measure details.

Table 10. Recreation Measures

Measure #	Item #	Complex Name	Long Notes
M_2	M_2	MeemanShelbyForest_EagleLake	Trail access improvements (1 mile loop paved) (note: there is an existing trail that could be refurbished, educational signage for surrounding ER measures to include large wood debris trap (boating hazard).
LW-1	LW-1a	Loosahatchie Wolf River	Partner with stakeholders to create a display board (Interpretive Media) and possibly a Large Woody Debris Demonstration in Harbor to promote ER Measures with project.

Figure 24. Woody Debris Trap Cautionary Signage

Figure 25. Recreational Trail Construction Details



2.6.10 Floodplain Vegetative Measures

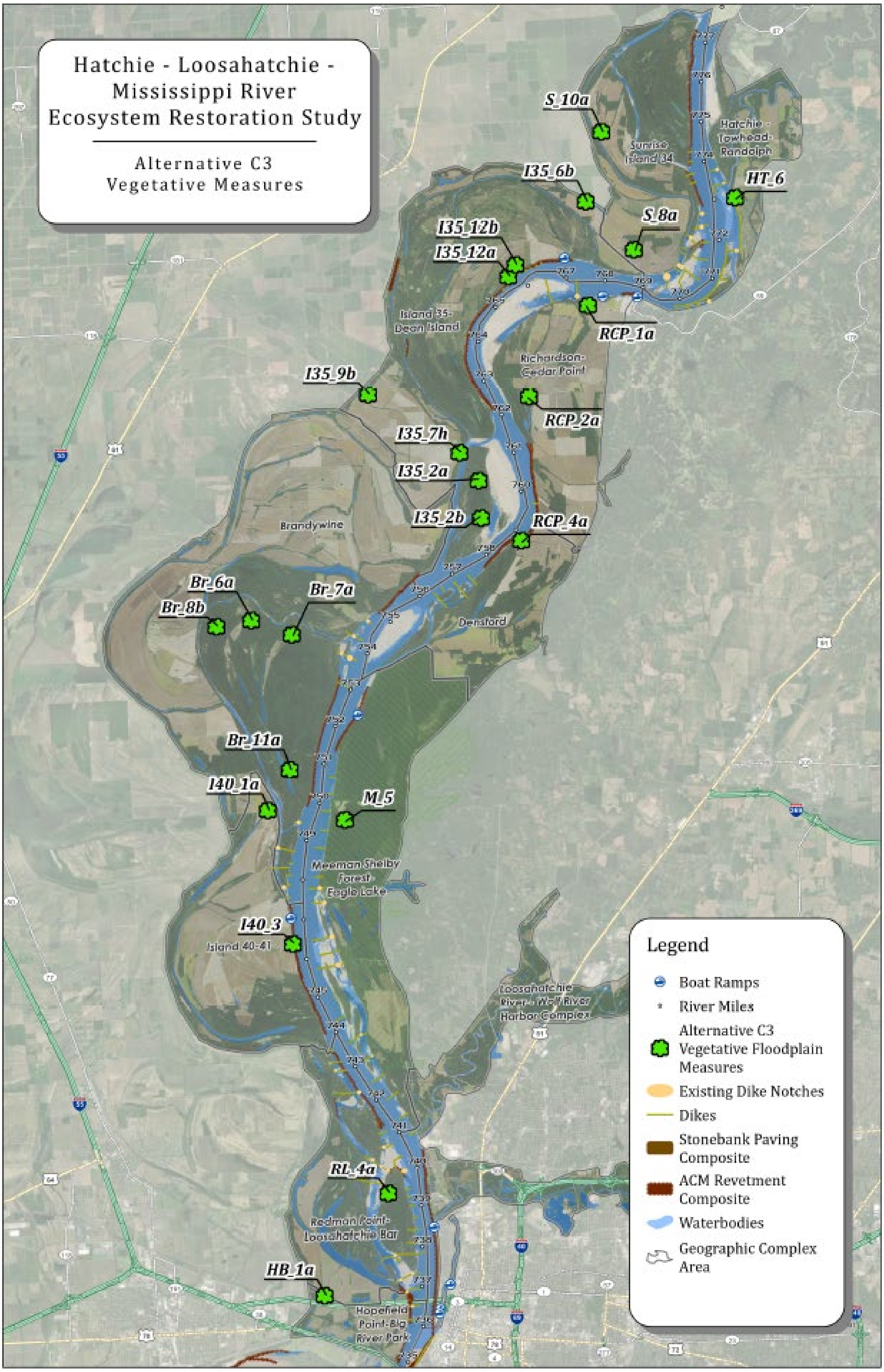
Floodplain vegetative measures are important for the enhancement and restoration of natural vegetation. This can be accomplished through a variety of methods, including canopy gaps, cypress tupelo planting, herbaceous wetland planting and various forms of reforestation. The measure specific designs and costs were developed by ERDC. The detailed analysis and design of these measures can be found in the Ecological Models Appendix. Cost assumptions can be found in Ecological Models Appendix, as well as the A-2 Cost Engineering Appendix. Table 11 below lists the Floodplain Vegetative Measures. Figure 27 below shows the various locations for each of the Floodplain Vegetative Measures.

Table 11. Floodplain Vegetative Measures

Measure #	Item #	Complex Name	Long Notes
Br_6	Br_06a	Brandywine	Create canopy gaps (tree girdling) promote oak regeneration on Brandywine Island with additional oak planting. Enhance high ridge and scarce oak dominated habitat for Neotropical migrants such as Swainson's Warblers.
Br_7	Br_07a	Brandywine	Create canopy gaps (tree girdling) to promote river cane and some oak species on Brandywine Island for Neotropical migrants such as Swainson's Warblers. Adaptive Management for control of sweet gum through herbicide or prescribed fire.
HT_6	HT_6	HatchieTowhead_Randolph	Install 300-ft wide X 7500-ft long (52 acres) forested riparian buffer adjacent to hardpoints and bank.
HB_1	HB_1a	HopefieldPoint_BigRiverPark	Establish non-forested wetland surrounding waterbody connected to swale. Coordinate with Big River Park to establish herbaceous (non-forest) for A Gar spawn 47-acres). Establish wet prairie grasses or rivercane on high ridges.
I40_1a	I40_1a	Island40_41	Reforest channel enhance habitat and reduce sediment and nutrient inputs. Reforest ~2,700 ft and ~3,200 ft to fac wet or obligate species in flow paths to River.
I40_3	I40_3	Island40_41	Reforest 8,500 ft of the historic Island 40 main channel high bank from 745.7 - 747.6 to create a contiguous tree buffer strip and

			connect forest habitat. Include 300 ft width 8,500 ft (59 acres) long riparian buffer along the LMR bank.
I35_2	I35_2a	Island35_DeanIsland	Reforest this high field in mast producers (10 acres) Cannot be done with 1a
I35_2	I35_2b	Island35_DeanIsland	Reforest this high field in mast producers_ (13 acres) Cannot be done with 1b
I35_6b	I35_6b	Island35_DeanIsland	Create Forested Buffer for Borrow Pit (could use to mimic meander scroll ridges with Oak sp.). Assume 100-ft. buffer for 4900 ft. (11.25 acres)
I35_7h	I35_7h	Island35_DeanIsland	Reforest 8-acres ag land adjacent to Deans 2nd channel to maintain 300' forest buffer.
I35_9b	I35_9b	Island35_DeanIsland	Create forested Buffer for Borrow Pit. Area already floods from borrow area getting out of banks.
I35_12a	I35_12a	Island35_DeanIsland	Plant Cypress/Tupelo on this ponded area (14 acres) at RM766R
I35_12b	I35_12b	Island35_DeanIsland	Reforest 300ft Tree Screen/Buffer Strip adjacent to MS River /revetment/Bendway Weirs between RM767R -765.5R. 2 spots (total length 8,000-ft length x 300-ft. width).
RL_4	RL_4a	RedmanPoint_LoosahatchieBar	Forest stand improvements with planting mast production trees (20% of benefit area = 209.8 acres); ~ 98% of island inundated annually.
RCP_1	RCP_1a	Richardson_CedarPoint	Plant 8-acre depression in Cypress/Tupelo.
RCP_4	RCP_4a	Richardson_CedarPoint	Establish riparian buffer along MS River for 300-ft x 1600-ft width where it is lacking.
S_8	S_8a	Sunrise_Island34	Reforest with Cypress/Tupelo and surrounding bands of Fac-wet species. Reforest 19 acres with Cypress/Tupelo and surround bands of Fac-wet species.
S_10	S_10a	Sunrise_Island34	Create a 100-ft. width buffer (21acres=4500ft length x 210ft. width) along both sides of ag-ditch to reduce sedimentation into meander scarp.

Figure 26. Floodplain Vegetative Measures



Relocations and Utilities

Existing utilities, if any, should be avoided. Detailed survey data was not available to determine the location of utilities. Relocations of sewer and gas lines are prohibitively expensive and shall be minimized or avoided.

2.7 OPERATIONS, MAINTENANCE, REPAIR, REPLACEMENT, REHABILITATION (OMRR&R)

OMRR&R estimates are based on maintenance requirements for similar USACE structures in the region. Regular inspection through the District's Inspection of Completed Works program will monitor the structures and allow responsive maintenance to maintain expected performance. Cost estimates are included in A-2 Cost Engineering Appendix. It is currently assumed that no OMRR&R costs will be required for floodplain vegetative measures. Table 12 below provides a summary of OMRR&R assumptions.

Table 12. OMRR&R Assumptions

Measure Type	Operation and Maintenance
Stone Dike Notching	O&M at year 30 estimated at 75% of construction cost
Pile Dike Notching	High water years should flush debris. No assumed O&M, only AMM
Bridge Replacement	Assumed maintenance to be performed by ArDOT
Grade Control Structure (Rock Weir)	O&M 50% riprap replacement at year 30
Grade Control Structure (Stop Log)	O&M $2,500 per year
River Training Structures/Hardpoints	O&M 25% of construction cost every 15 years (Years 15, 30, 45)
Culverts (CMP)	Full replacement at year 30 due to the hydrologic conditions of each complex. $3,000 every 10 years for blockage removal per culvert (Years 10, 20, 40)
Culverts (Concrete)	No full replacement. $3,000 for minor repairs, cleanout/blockage removal every 10 years per culvert (years 10, 20, 30, 40)
Culverts (Flapgate)	Full replacement at year 30 due to the hydrologic conditions of each complex.
Woody Debris Traps	No assumed O&M, only AMM
Floodplain Vegetative Measures	No assumed O&M, only AMM
Riprap Bank Protection	O&M 50% riprap replacement at year 30
Channel Cleanout/Swale	O&M 25% every 15 years (Years 15, 30, 45)

Section 3

Planning, Engineering, and Design

3.1 TESTS AND DATA COLLECTION

To properly analyze and reduce risk, additional data must be acquired early in the Planning, Engineering, and Design (PED) phase to support final design. A detailed inventory of existing utilities in the project footprint must be obtained in cooperation with the sponsor and utility owners. This is particularly important to subsurface utilities that are not easily located with imagery or site visits. Discussions with owners must determine which conflicting utilities can be relocated, and at what cost. Topographic surveys are required to locate key existing features (including utilities) and gain the necessary fidelity of elevations needed for design. A topographic survey is required to improve the confidence of material quantity estimates, aid in validating hydraulic models, and identify conflicts with existing features. Modeling will also be used to refine design. Topographic data for all GCS will be necessary for design and quantity calculations. Subsurface Geotechnical exploration will also be required during PED to accurately evaluate soil stratification used for slope stability analysis and other Geotechnical analysis.

3.2 ANALYSIS/OPTIMIZATION STRATEGY

Layout and quantities are based on publicly-available data and limited modeling to develop cost and performance estimates. These are not to be considered final designs for construction. Additional data collected during Feasibility or PED will allow a final analysis for design features. This will be particularly important for hydraulic and geotechnical evaluations. The improved fidelity of this data will support the final constructed work items. During PED, the team will first refine models and test design features to validate performance anticipated in this report. Next, design features may be field fit based on current data to provide the maximum environmental benefit.

Construction sequence and phasing will be addressed during feasibility level of design and during PED.

3.3 INTEGRATION WITH OTHER AUTHORIZED PROJECTS

Analysis and coordination will be done to ensure this plan integrates into existing structures owned by municipal interests, private entities, and other government agencies. There has been ongoing coordination within the Memphis District to mediate potential impact to Federal projects within the study footprint, specifically the MR&T Project Navigation and Levee features.

3.4 COORDINATION WITH OTHER AGENCIES

The design team will coordinate with other state and federal agencies to identify and incorporate regulatory and ecosystem requirements into the feasibility-level design.

References

Biedenharn, David S., Charles M. Elliot, & Chester C. Watson, 1997, The WES Stream Investigation and Streambank Stabilization Handbook. U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

U.S. Army Corps of Engineers (USACE), 1999, Moist-Soil Impoundments for Wetland Wildlife