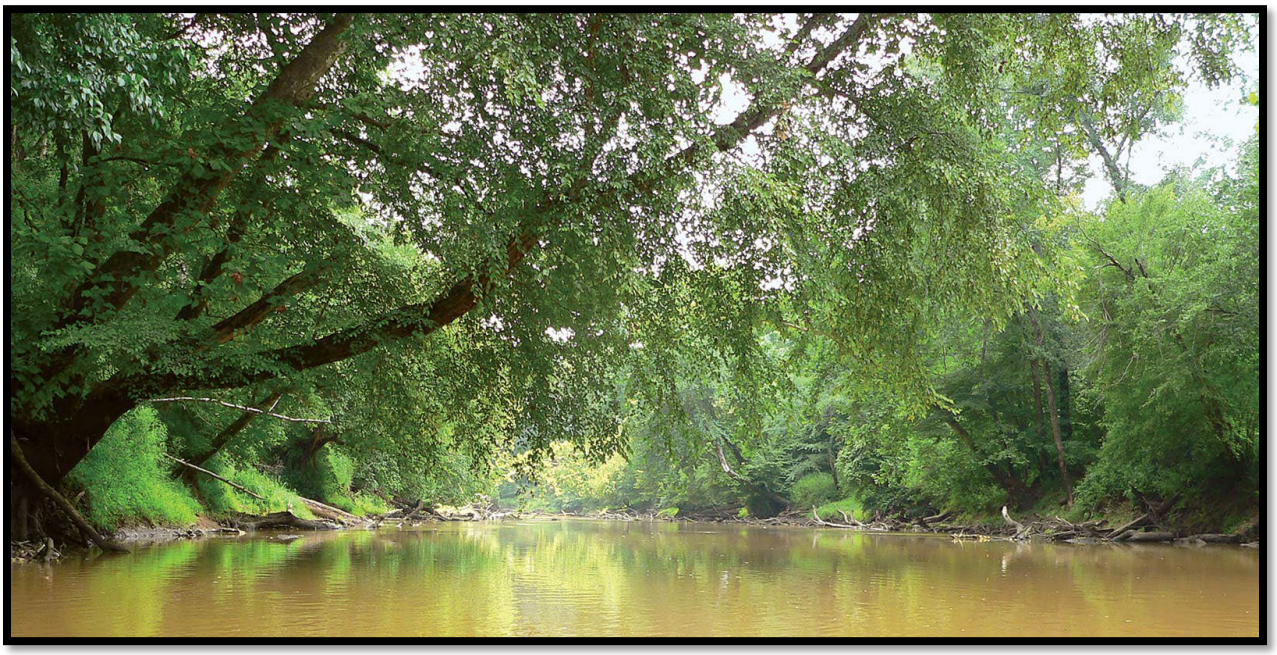
Appendix E. Civil & Structural Engineering Appendix



April 2024

US Army Corps of Engineers®
Pittsburgh District

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1. Introduction

1.1. Background

Communities along the Tar River have experienced significant flooding impacts due to both hurricane [e.g., Hurricane Fran (1996), Floyd (1999), and Matthew (2016)] and non-hurricane-driven rainfall events. Notably, the Tar River has reached flood stage a total of 18 times at Louisburg, 8 times at Rocky Mount, 39 times at Tarboro, and 32 times at Greenville over the period of record for each gauge. Riverine flooding associated with these flood events has resulted in severe damage to properties and infrastructure, as well as loss of life. The most impactful hurricane was Hurricane Matthew. In North Carolina, an estimated 100,000 structures incurred damages, 800,000 homes were without power, and at least 25 people lost their lives.

In response to recent flood events, USACE received $3M through the 2019 Additional Supplemental Appropriations for Disaster Relief Act (Actions - HR2157 - 116th Congress (2019-2020), 2019) for a feasibility study—officially referred to as the Tar-Pamlico River Basin Flood Risk Management Feasibility Study and subsequently referred to here as the 'Feasibility Study'—to assess and recommend actions that reduce flood risk and increase resiliency within the Tar-Pamlico River Basin.

1.2. USACE Planning Process

The USACE planning process, which was used in this study, follows the six-step process defined in the USACE Principles, Requirements, and Guidelines (PR&G) (USACE 2013). This process is a structured approach to problem solving which provides a rational framework for sound decision making. The six-step process is used for all planning studies conducted by the Corps of Engineers. The six steps are:

- Step 1 - Identifying Problems and Opportunities
- Step 2 - Inventorying and Forecasting Conditions
- Step 3 - Formulating Alternative Plans
- Step 4 - Evaluating Alternative Plans
- Step 5 - Comparing Alternative Plans
- Step 6 - Selecting Recommended Plan

Corps decision making is generally based on the accomplishment and documentation of all these steps. It is important to stress the iterative nature of this process. As more information is acquired and developed, it may be necessary to reiterate some of the previous steps. The six steps, though presented and discussed in a sequential manner for ease of understanding, usually occur iteratively and sometimes concurrently. Iterations of steps are conducted as necessary to formulate efficient, effective, complete, and acceptable plans.

This appendix details the civil and structural engineering analyses that informed decisions leading to the recommendations made within the main integrated feasibility report and environmental assessment. The level of analysis provided is appropriate and commensurate with the phase of the planning process, with additional detail being provided for flood risk reduction

features included in the array of alternatives and less detail provided for measures that did not move past the initial screening phase.

1.1. Study Area

The current study area comprises the entire Tar River Basin in North Carolina to just above Washington, NC. The study originally included the region of the Tar River near Washington, as well as the area along the Pamlico River immediately downstream of Washington (Figure 1). However, through the course of the study, the region near Washington was determined to be affected by coastal flooding and riverine flooding. As coastal flooding mitigation was beyond the scope and authority of the current study, the regions affected by coastal flooding were removed from consideration. The remaining study area includes portions of 13 counties.

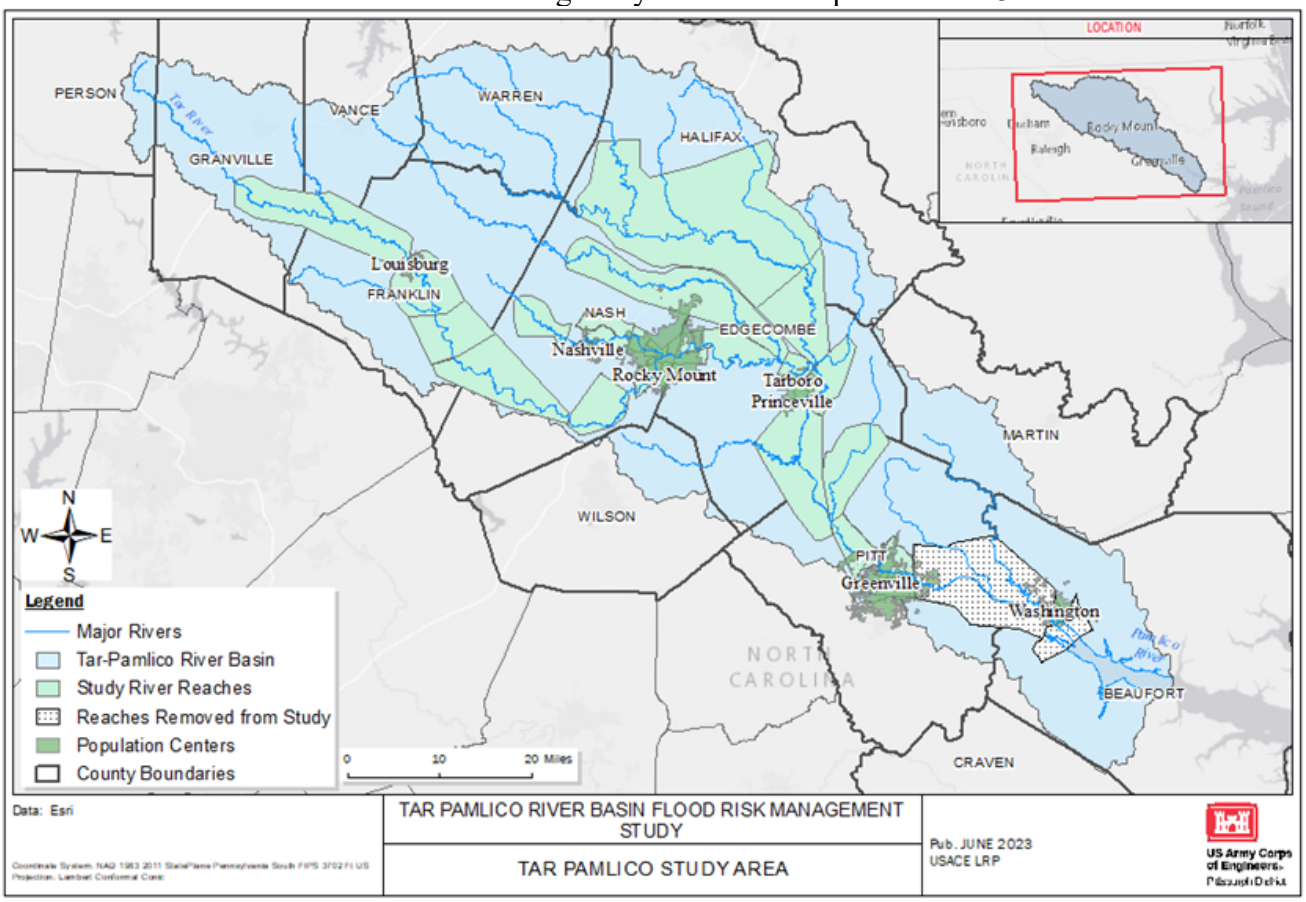

Figure 1. Tar Pamlico study area.

2. Flood Risk Management Measures

2.1. Measure Development & Screening

A planning charrette was held on May 1 and 4, 2020, during which the study team, local sponsor, experts from the Flood Risk Management Planning Center of Expertise, and relevant stakeholders, including the North Carolina Department of Transportation, North Carolina Department of Recovery and Resiliency, and East Carolina University executed the initial

iteration of the planning process. During the charrette, participants defined the problems and opportunities related to flood risk within the study area and used this information to develop the study objectives. Participants then developed a list of 11 general management measures that could potentially address the identified problems and realize identified opportunities (Table 1).

Management measures are classified as either structural, nonstructural, or natural and nature-based measures. Structural measures reduce or avoid damages by modifying the nature and/or extent of the flood hazard. Potential locations for structural measures were identified using two separate strategies. Potential storage areas were considered throughout the study area to achieve local and downstream benefits, and specific locations for these measures were identified using aerial imagery and topography. Potential areas for implementing floodwalls and levees, channel improvements, and diversion channels were limited to the five major population centers, as these areas were the only areas with concentrated damages to warrant location-specific structural measures. Nonstructural measures reduce or avoid damages by modifying the consequences of the flood hazard. Potential locations for nonstructural measures were identified using existing structure data and inundation grids for standard flood events (i.e., 10%, 4%, 2%, 1%, 0.5%, and 0.2% annual exceedance probability events). Natural and nature-based measures alter, restore, use, or mimic natural landscape features or processes to manage flood risk. Natural measures were considered throughout the study area as appropriate.

Table 1. General management measure types evaluated to manage flood risk within the Tar-Pamlico River study area.

Measure	**Description**
Structural Measures	
Floodwater Storage	Measures designed to capture and store floodwaters to reduce flood stages downstream. Storage measures can either be offline or online. Online storage measures are placed along the channel and attenuate flooding by ponding water during a flood event. Online storage includes reservoirs, which maintain a permanent pool, and online detention areas such as dry dams, which store water only during high flow events and allow unimpeded flow during normal flows. Offline storage refers to the diversion of streamflow to a storage site (e.g., auxiliary channels and detention areas) during a flood event. Water is then returned to the stream via pumping or gravity once floodwaters recede.
Floodwall/Earthen Levee	Construction of a concrete wall (floodwall) and/or earthen embankment (levee) along the watercourse or around critical infrastructure to temporarily exclude flood waters from protected areas.
Channel Improvements	Channel improvements result in increased channel capacity and/or expedited water movement through the system. Channel improvements include channel modifications such as widening, deepening, and/or straightening, as well as channel lining to maintain the desired geometry and decrease roughness.
Bridge Modifications	Bridge modifications designed to reduce constrictions and associated upstream water surface profiles.

Diversion Channel	Construction of a secondary channel designed to divert flows from an upstream location to an engineered channel, lowering the flood stages. The engineered channel discharges at a downstream location, bypassing potential damage areas.
Existing Water Resource Project Modifications	This measure would involve updating, improving, or removing existing water resources infrastructure, including existing flood risk management projects or dams and associated reservoirs. This measure could include structural modifications to increase storage capacity and modifications to operations.
Debris Management	Implement measures designed to remove debris from the channel, prevent debris from entering the channel, and/or prevent debris buildup to reduce risk of direct damage and altered hydraulics during high-water water events.
Nonstructural Measures	
Physical Non-structural Measures	Physical nonstructural measures include efforts to reduce flood damage to individual structures and their contents and include floodproofing, elevation, and acquisition and relocation. Floodproofing limits the potential damage to the structure and its contents and includes both wet and dry floodproofing. Wet floodproofing measures allow flood waters to enter the structure to equalize hydrostatic forces and reduce the risk of structural damage, while vulnerable items and utilities are relocated to higher locations and/or waterproofed. Dry floodproofing involves sealing building walls and openings to prevent the entry of flood waters and is most applicable in areas of shallow, low velocity flooding. Structure elevation involves raising structures in place so that the structure sees a reduction in frequency and/or depth of flooding during high-water events. Elevation can be done on fill, foundation walls, piers, piles, posts, or columns, depending on flood characteristics. Structure relocation is the process of physically moving a structure from one location to another. Acquisition and relocation, also called buyouts, includes acquisition and demolition of flood prone structures. Residents would be relocated outside of the floodplain. Participation in the relocation would be mandatory. The floodplain would be planted with native vegetation. The local sponsor would retain ownership of the acquired property and must ensure no future development or fill would occur.
Non-physical Nonstructural Measures	Non-physical nonstructural measures improve the ability to respond to a flood event and prevent future actions that could increase flood risk and include flood warning systems, flood preparedness planning, and land use regulations to prevent development in flood zones.
Natural and Nature-Based Measures	

Watershed Restoration and Conservation	Actions taken to protect, preserve, manage, and restore natural resources at the watershed scale, such as reforestation, that improve natural process and reduce downstream flooding.
Dispersed Water Management	Dispersed water management is a more natural form of off-channel storage. Off-channel areas, which may be part of the floodplain and include wetlands, marshes, and agricultural fields, would be used to temporarily store water diverted from the river channel. Lands used to store water could be public or private. Dispersed water management could involve restoration of floodplains (e.g., planting native vegetation) and wetlands (i.e., plugging surface drains and regulating storage). When agricultural lands are used for off-channel detention, this practice is often referred to as 'water farming'.

The study team identified a total of 81 individual management measures that underwent a screening evaluation to determine whether they would be incorporated into the development of flood risk management alternatives (Table 2). A summary of these measures is provided in Table 2 below. A detailed description of each measure that underwent civil and structural design efforts is provided in subsequent sections of this appendix.

Table 2. Type and result of screening assessments for each of the 81 individual management measures developed as part of this feasibility study. Measures assessed within this appendix (Appendix E) are highlighted, and the location of assessments for measures not included in this appendix are also shown.

Type	**Measure**	**Screening Result**	**Assessment**
Floodwater Storage	Dry Dam – Stony Creek	Retained	Appendix E
Floodwater Storage	Dry Dam – Upper Tar River	Retained	Appendix E
Floodwater Storage	Dry Dam – Fishing Creek	Screened	Appendix E
Floodwalls / Levees	Rocky Mount Levee System	Screened	Appendix E
Floodwalls / Levees	Tarboro Wastewater Treatment Plant	Screened	Appendix E
Floodwalls / Levees	East Tarboro	Screened	Appendix E
Floodwalls / Levees	Tarboro-Edgecombe Airport	Screened	Appendix E
Floodwalls / Levees	Greenville Levee System	Screened	Appendix E
Floodwalls / Levees	Green Mill Run	Screened	Appendix E
Diversion Channel	Nashville Auxiliary Diversion Channel – Stony Creek	Screened	Appendix E
Diversion Channel	Logsboro / Hartsboro Auxiliary Diversion Channel	Screened	Appendix E
Diversion Channel	Tarboro / Princeville Auxiliary Diversion Channel #1	Screened	Appendix E
Diversion Channel	Tarboro / Princeville Auxiliary Diversion Channel #2	Screened	Appendix E
Diversion Channel	Tarboro / Princeville Auxiliary Diversion Channel #3	Screened	Appendix E

Diversion Channel	Tarboro / Princeville Auxiliary Diversion Channel #4	Screened	Appendix E
Diversion Channel	Rocky Mount Auxiliary Diversion Channel #1	Screened	Appendix E
Diversion Channel	Rocky Mount Auxiliary Diversion Channel #2	Screened	Appendix E
Diversion Channel	Rocky Mount Auxiliary Diversion Channel #3	Screened	Appendix E
Diversion Channel	Rocky Mount Auxiliary Diversion Channel #4	Screened	Appendix E
Diversion Channel	Rocky Mount Auxiliary Diversion Channel #5	Screened	Appendix E
Diversion Channel	Diversion channels – Tar River to Cokey Swamp	Screened	Appendix E
Diversion Channel	Roseneath / Palmyra Fishing Creek	Screened	Appendix E
Channel Improvement	Rocky Mount	Screened	Appendix A
Channel Improvement	Green Mill Run	Screened	Appendix A
Transportation modification	Bridge Modification (n=17)	Screened	Appendix F
Debris Management	Modification of existing infrastructure (n=24)	Screened	Appendix F
Existing Water Resource Project Modification	Modify Tar River Reservoir	Screened	Appendix F
Existing Water Resource Project Modification	Rocky Mount Mill Dam Removal	Screened	Appendix F
Existing Water Resource Project Modification	Green Mill Run Reservoir Modification	Screened	Appendix A
Physical Nonstructural	Acquisition and relocation	Retained	Appendix B
Physical Nonstructural	Structure Elevation	Retained	Appendix B
Physical Nonstructural	Dry Floodproofing	Retained	Appendix B
Physical Nonstructural	Relocation	Screened	Appendix A
Non-Physical Nonstructural	Education & communication	Screened	Appendix A
Non-Physical Nonstructural Measures	Emergency preparedness / warning	Screened	Appendix A
Non-Physical Nonstructural	Flood ordinance / floodplain management	Screened	Appendix A
Watershed restoration and Conservation	Watershed restoration	Screened	Appendix A
Dispersed Water Management	Offline detention / water farming (n=5)	Screened	Appendix F

Management measures were screened to determine which measures would be incorporated into the formulation of flood risk management alternatives. During the screening process, management measures were evaluated based on completeness, effectiveness, efficiency, and acceptability, as outlined in the PR&G (USACE, 2013) (Table 3). Additional considerations for screening included environmental effects, environmental justice, and technical feasibility. A

detailed description of the screening process can be found in the main integrated feasibility report and environmental assessment, as well as Appendix A. Results of the screening process are summarized in the following sections for each measure included in this appendix.

Table 3. Criteria used to screen the initial list of management measures. Description and associated metrics used to assess each criterion are provided.

Criteria	**Description**	**Metric(s)**
Efficiency	Cost effectiveness. Comparison of economic benefits and costs	Quantitative – Comparison of preliminary costs and expected benefits.
Effectiveness – Damages Reduced	Damages to buildings, related contents, and vehicles	Semi-Quantitative – Expected benefits based on preliminary cost benefits analysis and hydrologic and hydraulic modeling.
Effectiveness – Industry and Commercial	Degree to which flood risk is reduced in commercialized reaches	Qualitative – expected benefits in targeted reaches
Effectiveness – Life Safety	Changes in life safety risk expected with alternative implementation.	Qualitative– population at risk, life loss, and expected changes in flooding characteristics (e.g., depth)
Acceptability	Workability and viability with respect to acceptance by NFS, local entities, the public, and compatibility with existing laws, regulations and policies.	Qualitative – description
Environmental Effects	Effects to aquatic (stream, wetland) and terrestrial (riparian, upland, critical) habitats, water quality, and threatened/endangered species.	Qualitative – low, medium, high based on footprint and effect of each alternative
Environmental Justice	Changes in flood risk or consequences within areas identified as traditionally disadvantaged with respect to environmental concerns per the CEQ's Climate and Economic Justice Screening tool and EPA's EJ Screen tool were used to characterize potential benefits to socially vulnerable communities.	Qualitative – Qualitative assessment of potential benefits in areas identified as socially vulnerable based on initial hydrologic and hydraulic modeling results.
Engineering Feasibility	Whether the measure is engineering feasible and constructable	Best professional judgement based on engineering practices and standards

2.2. Floodwater Storage

2.2.1. Measure Description

Three locations for dry dams were evaluated (i.e., Stony Creek, Fishing Creek, and Upper Tar River, Figure 2). Dry dams along Stony Creek and the Upper Tar River were the only structural measures retained following the screening process and included in the initial array of alternatives. As a result, this section details the design information required to effectively evaluate these measures, including development of costs. Typical design considerations are first described, followed by detailed design considerations for each dry dam.

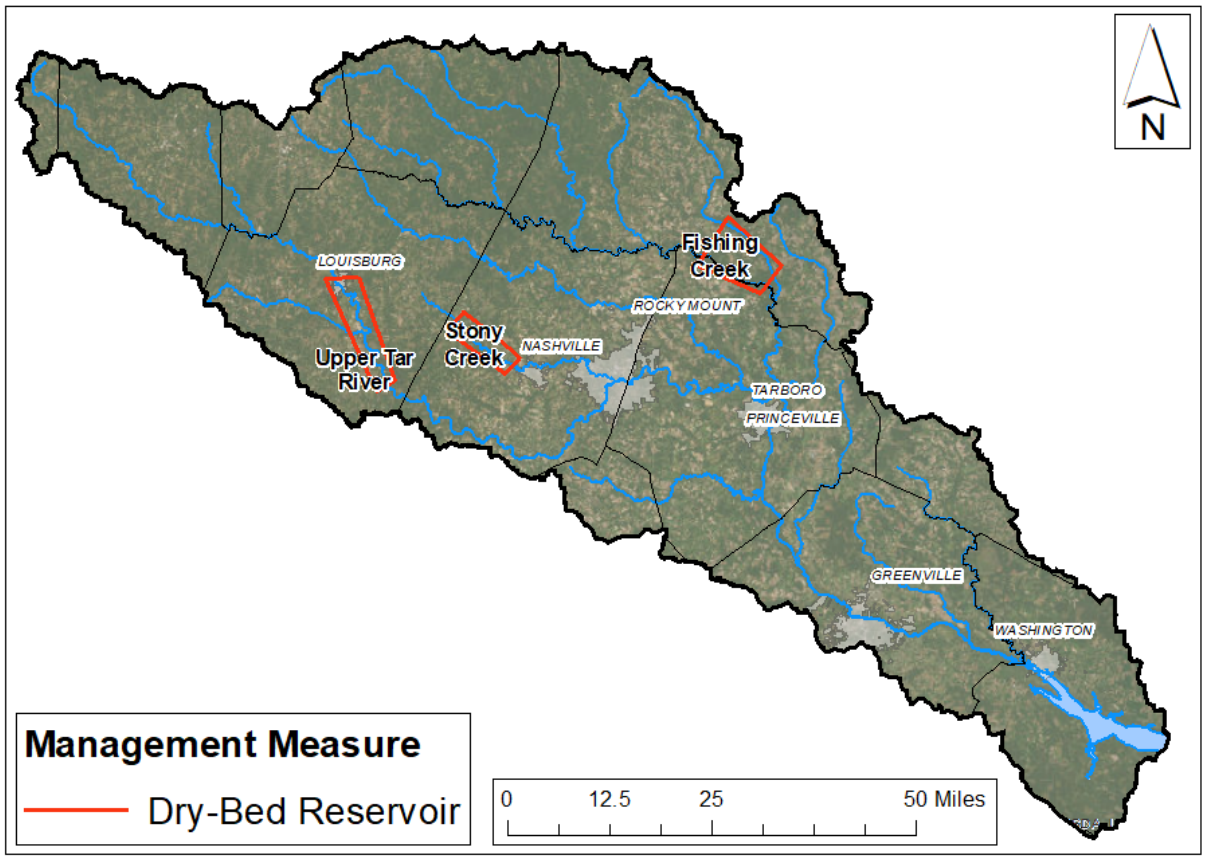

Figure 2. Locations where floodwater storage via dry dams were considered (red polygons).

Typical Design Considerations: Each dry dam consisted of the following features: an uncontrolled spillway, anchored stilling basin and stone protection, non-overflow monoliths, training walls, and earthen embankment tying the non-overflow monoliths to high ground. Non-overflow monoliths were used to abut the spillway monoliths and extended in deeper ravine locations since it may be more practical than constructing very large earthen embankment. The spillway, non-overflow section, and training walls were analyzed for stability utilizing multi-wedge method and criteria from EM 1110-2-2100. Stability was analyzed for Unusual and Extreme hydraulic events. Driving and resistive soil shear strength was assumed 35 degrees without cohesion. Concrete on bedrock interface used shear strength of 40 degrees without cohesion.

The uncontrolled spillways were reinforced concrete, which included an 18-foot-tall by 18-foot-wide access gallery. Two six-foot-wide by eight-foot-tall sluiceways were proposed per spillway monolith. Each sluiceway would be controlled by two sluice gates (one control gate and one emergency gate). Slots for stoplogs were detailed for the upstream face of each spillway monolith. The spillway monoliths were typically reinforced with No 9 rebar at 12 inches on center each way and each face, with two mats of reinforcement at the base of the monolith. Interior monolith lengths were 44 feet and end monoliths were 48 feet long. Waterstops were planned at each monolith joint. The width of each monolith was 100 feet. Concrete compressive strength was 4,500 psi with three inches max aggregate. Thermal transistors were expected for the mass placement quality control requirements. Spillway monoliths were detailed with upstream drains that would be drilled 15 feet into bedrock and discharge into gallery. The galleries would be drained intermittently downstream through the spillway concrete. A 12-inch diameter pipe was detailed downstream of the sluice gates and parallel to the sluiceway for ventilation. A cross section of the Upper Tar River Dry Dam spillway is shown in Figure 3. Spillway reinforcement for the Upper Tar River Dry Dam is shown in Figure 4.

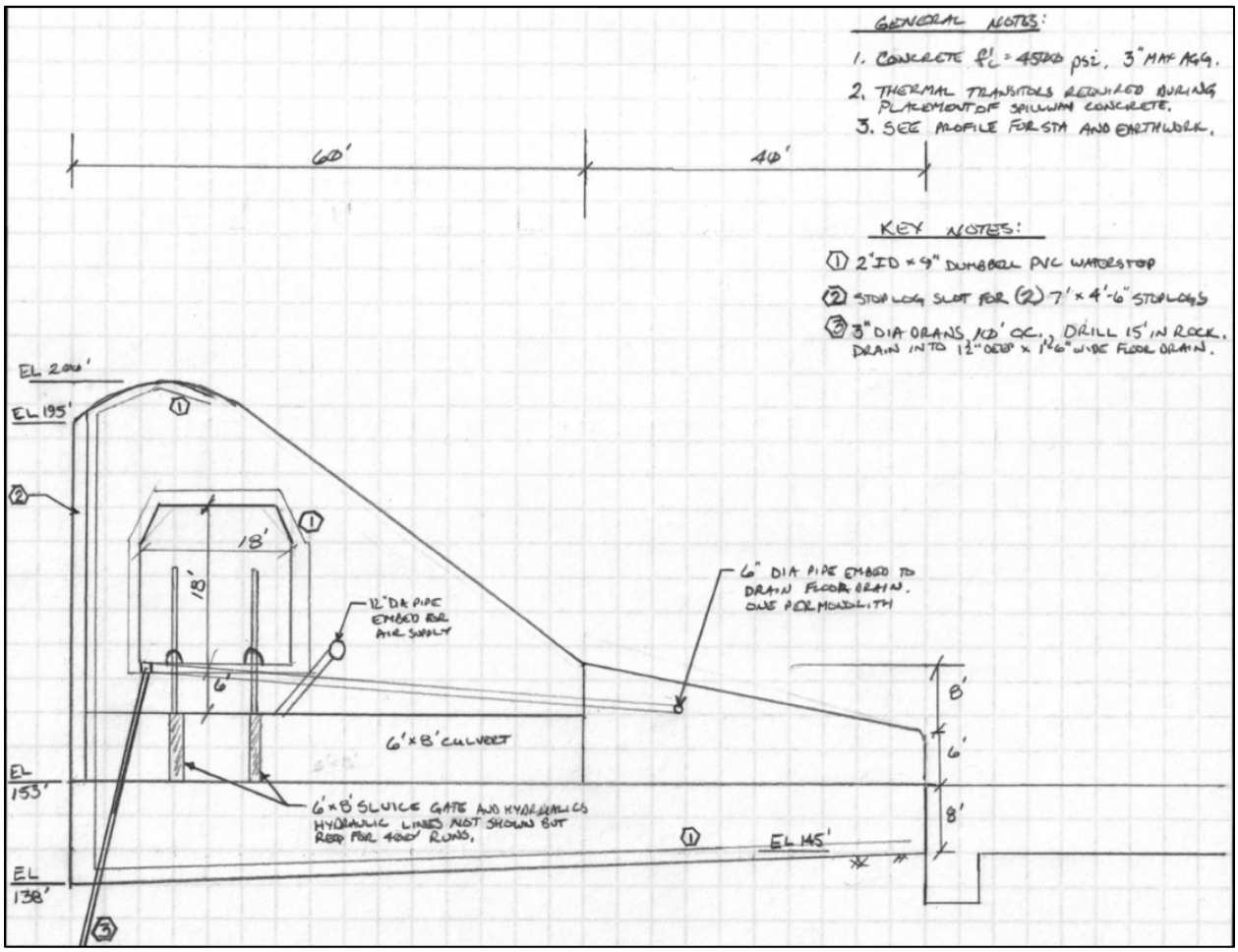

Figure 3. Upper Tar Dry Dam Spillway Cross Section

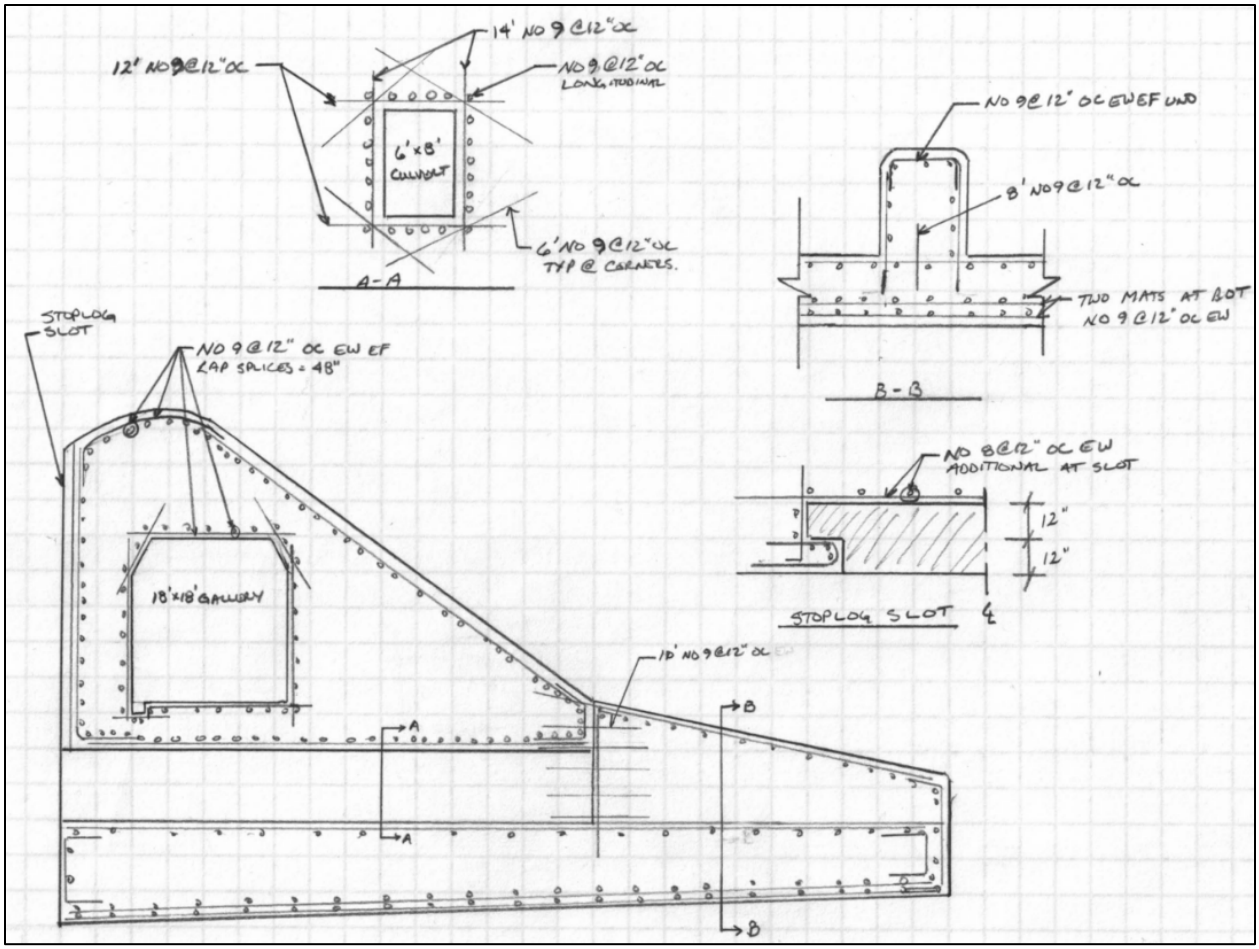

Figure 4. Upper Tar Dry Dam Spillway Reinforcement

An anchored stilling basin apron was designed immediately downstream of the spillway structure. The apron would be eight feet thick conventional concrete reinforced with No 9 rebar at 12 inches on center each way at each face. The slabs would have a six-foot-deep by six-foot-wide key at the upstream edge of each slab and contain waterstops along the perimeter of each slab. Slabs were proposed with concrete compressive strength equal to 5,000 psi with three inches max aggregate. Sixteen drains per slab of three inches diameter tipped 30 feet below the base of apron at a 30-degree incline were proposed. Passive No 14 Grade 75 anchors with PTI Class II corrosion protection, 37 feet long, were proposed for stability of the slabs during peak discharges. A pair of five-foot-high by five-foot-deep by five-foot-wide baffle blocks were proposed for each center slab. No 8 rebar at 12 inches on center was detailed for each face of a baffle, with 12 additional No 9 bars doweling each baffle block to the slab. A four-foot-thick stone protection would be placed for 25 feet downstream of the apron, transitioning to the stream bed. See Figure 5 for longitudinal cross section of the stilling basin and Figure 6 for typical apron slab reinforcing and drain detail.

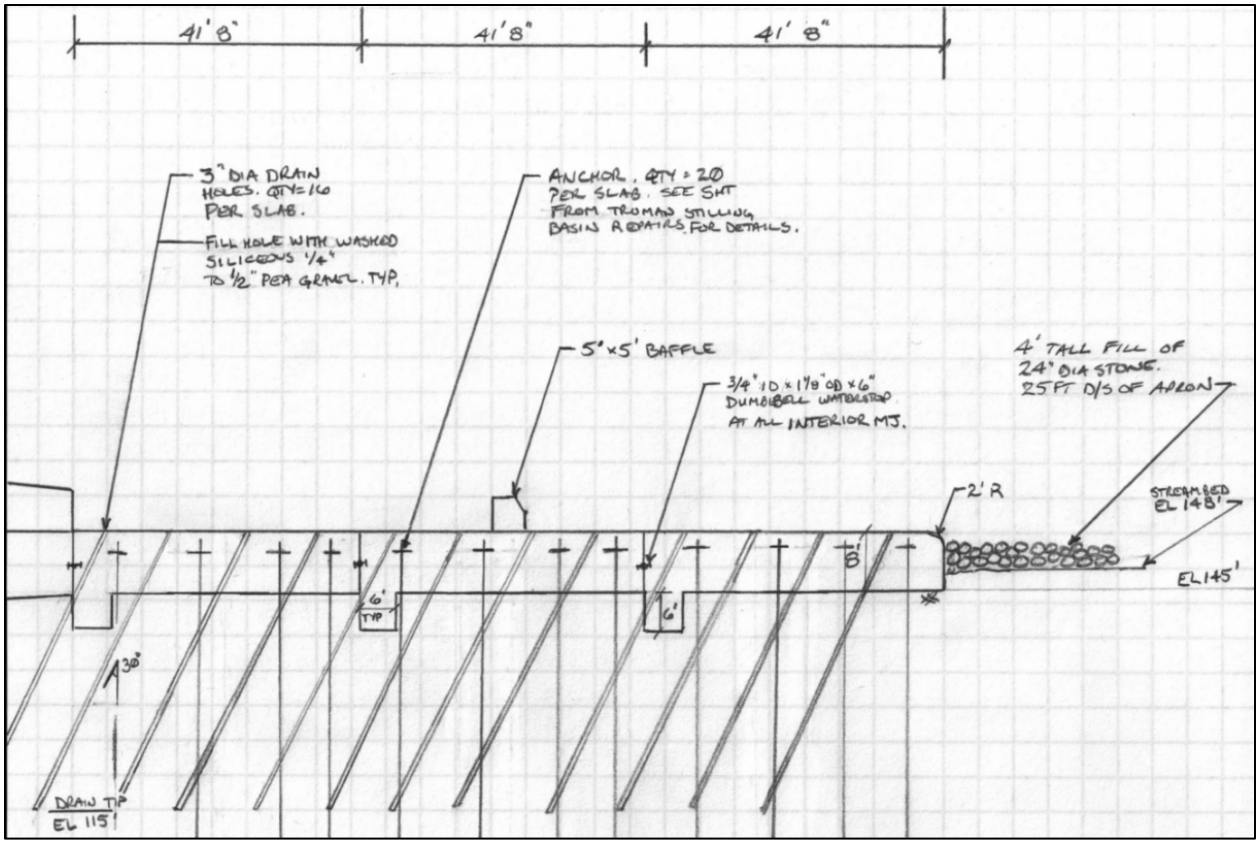

Figure 5. Typical Dry Dam Stilling Basin Longitudinal Cross Section

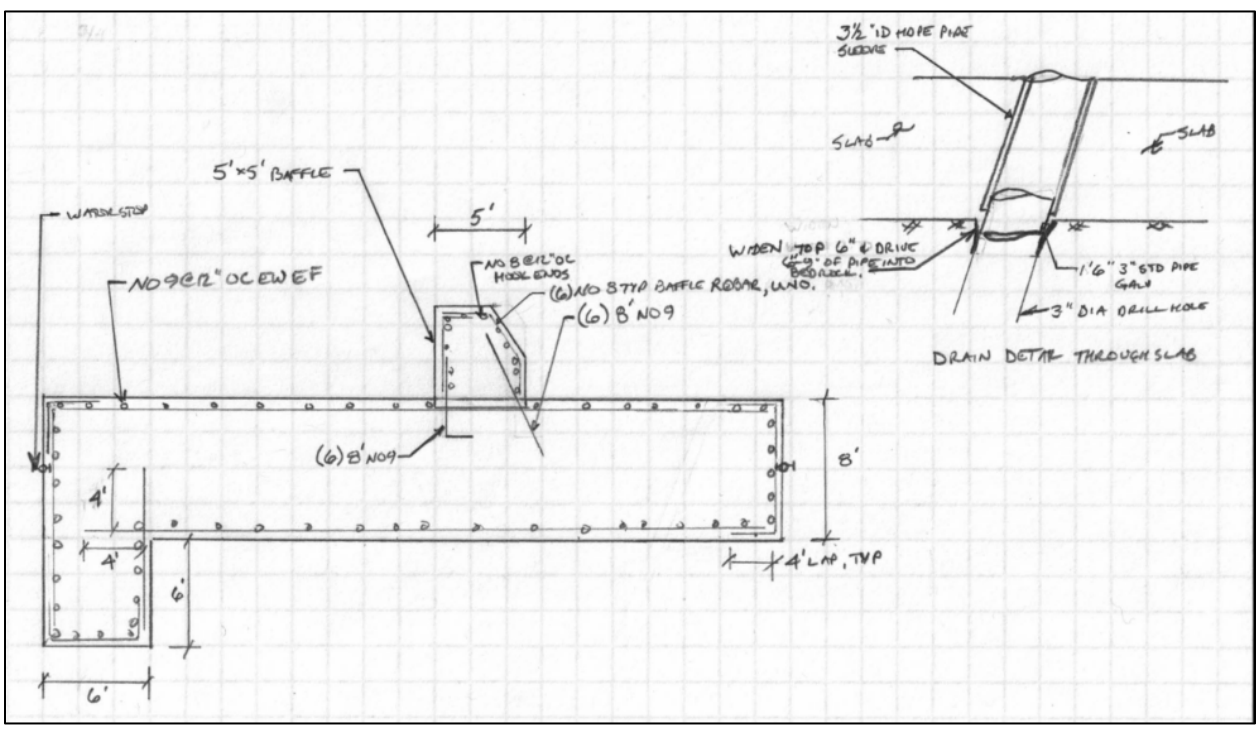

Figure 6. Typical Dry Dam Apron Reinforcing and Drain Detail

Non-overflow monoliths would be mass concrete with No 9 rebar at 12 inches on center each way at exterior faces. Due to mass placement, thermal transistors were expected for monitoring quality of concrete. The top of the monoliths adjacent to the spillway would have galvanized grating covering a three-foot by 12-foot access to a 30-foot-wide (and 55-foot high at Upper Tar) maintenance room. This room would be necessary for access, installation, and removal of sluice gates in the spillway. Embedded rails were proposed at the center of this room and constructed throughout the spillway galleries for transporting gates through the galleries. Waterstops were detailed at each monolith joint, and upstream waterstops would be embedded five feet into grouted 12 inches diameter hole drilled in bedrock. Monoliths adjacent to spillway would require a reinforced stem parallel to flow to retain grading and act as hydraulic training walls during spillway discharges.

Mass concrete gravity walls were designed for training walls each side of the spillway. The training walls would begin at the toe of the non-overflow monoliths and extend approximately 100 feet beyond the stilling basin end sill. The concrete would have minimum steel reinforcing to satisfy EM 1110-2-2104 temperature and shrinkage steel in the amount of No 9 rebar at 12 inches on center at each face. Monolith joints were constructed with water stops that would be grout-socketed into bedrock. Longitudinal drains would be located on landside that intermittently discharge through the training walls.

Upper Tar River Dry Dam: The Upper Tar River dry dam would have a larger design head compared to Stony Creek and Fishing Creek dry dams. Stoney Creek and Fishing Creek would have longer dams. All dry dams would have similar features. To accommodate planning metrics, Upper Tar dry dam was used for design and detailing all dry dam features, and then the other dry dams were scaled appropriately for quantity estimates. A plan view of Upper Tar spillway and stilling basin is shown in Figure 7. The Upper Tar spillway length is 400 feet.

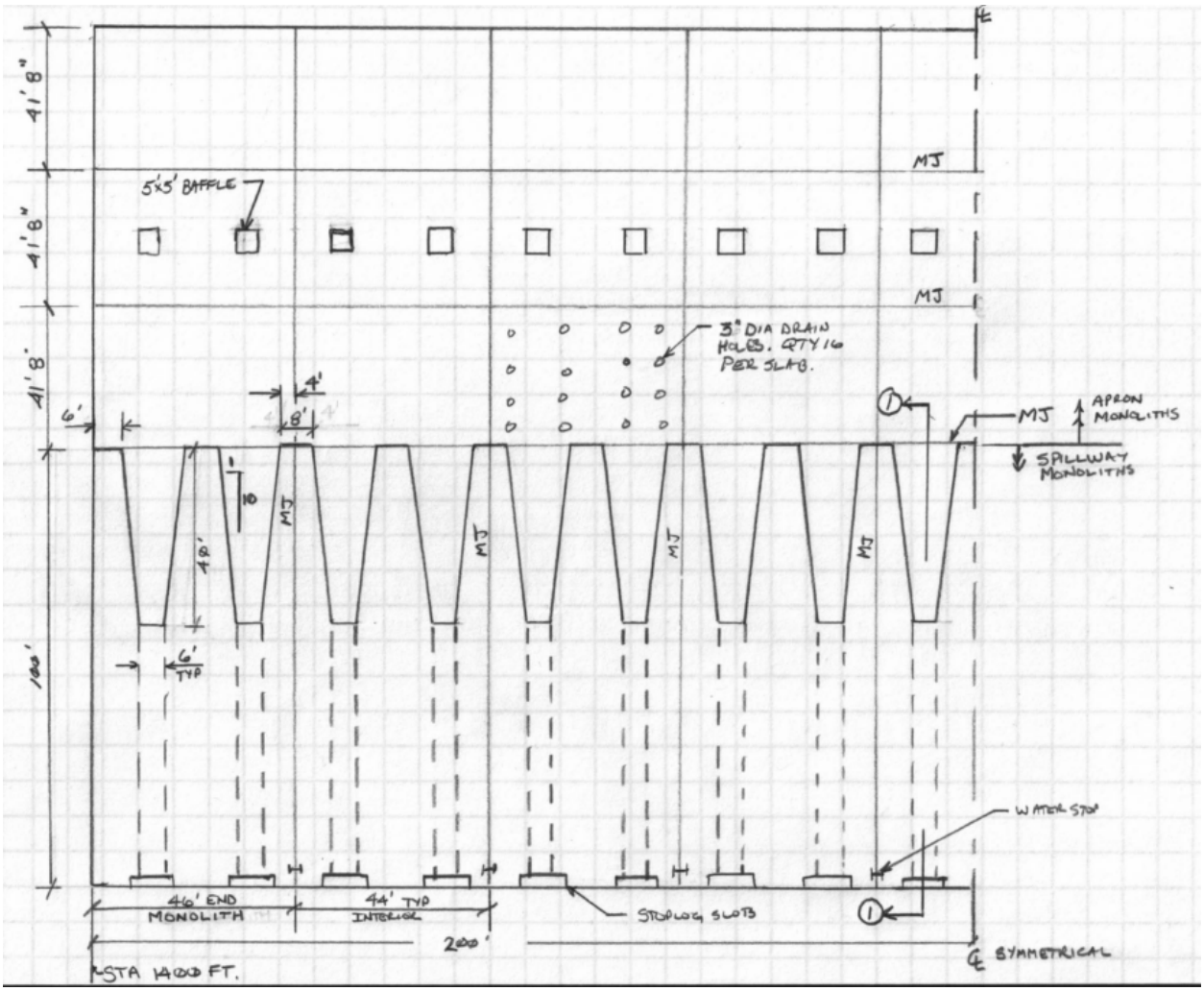

Figure 7. Upper Tar Dry Dam Spillway and Stilling Basin Plan View

To meet stability requirements, the Upper Tar dry dam non-overflow section would require a 95-foot-wide base. For monoliths adjacent to the spillway, the training wall stem bottom lift would require No 11 rebar at six inches on center at the landside face and No 9 rebar at six inches on center at the riverside face. The top lift and all horizontal reinforcement proposed No 9 rebar at 12 inches on center. See Figure 8 for a cross section view of non-overflow monolith adjacent to spillway. It is anticipated that non-overflow sections would be required for 780 linear feet (STA 8+00 to STA 14+00 and STA 18+00 to STA 19+80).

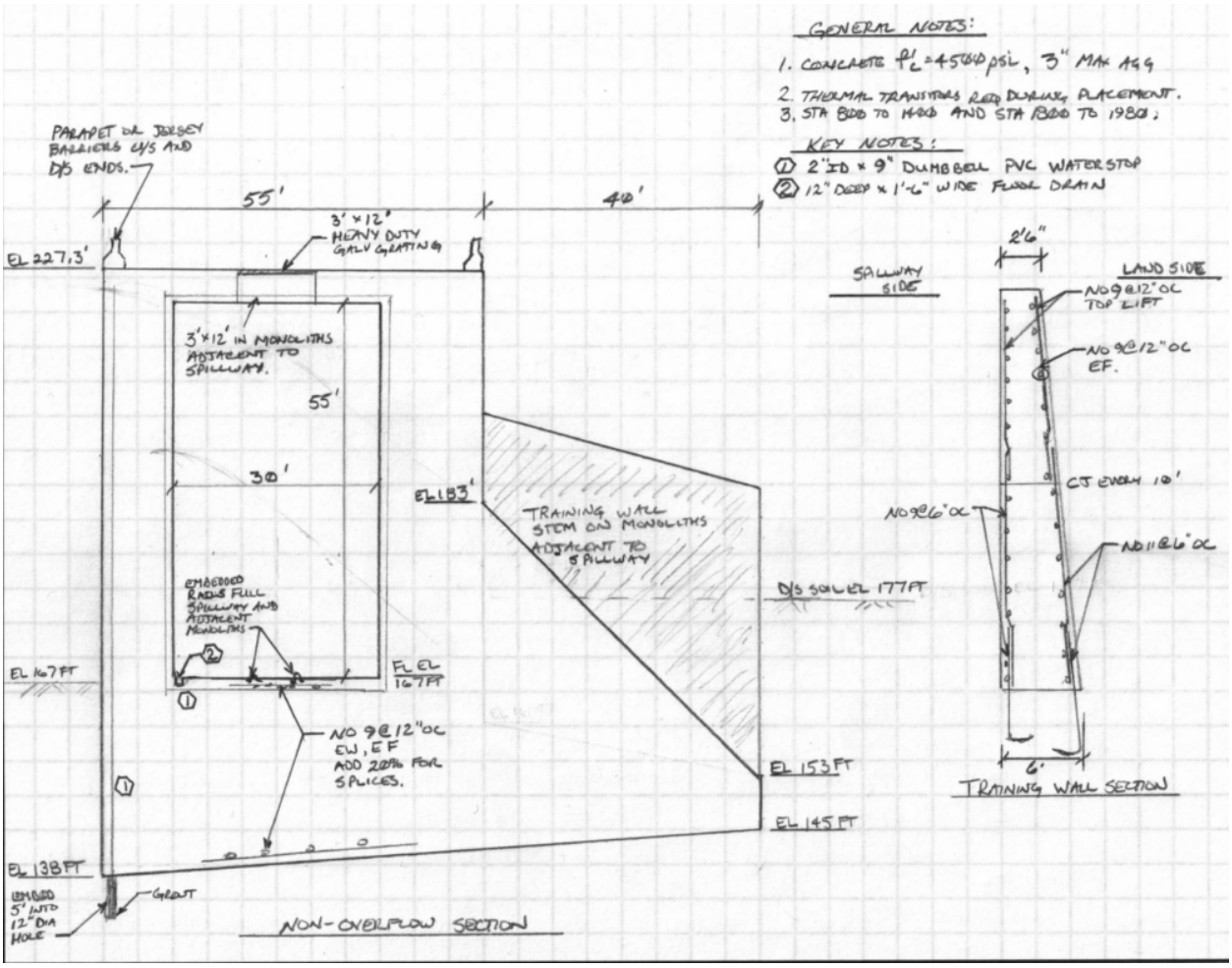

Figure 8. Upper Tar Dry Dam Non-Overflow Monolith Adjacent to Spillway Cross Section and Stem Detail

The Upper Tar training walls would be 40 feet wide to meet stability requirements and constructed for 213.33 linear feet each side of the stilling basin. A detail cross section is shown in Figure 9.

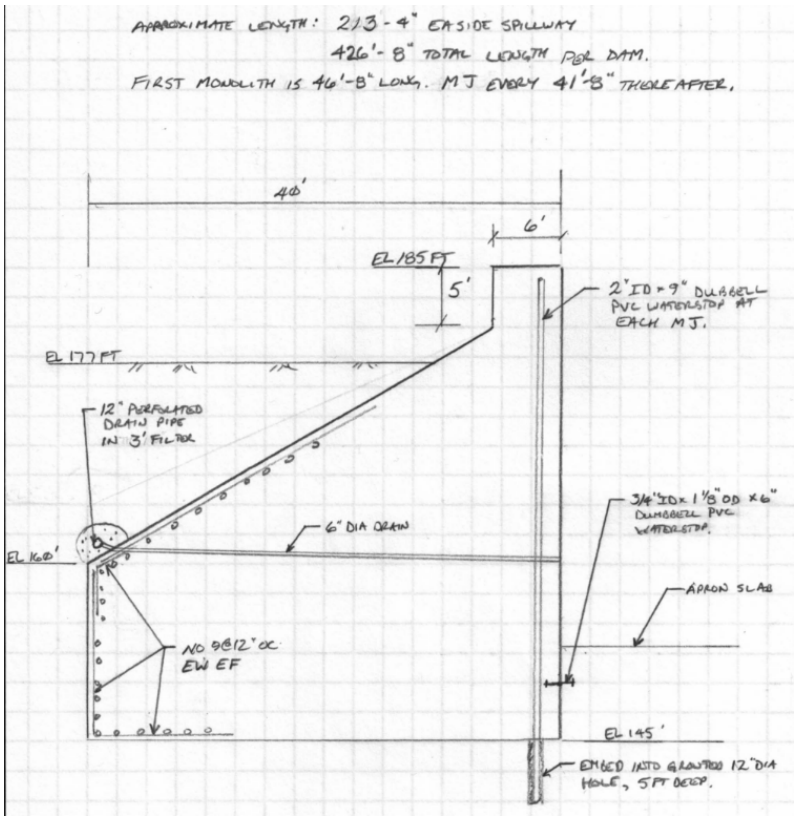

Figure 9. Upper Tar Dry Dam Stilling Basin Training Wall Cross Section

A summary of pertinent design data, quantities, and associated cost estimates for the Upper Tar River Dry Dam are provided below in Table 4.

Table 4. Summary of pertinent design data, quantities, and associated cost estimates for the Upper Tar River Dry Dam

Dam Location		
County and State	Franklin County, North Carolina	
Location Coordinates	Latitude: 35.953198°	Longitude: -78.218756°
River	Tar River	
Closest Downstream Population Center	Spring Hope, North Carolina	
Watershed Area Above Dry Dam	553 square miles	
Dam Features		
Dam Type	Rolled Earth Embankment with Gravity Spillway Monoliths	
Estimated Maximum Flood Storage	344,000 acre-feet	
Normal Pool Elevation	Dry Dam, Normal River Stage	
Top of Dam Elevation (NAVD 1929)	227.3 feet	
Top of Dam Length	3,100 feet	
Maximum Dam Height	79.2 feet	
Estimated Embankment Earthfill Quantity	108,100 cubic yards	

Estimated Embankment Foundation Excavation Quantity	18,600 cubic yards
Outlet Works and Spillway	
Spillway Type	Uncontrolled Ogee Service Spillway
Estimated PMF Design Discharge	122,400 cubic feet per second
Spillway Crest Elevation	200.0 feet
Spillway Crest Width	400 feet
Outlet Works Type	Eighteen (18) Gated Sluices with Stilling Basin
Outlet Invert Elevation	149 feet
Estimated Structural Concrete Quantity	183,000 cubic yards
Estimated Structural Steel Quantity	3,250 tons
Estimated Spillway Foundation Excavation Quantity	164,550 cubic yards
Estimated Preliminary ROM Costs to Build	
PED	$55,000,000
Construction	$202,000,000
S&A	$27,000,000
Environmental Mitigation	$10,000,000
Contingency	$71,000,000
Total	$365,000,000

Stony Creek Dry Dam: Based upon H&H data, the Stony Creek overflow structures would be very similar (slightly smaller) than Upper Tar overflow structures. Therefore, computed quantities for Upper Tar spillway, apron, rock anchors, drains, mechanical equipment, gates, water stops, piping, drains, and downstream rip rap were used for Stony Creek structures. Stony Creek non-overflow monoliths were analyzed for stability and found the width of the structures to be 85 feet. There would be a total of 550 feet of non-overflow monoliths, 350 feet on left side and 200 feet on the right side. From stability analysis, the mass concrete constructed training walls would be 35 feet wide. There would be 223.33 feet of training wall on each side of the stilling basin. The remaining 6,100 ft of dam was assumed to be earthen embankment.

A summary of pertinent design data, quantities, and associated cost estimates for the Stony Creek Dry Dam are provided below in Table 5.

Table 5. Summary of pertinent design data, quantities, and associated cost estimates for the Stony Creek Dry Dam

Dam Location		
County and State	Nash County, North Carolina	
Location Coordinates	Latitude: 35.988743°	Longitude: -77.997743°
River	Stony Creek	
Closest Downstream Population Center	Nashville, North Carolina	
Watershed Area Above Dry Dam	52.3 square miles	
Dam Features		

Dam Type	Rolled Earth Embankment with Gravity Spillway Monoliths
Estimated Maximum Flood Storage	54,000 acre-feet
Normal Pool Elevation	Dry Dam, Normal River Stage
Top of Dam Elevation (NAVD 1929)	198.8 feet
Top of Dam Length	8,800 feet
Maximum Dam Height	57.0 feet
Estimated Embankment Earthfill Quantity	323,280 cubic yards
Estimated Embankment Foundation Excavation Quantity	46,630 cubic yards
Outlet Works and Spillway	
Spillway Type	Uncontrolled Ogee Service Spillway
Estimated PMF Design Discharge	23,400 cubic feet per second
Spillway Crest Elevation	187.0 feet
Spillway Crest Width	400 feet
Outlet Works Type	Eighteen (18) Gated Sluices with Stilling Basin
Outlet Invert Elevation	143 feet
Estimated Structural Concrete Quantity	122,700 cubic yards
Estimated Structural Steel Quantity	2,600 tons
Estimated Spillway Foundation Excavation Quantity	142,660 cubic yards
Estimated Preliminary ROM Costs to Build	
PED	$37,000,000
Construction	$139,000,000
S&A	$19,000,000
Environmental Mitigation	$10,000,000
Contingency	$49,000,000
Total	$254,000,000

Fishing Creek Dry Dam: According to the alignment, grade, and H&H data, the spillway and non-overflow monoliths are about 67% the size of Upper Tar. The spillway length of 400 feet and apron length of 125 feet are the same as Upper Tar's structures. Therefore, 90% of the concrete and rebar quantities computed for Upper Tar spillway, apron, and training walls are used for Fishing Creek quantities. Fishing Creek's stilling basin are assumed to require 16 anchors pers slab. Quantities for gates, stoplogs, mechanical equipment, waterstops, piping, downstream rip rap, and drains are assumed equivalent to those computed for Upper Tar.
The cross-sectional quantities per unit length computed for Upper Tar non-overflow monoliths are scaled down by 83% to account for smaller structures at Fishing Creek. However, the length of non-overflow monoliths increases to 1,600 linear feet due to the alignment crossing the river three times at the spillway. The remaining 28,400 feet of dam is assumed earthen embankment.

A summary of pertinent design data, quantities, and associated cost estimates for the Fishing Creek Dry Dam are provided below in Table 6.

Table 6. Summary of pertinent design data, quantities, and associated cost estimates for the Fishing Creek Dry Dam.

Main Dam Location		
County and State	Halifax County, North Carolina	
Coordinates	Latitude: 36.109141°	Longitude: -77.548968°
River	Fishing Creek	
Closest Downstream Population Center	Tarboro, North Carolina	
Watershed Area Above Dry Dam	744 square miles	
Main Dam Features		
Dam Type	Rolled Earth Embankment with Gravity Spillway Monoliths	
Estimated Maximum Flood Storage	754,300 acre-feet	
Normal Pool Elevation	Dry Dam, Normal River Stage	
Top of Dam Elevation (NAVD 1929)	103.0 feet	
Top of Dam Length	30,000 feet	
Maximum Dam Height	48.2 feet	
Estimated Embankment Earthfill Quantity	4,236,970 cubic yards	
Estimated Embankment Foundation Excavation	295,370 cubic yards	
Outlet Works and Spillway		
Spillway Type	Uncontrolled Ogee Service Spillway	
Estimated PMF Design Discharge	40,400 cubic feet per second	
Spillway Crest Elevation	87.7 feet	
Spillway Crest Width	400 feet	
Outlet Works Type	Eighteen (18) Gated Sluices with Stilling Basin	
Outlet Invert Elevation	56 feet	
Estimated Structural Concrete Quantity	260,500 cubic yards	
Estimated Structural Steel Quantity	3,800 tons	
Estimated Spillway Foundation Excavation	417,940 cubic yards	
Marsh Dike Embankment		
County and State	Halifax County, North Carolina	
Location Coordinates	Latitude: 36.200991°	Longitude: -77.594167°
Closest Downstream Population Center	Tillery, North Carolina	
Maximum Embankment Height	26 feet	
Embankment Length	4,300 feet	
Estimated Embankment Earthfill Quantity	208,760 cubic yards	
Estimated Embankment Foundation Excavation	39,280 cubic yards	
Halifax Dike Embankment		
County and State	Halifax County, North Carolina	
Location Coordinates	Latitude: 36.305840°	Longitude: -77.600561°
Closest Downstream Population Center	Halifax, North Carolina	

Maximum Embankment Height	9 feet	
Embankment Length	2,600 feet	
Estimated Embankment Earthfill Quantity	25,570 cubic yards	
Estimated Embankment Foundation Excavation	14,425 cubic yards	
Enfield Dike Embankment		
County and State	Halifax County, North Carolina	
Location Coordinates	Latitude: 36.185510°	Longitude: -77.657083°
Closest Downstream Population Center	Enfield, North Carolina	
Maximum Embankment Height	5 feet	
Embankment Length	7,100 feet	
Estimated Embankment Earthfill Quantity	46,935 cubic yards	
Estimated Embankment Foundation Excavation	31,865 cubic yards	
Estimated Preliminary ROM Costs to Build Project		
PED	$126,000,000	
Construction	$460,000,000	
S&A	$60,000,000	
Environmental Mitigation	$70,000,000	
Contingency	$161,000,000	
Total	$877,000,000	

2.2.2. Measure Screening

This section provides an overview of measure screening. Please refer to Appendix F, Hydraulics and Hydrology Report and Appendix B, Economic Analysis for descriptions of the effects of the dry dams on downstream flood risk and associated benefits, respectively.

Stony Creek Dry Dam: Hydrologic and hydraulic (H&H) modeling of the Stony Creek Dry Dam indicated that it was effective at reducing downstream flood elevations and associated risk. An assessment of preliminary costs and benefits associated with the Stony Creek Dry Dam indicated that additional analysis and incorporation into the initial array of alternatives was warranted (i.e., preliminary benefit cost ratio of 1.6). However, during evaluation of the initial array of alternatives with more refined two-dimensional modeling, it became evident that the Stoney Creek Dry Dam did not have sufficient benefits to justify the cost. As a result, alternatives including this measure were screened from further consideration. The dry dam would have significant environmental impacts to critical habitat and associated threatened and endangered species that would require mitigation.

Upper Tar River Dry Dam: Initial hydrologic and economic analysis indicated that the Upper Tar River Dry Dam would work together with the Stony Creek Dry Dam to reduce flood risk within Rocky Mount and that additional design work and screening is warranted. However, during evaluation of the initial array of alternatives with more refined two-dimensional modeling, it became evident that the Upper Tar River Dry Dam did not have the benefits to justify the cost. As a result, alternatives including this measure were screened from further consideration. The

dry dam would have significant environmental impacts to critical habitat and associated threatened and endangered species that would require mitigation.

Fishing Creek Dry Dam: Hydrologic and hydraulic (H&H) modeling of the Fishing Creek Dry Dam indicated that it was effective at reducing downstream flood elevations and associated risk. However, an assessment of preliminary costs and benefits determined that the Fishing Creek Dry Dam would not be economically justified. Therefore, the Fishing Creek Dry Dam was removed from further consideration. The dry dam would have significant environmental impacts to critical habitat and associated threatened and endangered species that would require mitigation.

2.3. Floodwalls and Earthen Levees

2.3.1. Measure Description

Typical Design Considerations and Assumptions: Each levee and floodwall system was proposed as a standalone management measure for the purposes of screening and was aligned attempt to protect the greatest population density. Each levee and floodwall was generally evaluated up to the 1% annual exceedance events. This is based on the existing Princeville Levee which, provides protection up to the 1% annual exceedance event. It was assumed that the proposed levee geometries (Figure 10), foundation conditions (i.e., moderately pervious sands with varying lenses of fine-grained material and intermittent fine-grained blanket material) would be similar to the existing Princeville Levee. Levees were assumed to require stability berms on both the landside and riverside.

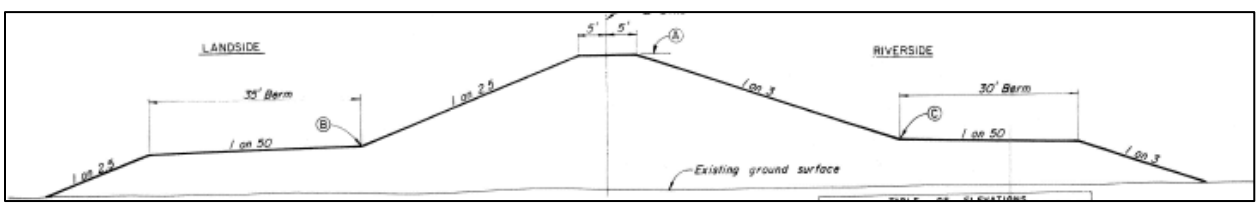

Figure 10. Typical geometries for proposed levees.

Rocky Mount Levee System: An elevation 100 feet was the assumed design elevation. Five different levee segments were proposed, totaling 58,100 feet (Figure 11). The maximum embankment height could be as great as thirty (30) feet. Several closure structures will be needed along the length of the levee segments, including two railroad closures. A minimum of two pump stations will be needed within this levee system. The pump station on levee 2B would need to be a major structure capable of handling significant interior ponding. Modification to the US 64 Bridge where it crosses the Tar River would be required.

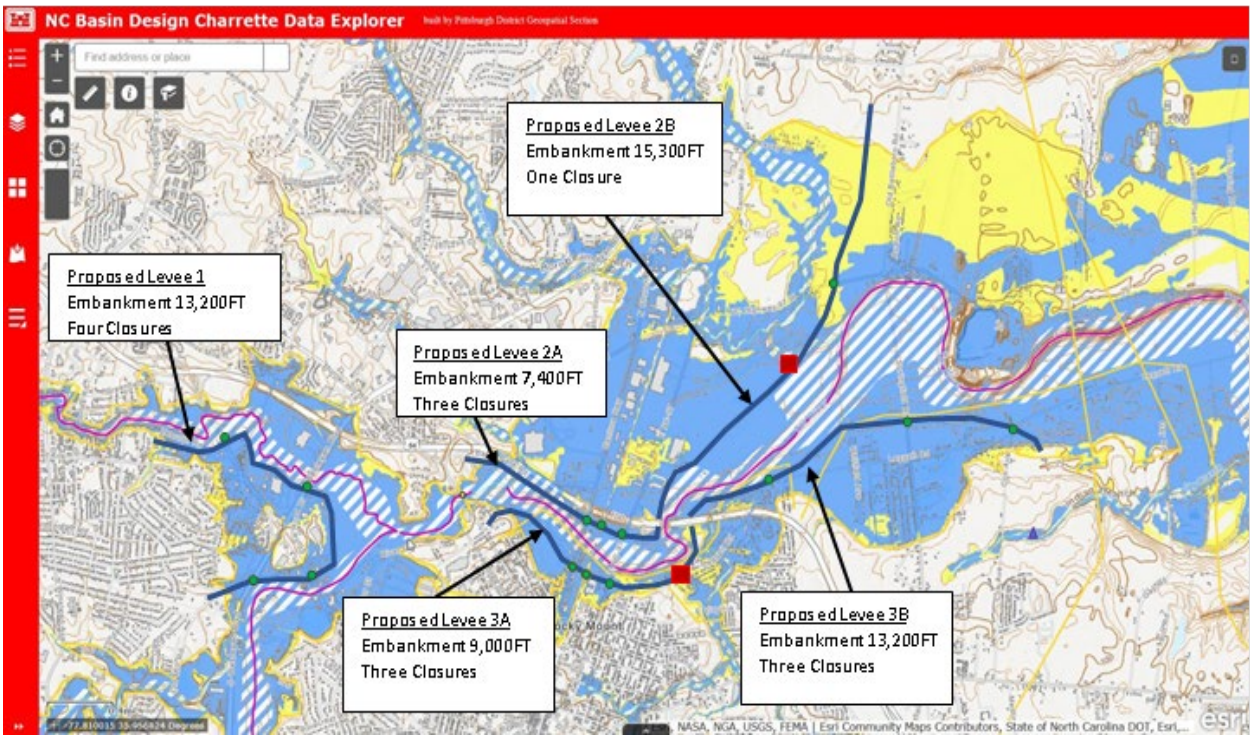

Figure 11. Proposed alignment of the five levee segments for the Rocky Mount Levee System.

Tarboro Wastewater Treatment Plant: Floodwall along the right descending bank of the Tar River adjacent to the Tarboro Wastewater Treatment Plant. Minimal design effort was undertaken due to anticipated costs and lack of benefits.

East Tarboro: An elevation 50 feet was the assumed design elevation. One levee segment (9,200 liner feet) and one floodwall segment (2,200 linear feet) separated by a railroad closure were proposed, totally approximately 11,400 feet (Figure 12). The floodwall would be a T wall. The levee and floodwall heights could be as high as thirty (30) feet. Three closure structures and two pump stations would be needed. Modification to the Main Street Bridge and Railroad Bridge where it crosses the Tar River.

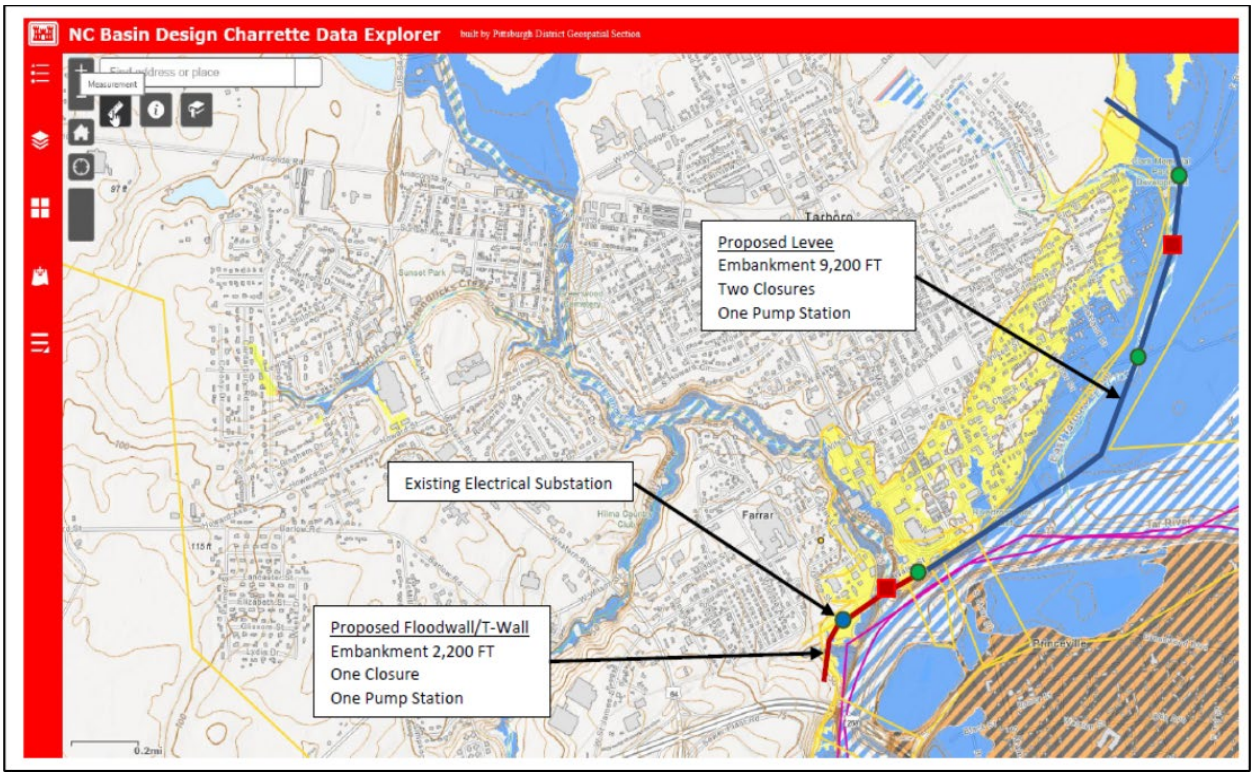

Figure 12. Proposed alignment of the levee and floodwall and associated features proposed for east Tarboro.

Tarboro-Edgecombe Airport: An elevation 50 feet was the assumed design elevation. One levee segment totaling 13,200 linear feet was considered around the Tarboro-Edgecombe Airport. Minimal design effort was undertaken due to anticipated costs and lack of benefits.

Greenville Levee System: An elevation 25 to 30 feet approximately represents the 1% annual exceedance event. Two different levee segments separated by high ground adjacent to US 264 were proposed for this exercise (Figure 13). Total linear feet of protection would be approximately 27,700 feet. An estimate of maximum levee height could be as great as fifteen feet. A levee system in this area would include four closure structures and a pump station for interior drainage. Foundation seepage will be a major concern and will likely have to be mitigated during construction.

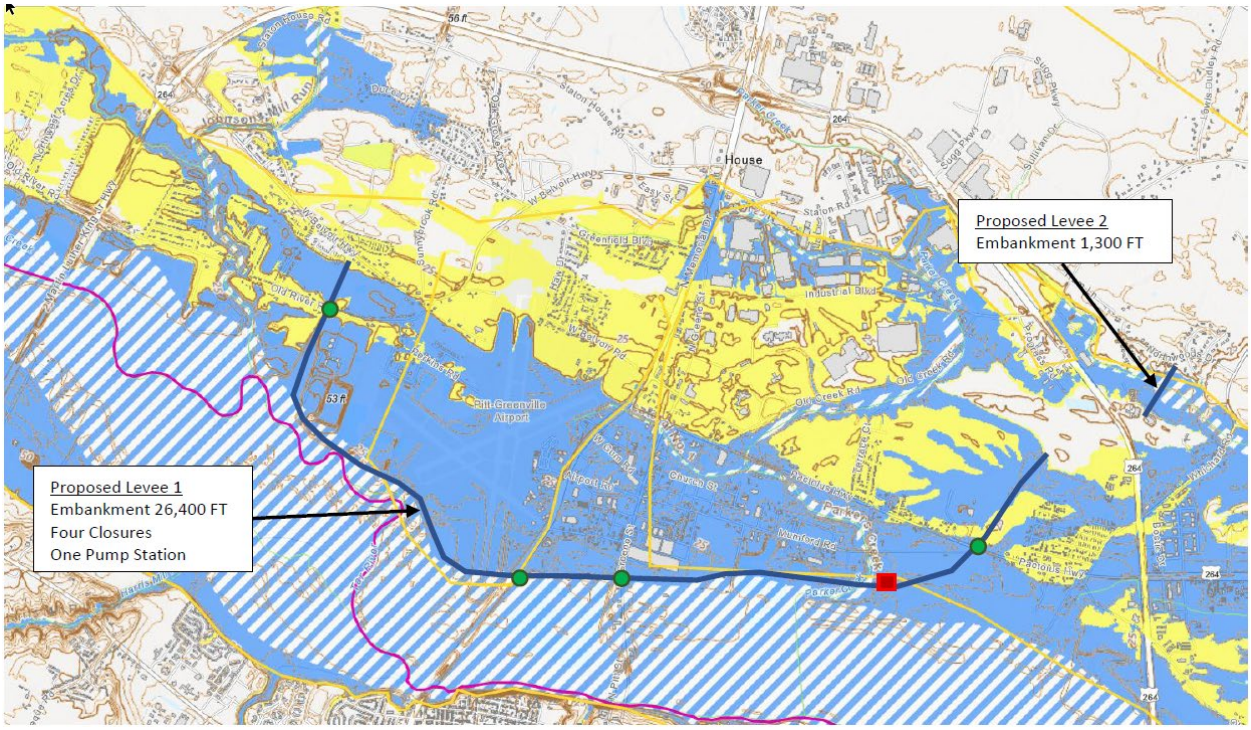

Figure 13. Proposed alignment of the two levee segments for the Greenville Levee System.

Green Mill Run: An elevation of 25 to 30 feet approximately represents the 1% annual exceedance event. One levee segment with a pump station and ponding area were proposed (Figure 14). Total linear feet of protection would be approximately 800 feet. An estimate of maximum levee height could be as great as fifteen feet. The pump house required could cost in the range of $20M to $50M. The pump house design can be optimized and construction costs potentially reduced if fourteen constrictions (i.e. bridge crossings/culverts) are modified to increase channel capacity. Removal of vegetation within channel, channel armoring, and channel straightening are recommended, as well, to increase capacity of Green Mill Run.

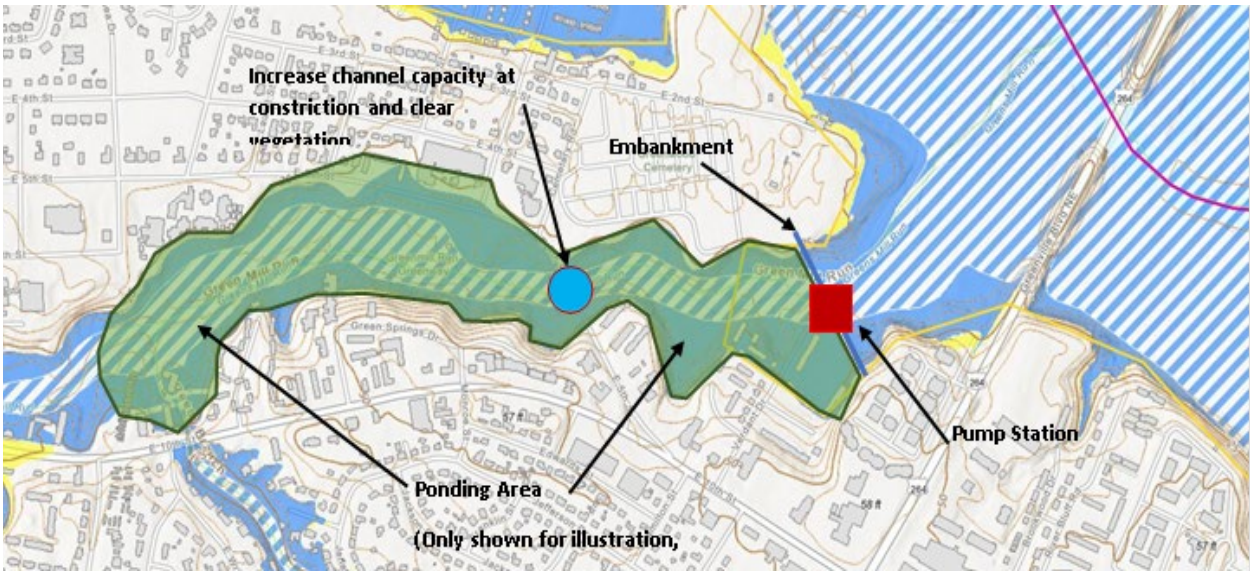

Figure 14. Proposed location of the levee segment and pump station on Green Mill Run.

2.3.2. Measure Screening

Preliminary costs and benefits were assessed for all floodwall and levee systems. None of the floodwall and/or levee systems had positive net economic benefits, with benefit cost ratios ranging from 0.04 to 0.6. As a result, they do not represent efficient measures and were screened from further consideration.

2.4. Diversion Channels

2.4.1. Measure Description

A series of 13 diversion or auxiliary diversion channels were considered by the study team (Figure 15). The level of design detail varied for each channel and was based on risk-informed decisions that leveraged information gathered from the design and analysis of other measures.

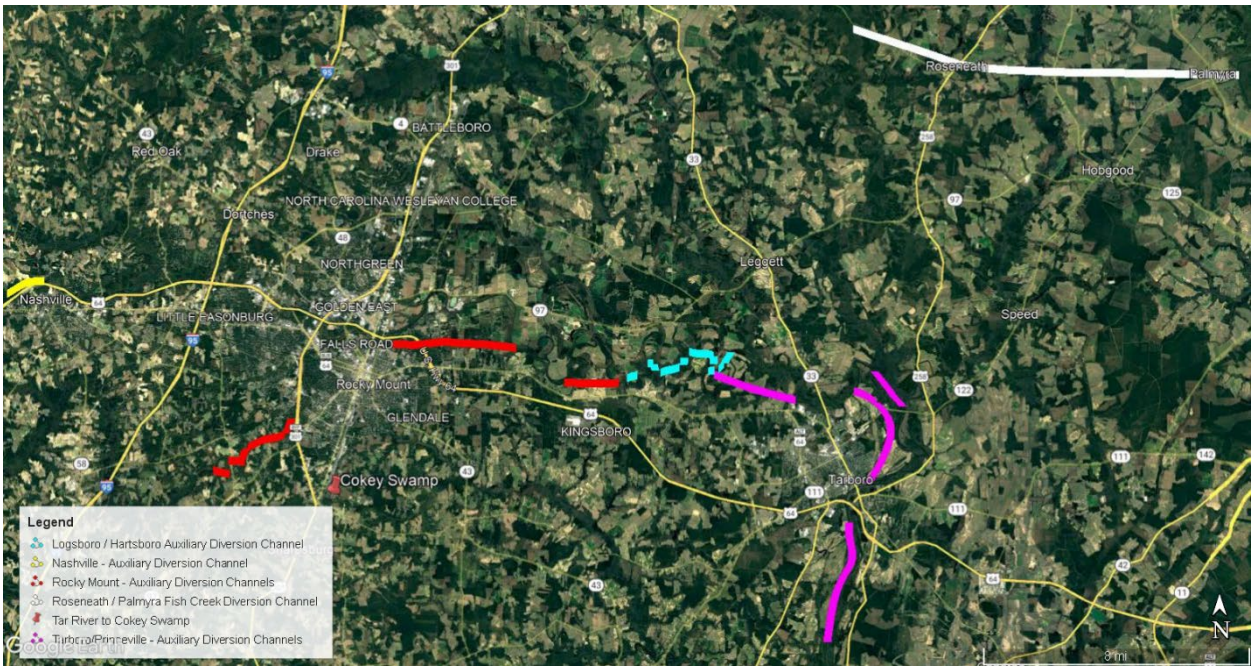

Figure 15. Location of the 13 diversion channels considered for flood risk reduction.

Nashville Auxiliary Diversion Channel – Stony Creek: Diversion channel that would reroute water upstream Nashville north of Highway 64. The channel would be 6,500 linear feet with a 30-foot channel bottom width and 2.5:1 side slopes. The channel would include two weir structures—one upstream and one downstream. Bottom of the channel would be unlined, with 18-inch-thick riprap on side slopes.

Logsboro / Hartsboro Auxiliary Diversion Channel: This measure consists of a series of seven auxiliary channels that connect meanders, increasing storage capacity and hydraulic conductivity.

Tarboro / Princeville Auxiliary Diversion Channel #1: This measure consists of redirecting Penders Mill Run and creation of an auxiliary channel on the Tar River that would connect meanders, increasing storage capacity and hydraulic conductivity.

Tarboro / Princeville Auxiliary Diversion Channel #2: Creation of an auxiliary channel on the Tar River that would connect meanders, increasing storage capacity and hydraulic conductivity.

Tarboro / Princeville Auxiliary Diversion Channel #3: Creation of an auxiliary channel on the Tar River that would connect meanders, increasing storage capacity and hydraulic conductivity.

Tarboro / Princeville Auxiliary Diversion Channel #4: Diversion channel #4 is located south of Tarboro and Princeville, NC and runs roughly parallel to the Tar Pamlico River, increasing storage and hydraulic conductivity. The channel would be approximately 19,500 feet with a 160-foot channel bottom and 2.5:1 side slopes. The channel would include two weir structures—one upstream and one downstream. Bottom of the channel would be unlined, with 18-inch-thick riprap on side slopes.

Rocky Mount Auxiliary Diversion Channel #1: Creation of an auxiliary channel on the Tar River that would connect meanders, increasing storage capacity and hydraulic conductivity.

Rocky Mount Auxiliary Diversion Channel #2: Creation of an auxiliary channel on the Tar River that would connect meanders, increasing storage capacity and hydraulic conductivity.

Rocky Mount Auxiliary Diversion Channel #3: Creation of an auxiliary channel that runs parallel with the Tar River upstream and within Rocky Mount that would increase storage capacity and reduce adjacent flooding. The channel would be 6,500 linear feet with a 45-foot channel bottom width and 2.5:1 side slopes. The channel would include two weir structures—one upstream and one downstream. Channel would unlined.

Rocky Mount Auxiliary Diversion Channel #4: Creation of an auxiliary channel on the Tar River that would connect meanders, increasing storage capacity and hydraulic conductivity, and divert flows around populated areas downstream of Rocky Mount.

Rocky Mount Auxiliary Diversion Channel #5: Creation of an auxiliary channel on the Tar River that would connect meanders, increasing storage capacity and hydraulic conductivity.

Tar River to Cokey Swamp: Divert the Tar River into Cokey Swamp upstream of Rocky Mount.

Roseneath / Palmyra Fishing Creek: Divert Fishing Creek into the Roanoke River. Would discharge into a separate drainage—the study of which is outside the scope of this feasibility effort and study authority.

2.4.2. Measure Screening

Nashville Auxiliary Diversion Channel – Stony Creek: Preliminary costs and benefits were assessed for the Nashville Auxiliary Diversion Channel – Stony Creek. However, it was determined that this measure would not result in positive net economic benefits (preliminary benefit cost ratio of 0.2). As a result, it was screened from further consideration. This measure would also have significant impacts to environmental resources, including critical habitats for threatened and endangered species.

Logsboro / Hartsboro Auxiliary Diversion Channel: A risk-informed decision was made to screen the Logsboro / Hartsboro Auxiliary Diversion Channel based on the screening of the Rocky Mount Auxiliary Diversion Channel #3 (benefit cost ratio of 0.1), which was deemed to have a greater likelihood of being economically justified. Thus, this measure was screened due to lack of efficiency. This measure would also have significant impacts to environmental resources, including critical habitats for threatened and endangered species.

Tarboro / Princeville Auxiliary Diversion Channel #1: A risk-informed decision was made to screen the Tarboro / Princeville Auxiliary Diversion Channel #1 based on the screening of the Rocky Mount Auxiliary Diversion Channel #3 (benefit cost ratio of 0.1), which was deemed to have a greater likelihood of being economically justified. Thus, this measure was screened due to lack of efficiency. This measure would also have significant impacts to environmental resources, including critical habitats for threatened and endangered species.

Tarboro / Princeville Auxiliary Diversion Channel #2: A risk-informed decision was made to screen the Tarboro / Princeville Auxiliary Diversion Channel #2 based on the screening of the Rocky Mount Auxiliary Diversion Channel #3 (benefit cost ratio of 0.1), which was deemed to have a greater likelihood of being economically justified. Thus, this measure was screened due to lack of efficiency. This measure would also have significant impacts to environmental resources, including critical habitats for threatened and endangered species.

Tarboro / Princeville Auxiliary Diversion Channel #3: A risk-informed decision was made to screen the Tarboro / Princeville Auxiliary Diversion Channel #3 based on the screening of the Rocky Mount Auxiliary Diversion Channel #3 (benefit cost ratio of 0.1), which was deemed to have a greater likelihood of being economically justified. Thus, this measure was screened due to lack of efficiency. This measure would also have significant impacts to environmental resources, including critical habitats for threatened and endangered species.

Tarboro / Princeville Auxiliary Diversion Channel #4: A risk-informed decision was made to screen the Tarboro / Princeville Auxiliary Diversion Channel #4 based on the screening of the Rocky Mount Auxiliary Diversion Channel #3 (benefit cost ratio of 0.1), which was deemed to have a greater likelihood of being economically justified. Thus, this measure was screened due to lack of efficiency. This measure would also have significant impacts to environmental resources, including critical habitats for threatened and endangered species.

Rocky Mount Auxiliary Diversion Channel #1: A risk-informed decision was made to screen the Rocky Mount Auxiliary Diversion Channel #1 based on the screening of the Rocky Mount Auxiliary Diversion Channel #3, which was deemed to have a greater likelihood of being economically justified. Thus, this measure was screened due to lack of efficiency. This measure would also have significant impacts to environmental resources, including critical habitats for threatened and endangered species.

Rocky Mount Auxiliary Diversion Channel #2: A risk-informed decision was made to screen the Rocky Mount Auxiliary Diversion Channel #2 based on the screening of the Rocky Mount Auxiliary Diversion Channel #3, which was deemed to have a greater likelihood of being economically justified. Thus, this measure was screened due to lack of efficiency. This measure would also have significant impacts to environmental resources, including critical habitats for threatened and endangered species.

Rocky Mount Auxiliary Diversion Channel #3: Initial hydrologic and economic analysis indicated that the benefit cost ratio of the Rocky Mount Auxiliary Diversion Channel #3 is 0.1. Therefore, this measure was screened due to lack of efficiency. This auxiliary diversion channel was expected to provide the greatest economic benefit based on optimistic benefit estimates and rough order of magnitude cost estimate for the diversion channel. Therefore, this measure was used to screen other similar measures on the Tar River around Rocky Mount and Tarboro/Princeville. This measure would also have significant impacts to environmental resources, including critical habitats for threatened and endangered species that would require mitigation.

Rocky Mount Auxiliary Diversion Channel #4: A risk-informed decision was made to screen the Rocky Mount Auxiliary Diversion Channel #4 based on the screening of the Rocky Mount Auxiliary Diversion Channel #3 (benefit cost ratio of 0.1), which was deemed to have a greater likelihood of being economically justified. Thus, this measure was screened due to lack of efficiency. This measure would also have significant impacts to environmental resources, including critical habitats for threatened and endangered species.

Rocky Mount Auxiliary Diversion Channel #5: A risk-informed decision was made to screen the Rocky Mount Auxiliary Diversion Channel #5 based on the screening of the Rocky Mount Auxiliary Diversion Channel #3 (benefit cost ratio of 0.1), which was deemed to have a greater likelihood of being economically justified. Thus, this measure was screened due to lack of efficiency. This measure would also have significant impacts to environmental resources, including critical habitats for threatened and endangered species.

Tar River to Cokey Swamp: Topographic limitations would necessitate a pump station for the diversion channel to function, which would be expensive to install and operate. Diversion of water into Cokey Swamp would also necessitate significant modification to Cokey Swamp to prevent transferred risk. This measure would also have significant impacts to environmental resources, including critical habitats for threatened and endangered species that would require mitigation.

Roseneath / Palmyra Fishing Creek: The Roseneath / Palmyra Fishing Creek Diversion Channel would discharge into a separate drainage—the study of which is outside the scope of this feasibility effort and study authority. As a result, this measure was screened due to lack of acceptability with respect to USACE planning policy and guidance.