

Oconaluftee River Trail
Great Smoky Mountains National Park
Floodplain Statement of Findings
PMIS 321788 and PEPC 118995



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Oconaluftee River Trail

Great Smoky Mountains National Park

FLOODPLAIN STATEMENT OF FINDINGS

1 INTRODUCTION

Executive Order (EO) 11988, *Floodplain Management*, requires the National Park Service (NPS) and other federal agencies to evaluate the likely impacts of actions in floodplains. The objective of EO 11988 is to avoid, to the extent possible, the long-term and short-term adverse impacts associated with occupancy, modification, or destruction of floodplains and to avoid indirect support of development and new construction in such areas wherever there is a practicable alternative. NPS administers floodplain policy through Director's Order 77-2: *Floodplain Management* (DO 77-2) and Procedural Manual 77-2 *Floodplain Management* (PM 77-2). NPS also complies with Department of Interior guidance outlined in 520 DM 1, *Floodplain Management and Wetlands Protection Policy and Responsibilities*, and 520 DM 2, *Floodplain Management and Wetlands Protection Program Requirements*.

It is NPS policy to preserve floodplain functions and values and minimize potentially hazardous conditions associated with flooding, including threats to human health and safety, risk to NPS capital investment, and impacts on natural and beneficial floodplain values. If a proposed action is found to be in, or possibly affecting a floodplain, and relocating the action to a nonfloodplain site is considered not to be a viable alternative, then a formal Floodplain Statement of Findings (FSOF) must be prepared unless the action is considered excepted. The FSOF must (a) describe the rationale for selection of a floodplain site, (b) disclose the degree of risk associated with the chosen site (with respect to human life, health and safety, resource protection, and capital investment), and (c) explain strategies for mitigation of flood risk. The FSOF will be available for public review.

This FSOF provides:

1. A detailed justification for selecting a proposed action that would adversely impact the Federal Flood Risk Management Standard (FFRMS) floodplain (Section 2)
2. A detailed and comprehensive description of the flood hazard and risk associated with implementation of the proposed action (Section 3)
3. A thorough description of mitigation measures chosen to minimize or eliminate adverse floodplain impacts associated with the proposed action(s) (Section 4)

1.1 PREPARER

In accordance with DO 77-2 and PM 77-2, I, Eric Webb, PhD, the author of this FSOF, affirm I am a Wetland Scientist and Aquatic Ecologist with Vernadero Group Inc. and am technically qualified to prepare this document. Emily Creighton, NPS Floodplains Specialist, provided substantial input and updates to this FSOF. Additional support on nontechnical elements of the document was provided by Christopher Squires, Project Geologist; Katharine Hewlings, Geospatial Specialist; and Tim Auten, Geospatial Specialist.

1.2 LOCATION

The proposed action, described in Section 1.3, is directed at improving the Oconaluftee River Trail, Great Smoky Mountains National Park (GRSM), Swain County, North Carolina. The trail, which was constructed in 1988 and is approximately 8,513 feet (1.61 miles) in length (Figure 1), is positioned along the Oconaluftee River corridor from the Oconaluftee Visitor Center/Mountain Farm Museum to the park boundary with the Eastern Band of Cherokee Indians (EBCI) Qualla Boundary, in Cherokee, North Carolina (Figure 1; approximately latitude 35.4996, longitude -83.3047). The trail parallels the Oconaluftee River for most of its length.

The site lies in the Tuckasegee subbasin (Hydrologic Unit Code 06010203). The average monthly precipitation in Swain County, North Carolina, from January 1895 through April 2026, is 5.26 inches. The most extreme precipitation events have historically occurred in the winter and early spring months, likely associated with strong frontal passages, and in late summer when remnants of tropical storms cross the southern Appalachians. Since 1895 (1,576 total months), there have been 60 months (less than 4 percent) with precipitation exceeding 10 inches in Swain County; of those, 38 events occurred between December and March, 12 events occurred between July and October, with the remaining 10 events occurring in other months. The least precipitation occurs in the fall, with nearly all extremely low precipitation months on record occurring between September and November. Extreme precipitation events are evenly distributed through time since records that began in 1895, with 10 of 60 months (17 percent of all events) with precipitation exceeding 10 inches occurring since 2000 (20 percent of the period of record) (National Oceanic and Atmospheric Association [NOAA] 2026).

Topographic and geomorphic conditions (i.e., narrow river valley, steep adjacent slopes, and orographic precipitation patterns) contribute to high-velocity flows that mostly remain within the Oconaluftee River channel. During some precipitation events, flow overtops the riverbanks and under the most extreme precipitation events, flow will inundate the Oconaluftee River Trail (Stantec 2026a; Appendix A). Because land ownership is entirely NPS federal land, and the watershed is heavily forested, there is a high capacity in the watershed to slow and store precipitation. Additionally, although the upper reaches of the Oconaluftee River are confined V-shaped valleys with steep gradients typical of high-energy mountain headwater streams. In the lower reaches at the confluence with Raven Fork in the project area, the Oconaluftee River forms broad bottomlands with established floodplains featuring flat terrain and natural levee-like depositional zones (US Geological Survey 2026). Therefore, in the project area, with its broad floodplain and reduced channel slope, high-intensity, localized rainfall does not cause flash flooding, which is the most life-threatening type of flooding. The flooding that occurs does not meet the PM 77-2 definition of flash flooding.

1.3 PROPOSED ACTION

GRSM proposes to improve the multiuse Oconaluftee River Trail as well as Saunooke Bridge Connector and supporting infrastructure in the vicinity of the trail; the proposed action is described in detail, section by section from south to north, below (Figures 2 through 6; Table 1). The purpose of this project is to provide a safe and more accessible trail on which to approach the Oconaluftee River and to connect the Oconaluftee Visitor Center to the EBCI Qualla Boundary. The need is associated with the generally high use of the trail and issues with trail maintenance, such as persistent

erosion, locations that are not at an accessible grade, and inadequate widths to allow for safe use by pedestrians and bicyclists. In many instances along the trail, use of fill is the preferred technique to maintain and protect cultural resources.

The proposed action rehabilitates the existing multiuse Oconaluftee River Trail (pedestrians and bicycles only) to improve safety, accessibility (Architectural Barriers Act Accessibility Standard), and connectivity.

Components of the trail project are described from the southern end of the trail past the intersection of the Saunooke Bridge Road and Newfound Gap Road (Highway 441) to the northern end of the trail near the Oconaluftee Visitor Center (see Figures 2 through 6). Project elements marked as Excepted Actions as shown in Table 1 will not be analyzed further in this document; they are listed in Table 1 and shown on Figures 3 through 6 as appropriate to document their consideration for floodplain compliance and excepted status under PM 77-2.

Southern Trail Terminus at Highway 441 to Footbridge #1 (Figures 3 and 4). From the southern project terminus to the road crossing and continuing east, the trail tread would be expanded to a width of approximately 10 feet except from a point approximately 90 feet from the end of the trail to the trail terminus. This most southern short section of trail would remain at its current width, and the dense cluster of trees in this area would remain in place. Fill material would be added throughout to widen the trail.

As shown on Figure 3, an approximately 250-foot-long, 10-foot-wide aggregate and asphalt trail would be constructed to connect to the existing sidewalk on the northeast side of Saunooke Bridge. As the tread would be up to approximately 8 feet above the surrounding grade, a wooden post and steel railing would be installed on the north side of the new trail. At the junction with the existing Saunooke Road Bridge, approximately 110 linear feet of existing guardrail would be replaced. Approximately 65 square feet of existing concrete curb and gutter on the bridge would also be removed, and new curb and gutter and asphalt swale would be installed to align with the road edge of the new trail.

Continuing north toward Footbridge #1, the trail tread will be widened to 10 feet. Where the trail currently passes around the east end of a dry-stacked stone wall that connects to the park entrance sign, the new trail would be routed further to the east to avoid the wall, with fill added on the adjacent slope to support the tread.

Footbridge #1 to Blue Ridge Parkway (Figures 4 and 5). In this segment the trail will be shifted slightly to the southeast. A wooden footbridge (Footbridge #1) will be removed and replaced with a new steel truss bridge with steel floor beams, steel and wood railings, 10-foot-wide composite wooden decking, concrete and steel abutments, and concrete wing walls with native stone veneer. Mortared stone riprap would also be added to the base of the abutments and wingwalls to reduce the potential for scour damage from flooding. The bridge would be approximately 60 feet long, and the wingwalls would extend from all four corners of the abutments to approximately 30 feet from the decking. Approximately 100 feet of 10-foot-wide new trail would be constructed on top of the fill to connect to the new bridge. Construction of the approaches to the new bridge would involve adding a substantial amount of fill to match the higher elevation of the bridge decking, with the toe of the fill slopes extended up to approximately 15 feet from the edge of the trail.

Oconaluftee River Trail

Great Smoky Mountains National Park

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Figure 1. Location of the Oconaluftee River Trail

Oconaluftee River Trail

Great Smoky Mountains National Park

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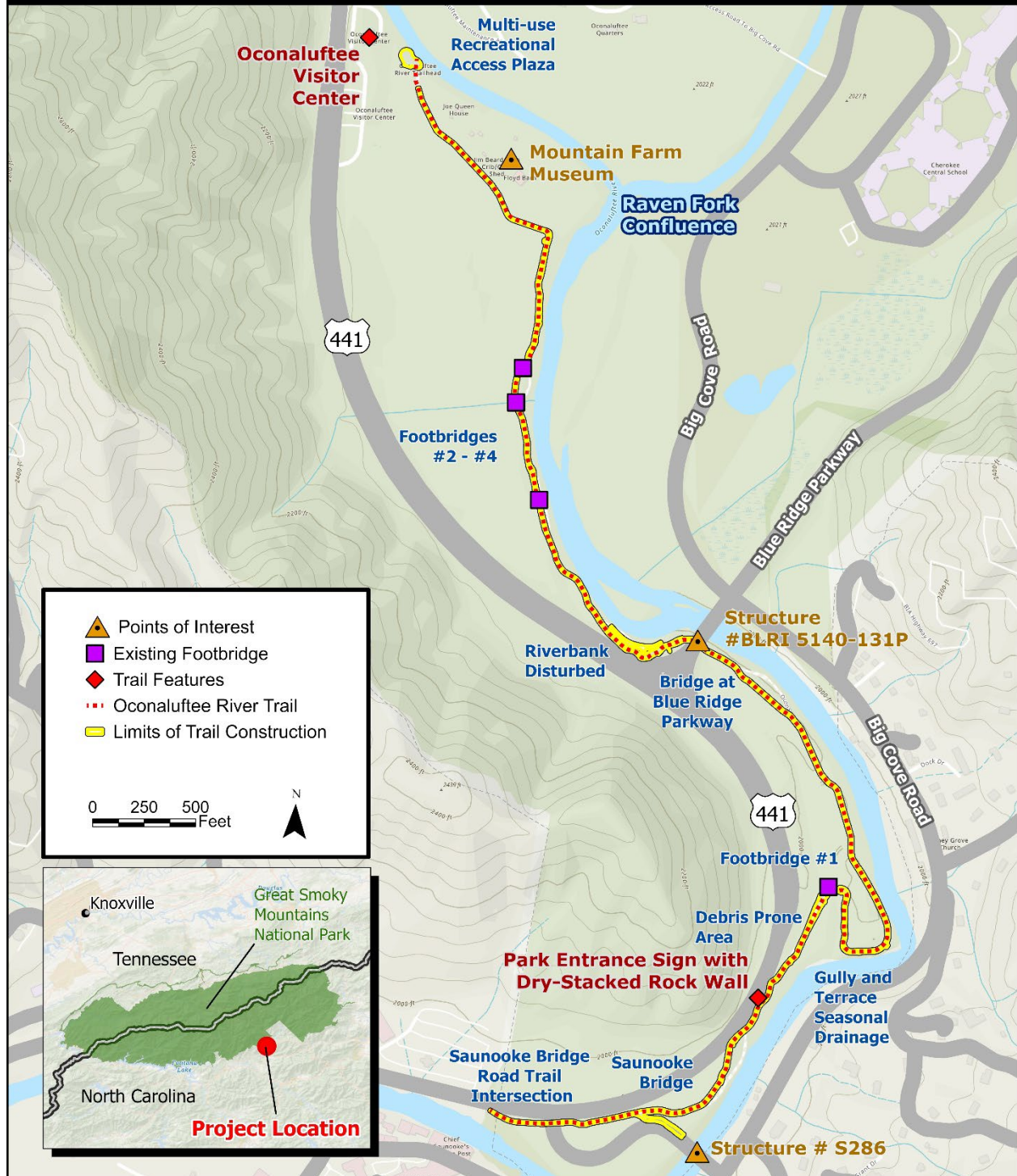


Figure 2. Oconaluftee River Trail Proposed Action Components

Oconaluftee River Trail

Great Smoky Mountains National Park

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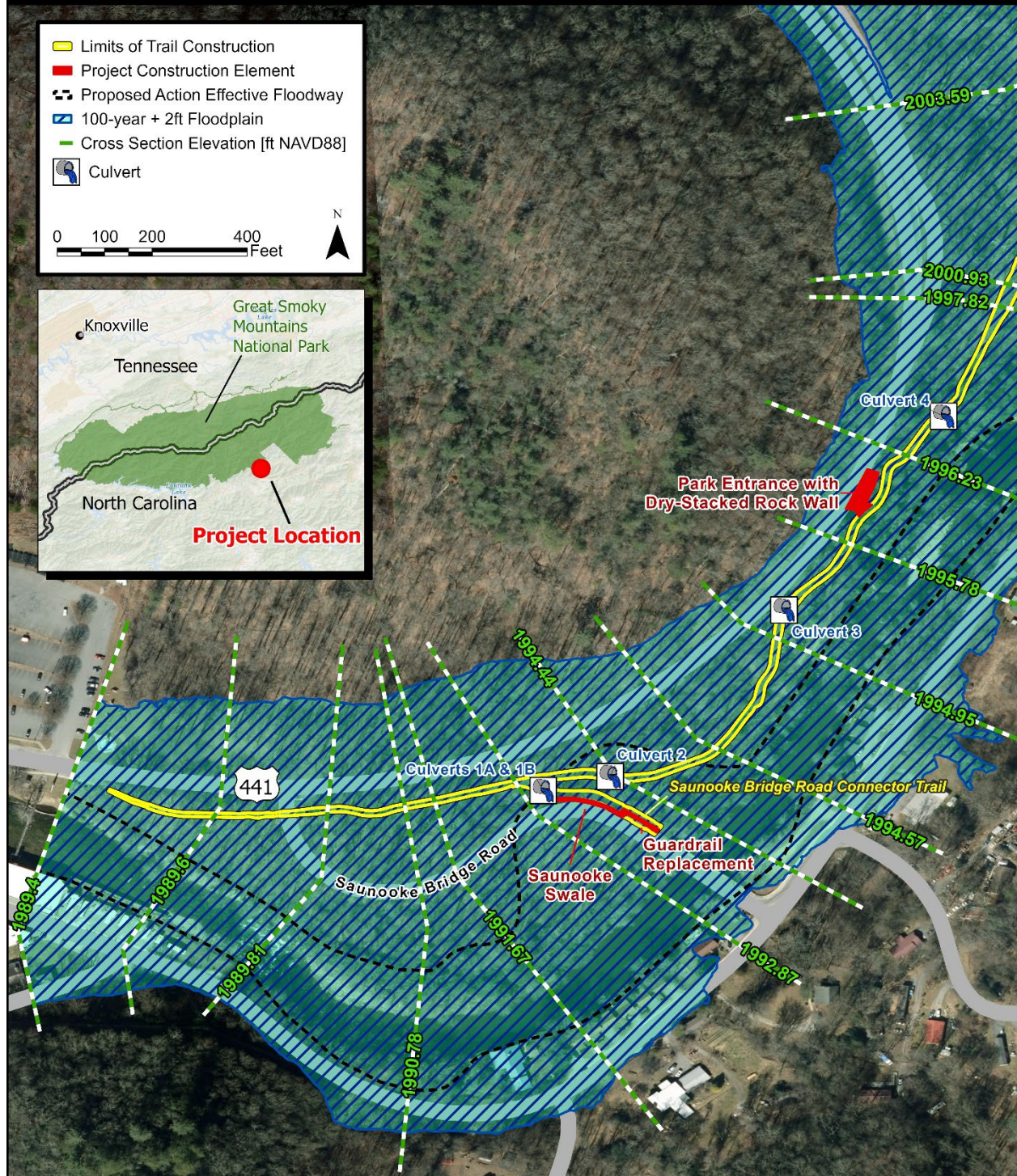


Figure 3. Subarea 1 Floodplain and Proposed Action

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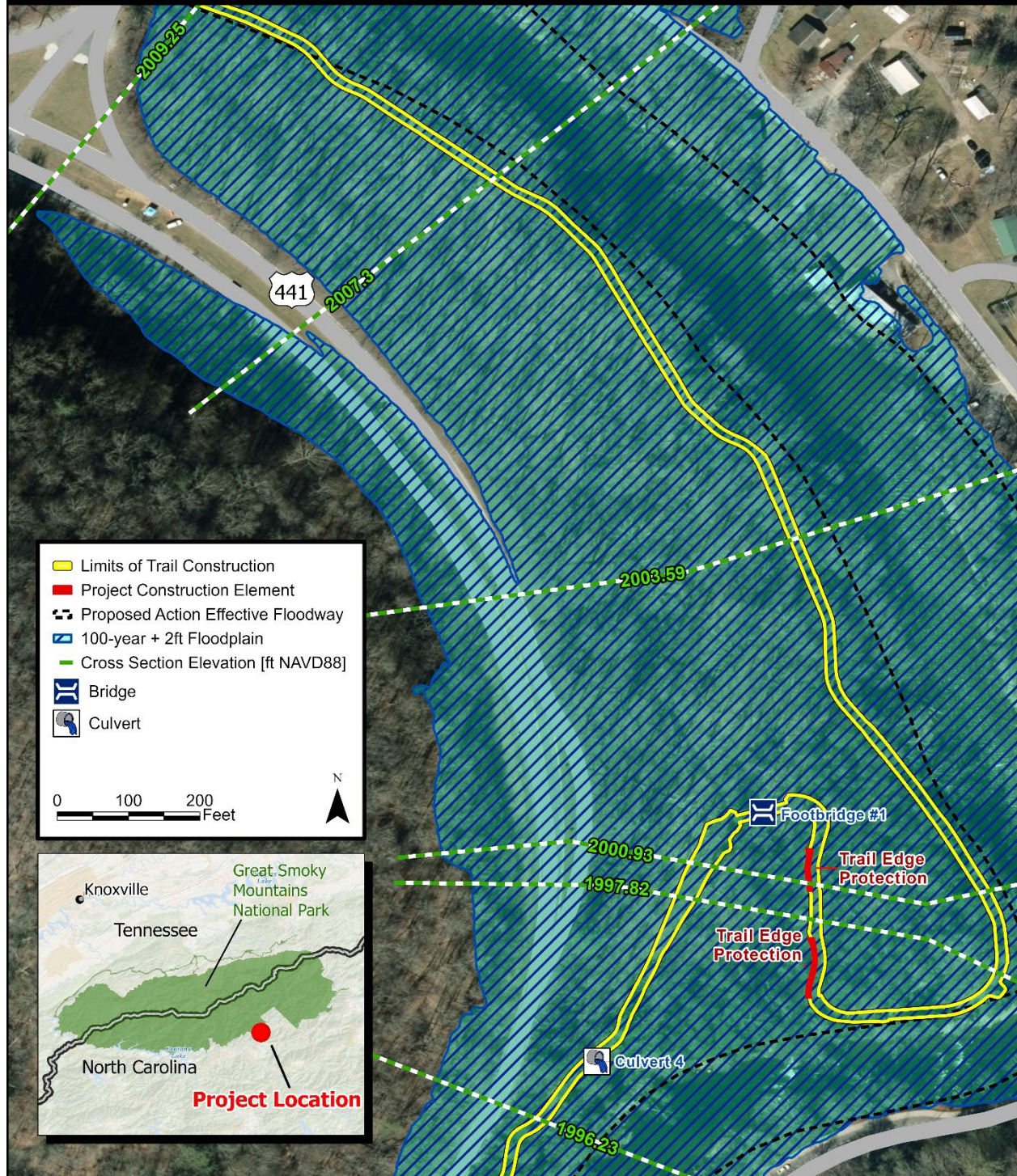


Figure 4. Subarea 2 Floodplain and Proposed Action

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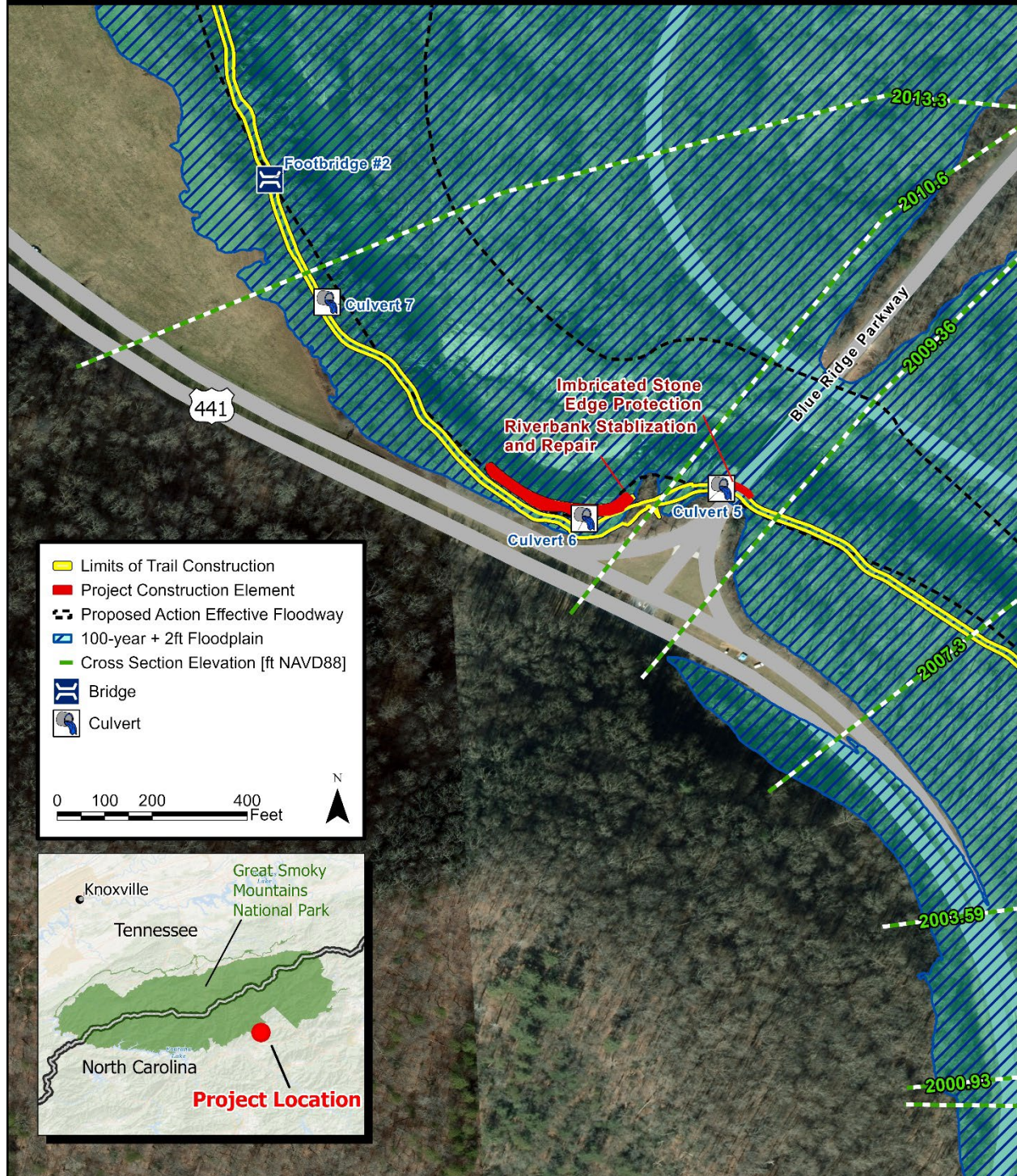


Figure 5. Subarea 3 Floodplain and Proposed Action

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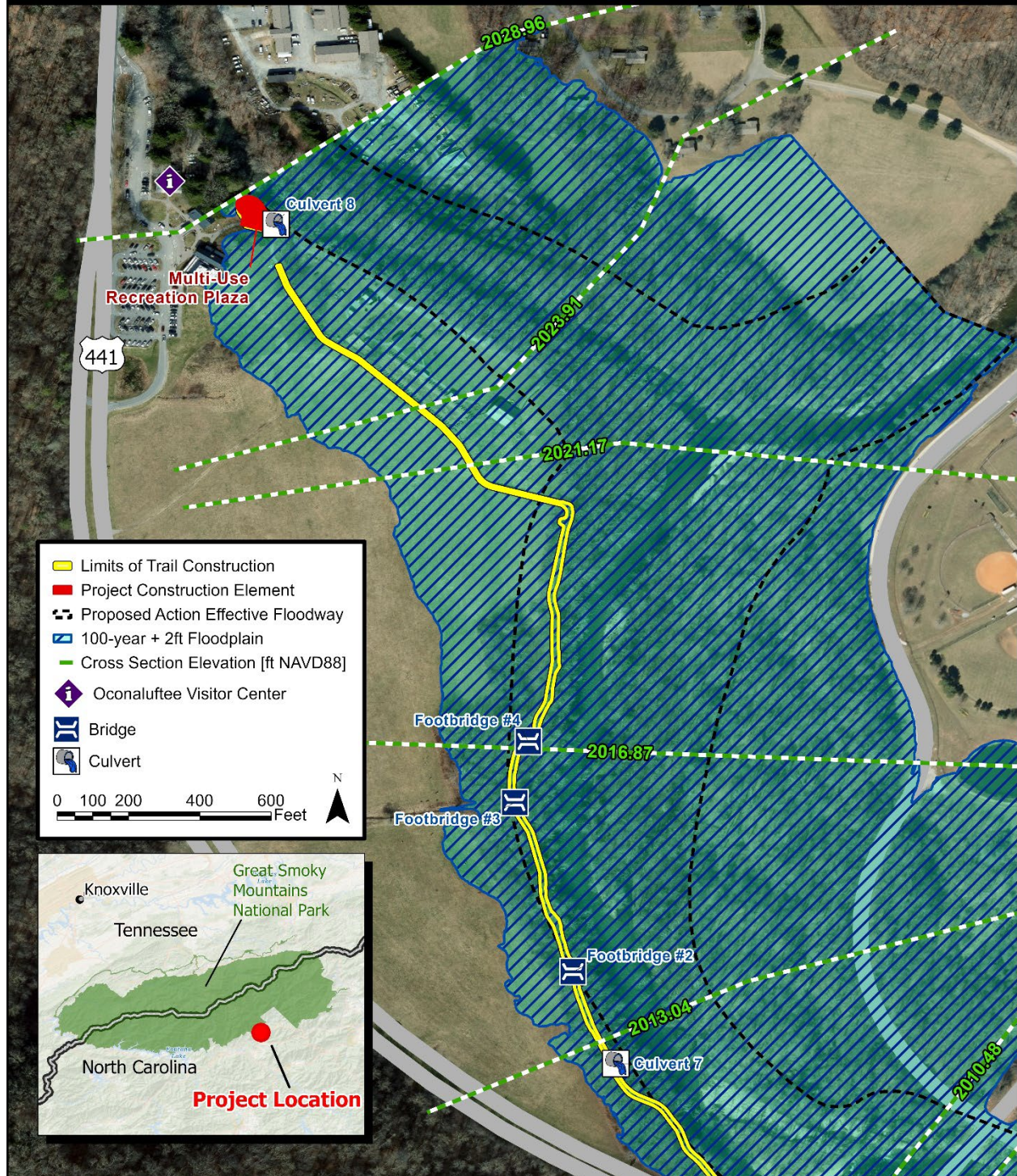


Figure 6. Subarea 4 Floodplain and Proposed Action

Table 1. Proposed Project Components and Associated Regulatory Status		
Proposed Project Component	Action	Regulatory Status
Footbridges		
Footbridge #1	Replacement with a 60.2-foot-long steel truss bridge with steel floor beams, steel and wood railings, 10-foot-wide composite wooden decking, concrete and steel abutments, concrete wing walls with native stone veneer.	Floodplain compliance required.
Footbridges #2, #3, and #4	Replacement with small, easily replaceable (exception-eligible) structures	Excepted under PM 77-2 (exception 2).
Trail Fill Locations		
Southern Trail Extent to Footbridge #1	Widen trail and place fill to raise trail elevation by approximately 6 inches to 1 foot.	Floodplain compliance required except for dissipation basin (reduces flooding effects).
Footbridge #1	Widen and reroute trail, add approximately 4 feet of fill to raise the trail to the bridge grade. Mortared stone riprap at abutments and wing walls.	
Footbridge #1 to Imbricated-Stone Edge Slope Protection	Widen trail, construct a wayside rest/passing area, and place fill to raise trail elevation by approximately 6 inches to 1 foot.	
Imbricated-Stone Edge Slope Protection	Place imbricated stone along trail for bank stabilization.	
Imbricated-Stone Edge Slope Protection to Dissipation Basin and Riverbank Stabilization and Repair	Widen trail and change the trail slope by adding approximately 3 to 4 feet of fill.	
Riverbank Stabilization and Repair	Widen trail and place fill to raise trail elevation by approximately 6 inches to 1 foot.	
Footbridges #2, 3, and 4	Increased abutment, fill	
Riverbank Stabilization and Repair to Mountain Farm Museum	Widen trail and place fill to raise trail elevation by approximately 6 inches to 1 foot.	
Multi-use recreational access plaza	Construct a 10- to 16-foot-wide trail with edge protection and place fill to raise the trail elevation by 2 feet.	
Land Stabilization		
Imbricated-Stone Edge Protection	Buried stones, approximately 3 feet by 2 feet in size, for slope protection	Floodplain compliance required.
Riverbank Stabilization and Repair	Layer fill, woody debris, and rocks and anchor into bedrock to create a flood-resistant channel embankment.	
Trail Edge Protection	Stone retainer placed along the trail edge along existing ground	
Protective Aprons at Culvert Outlets	Placement of riprap at culvert outlets to a depth of 1.5 to 2.4 feet	
Saunooke Bridge Connector Trail	Steel-backed timber guardrail with curb and gutter	

Visitor Support and Control		
Multiuse Recreational Access Plaza	Stone bench, bike rack, a retaining wall, and railings	Excepted under PM 77-2 (exception 2).
Saunooke Connector Trail	Wooden post and steel railing fence	
Intersection of Oconaluftee Trail and Saunooke Bridge Road	Two removable steel bollards and boulders	
Conveyances		
Culverts 1A and 1B	One pair of 18-inch-diameter, 16-foot-long new culverts	Excepted under PM 77-2 (exception 7).
Culvert 2	One 18-inch-diameter, 17-foot-long replacement culvert	
Culvert 3	Tie into the existing masonry headwalls of the existing culvert	
Culvert 4	One 18-inch-diameter, 21-foot-long new culvert	
Culvert 5	One 18-inch-diameter, 20-foot-long replacement culvert	
Culvert 6	One 24-inch-diameter, 27-foot-long new culvert	
Culvert 7	One 18-inch-diameter, 12-foot-long replacement culvert	
Culvert 8	One 15-inch-diameter, 18-foot-long new culvert	
Saunooke swale	Asphalt swale	

At a point approximately 0.39 mile south of the Blue Ridge Parkway and immediately east of Footbridge #1, the trail makes a sharp turn to transition to the edge of a terrace above a gully that drains seasonally into the Oconaluftee River. To keep the trail in place and minimize erosion, an approximately 130-foot-long section of trail will be lined with imbricated-stone edge protection. This includes a single stone course approximately up to 1 foot wide buried in construction fill or into the existing ground surface to approximately 1 foot deep at the edge of the trail. Between Footbridge #1 and the Blue Ridge Parkway, the trail will be widened to 10 feet.

Riverbank Stabilization Area (Figure 5). For the portion of the trail within 50 feet of the bridge that carries the Blue Ridge Parkway across the Oconaluftee River and Trail, the trail will be lined on its northern (i.e., river) side with imbricated stone. Along the portion of trail that has been heavily disturbed by erosion of the riverbank, approximately 350 feet of the trail would be shifted approximately 50 feet south to the toe of the fill slope for the adjacent Newfound Gap Road. The shift of the trail away from the riverbank would raise the elevation of the tread to approximately 5 feet above the existing grade, requiring substantial fill. Local materials (e.g., felled trees, rocks) will be recruited for use in riverbank stabilization efforts, and stabilization will use approximately 10 linear feet of boulder-toe revetment and approximately 265 linear feet of brush-toe revetment. Bioengineered/nature-based solutions (e.g., woody debris reuse, native revegetation, plant salvage) will be employed at bank stabilization areas, which will reduce the velocity and erosive capacity of floodwaters.

West of Blue Ridge Parkway to Mountain Farm Museum Area (Figures 2, 5, and 6). At the end of Footbridges #2, #3, and #4, additional fill will widen the trail tread to approximately 15 feet, tapering down to 10 feet wide within 20 feet of the ends of the bridges. In the Mountain Farm Area, a 10-foot-wide aggregate trail with asphalt surface will be constructed.

Multiuse Recreational Access Plaza Area (Figure 6). At the northern end of the project, a multiuse recreational access plaza will be constructed. Fill will be imported to create a level surface with the concrete tread on top. A new trail surface approximately 180 feet long and 10 to 16 feet wide will be constructed, with the 60-foot-long section closest to the river lined with a short rock-retaining wall and railing.

1.4 DETERMINATION OF ACTION CLASS AND REGULATORY FLOODPLAIN

Following PM 77-2, three action classes were considered when establishing the regulatory floodplain:

1. Class I Actions (i.e., noncritical actions) include location or construction of administrative, residential, warehouse, and maintenance buildings; nonexcepted parking lots; or other human-made features, which by their nature entice or require individuals to occupy the site, are prone to flood damage, or result in impacts to natural floodplain values.
2. Class II Actions (i.e., critical actions) include any activity for which even a slight chance of flooding is too great, such as construction of schools, medical facilities, emergency services, hazardous material storage, and records/collections storage.
3. Class III Actions include any action that involves human occupation or substantial human exposure in high-hazard areas, such as drainages subject to flash flooding.

The proposed action is classified as a **Class I Action** (noncritical). Components involve trail infrastructure, elevated structures, and minor fill that may entice public use but do not include critical facilities such as emergency services or hazardous material storage.

Proposed actions on NPS lands comply with FFRMS for new construction, substantial improvement, or repairing substantial damage. Per departmental guidance, agencies may select one of three approaches to implement flood resiliency measures:

- **Climate-Informed Science Approach** – The elevation and flood hazard area that result from using the best-available, actionable hydrologic and hydraulic data and methods that integrate current and future changes in flooding, including climate change and other physical processes (e.g., land-use change).
- **Freeboard Value Approach (FVA)** – The elevation and flood hazard area that result from adding an additional 2 feet to the base flood elevation (BFE) for noncritical actions and by adding an additional 3 feet to the BFE for critical actions.
- **0.2 Percent Annual-Chance Flood Approach** – The area subject to flooding by the 0.2 percent (500-year) annual-chance flood.

An FVA establishing the NPS regulatory flood elevation is employed for this proposed action (Figures 3 through 6). The regulatory floodplain elevation for the proposed action is the 1 percent annual chance (100-year) flood elevation plus 2 feet; site-specific elevations are listed in Table 2.

Floodplain mapping is based on Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps for Swain County, North Carolina (FEMA 2010). FEMA defines Zone AE floodplains as areas with a 1 percent annual chance of flooding (i.e., located within the 100-year floodplain) with defined BFEs. The entire project corridor has been mapped by FEMA as Zone AE. The FEMA Flood Insurance Rate Maps were supplemented by site-specific hydraulic modeling (Stantec 2026a, 2026b) to further refine the estimated 100-year floodplain Water Surface Elevation (WSE) for the project area.

Key flood-related components of the proposed Oconaluftee River Trail improvements include:

- Footbridge #1 replacement: New 60.2-foot-long and 10-foot-wide steel truss bridge with higher decking at an elevation of 2,002.4 feet (which is below the FVA elevation), a low chord elevation at 2,000.7 feet, and a finished grade elevation of 1,996.4 feet. The FVA elevation is 2,004.9 feet, where the BFE is approximately 2,002.9 feet North American Datum 88 [NAVD88]). Other design elements include concrete/steel abutments (with a top elevation of 1,995.4 feet and approximately 10-foot-deep disturbance); wingwalls at an elevation of 2,002.4 feet, extending laterally approximately 30 feet; and mortared stone riprap scour protection with a typical top-of-grade elevation of 1,996.4 feet. Approaches include significant fill to match the bridge deck height (toe of fill would slope up to 15 feet from trail edge).
 - To meet the FVA elevation for the footbridge deck, significant fill would be required within the floodplain to further raise the deck height; therefore, to minimize floodplain impacts the decision was made to make the abutments and foundational supports meet the scour requirements for a 100-year flood event.

Table 2. Hazard Evaluation for Nonexcepted Proposed Project Components					
Proposed Project Component		Regulatory Floodplain (1% AEP+2) Elevation (feet)	Structure Elevation (feet)	Depth at Regulatory Flood (feet)	Other Hazards*
Footbridge #1					
Footbridge #1		2,004.9	Deck: 2,002.4	Deck: 2.5	Scour depth (feet): Left Abutment = 15.3; Right Abutment = 7.3
			Low Chord: 2,000.7	Low Chord: 4.2	
Trail Fill Locations					
Southern Trail Extent to Footbridge #1		1,991.4 to 2,003	1,988.1 to 2,002.4	4.5 to 5.4	
Footbridge #1		2,004.9	2002.4	2.5	
Footbridge #1 to Imbricated-Stone Edge Slope Protection		2,001.6 to 2,006.7	2,002.4 to 2,004.7	0.0 to 2.0	
Imbricated-Stone Edge Slope Protection		2,009.7	2,004.7	5.0	
Imbricated-Stone Edge Slope Protection to Riverbank Stabilization and Repair		2,009.7 to 2,011.5	2,004.7 to 2,008.0	5.0 to 3.5	Average velocity = 2.0 ft/sec Average shear = 0.3 lb/sq. ft.
Riverbank Stabilization to Oconaluftee Visitor Center		22	2,008.0 to 2,026.6	1.3 to 3.5	
Footbridge #2		2,013.6	2,011.2	2.4	
Footbridge #3		2,015.9	2,015.5	0.4	
Footbridge #4		2,016.7	2,013.6	3.1	
Multiuse Recreational Access Plaza		2,028.8 to 2028.8	2,027.3 to 2030.9	0.0 to 1.5	
Land Stabilization					
Riverbank Stabilization and Repair		2,011.1	2,008.0	3.1	
Imbricated-Stone Edge Protection		209.7	2,004.7	5.0	
Trail Edge Protection		1,997.6 to 2,001.3	1,995.7 to 1,997.8	1.9 to 3.5	
Saunooke Bridge Connector Trail		1,993.2 to 1,994.2	1,987.2 to 1,996.0	0.0 to 6.0	
Protective Aprons at Culvert Outlets (Invert Elevation)					
	Culvert 1 (1A and 1B)	1,993.2	1,984.5	8.7	

Table 2. Hazard Evaluation for Nonexcepted Proposed Project Components					
Proposed Project Component		Regulatory Floodplain (1% AEP+2) Elevation (feet)	Structure Elevation (feet)	Depth at Regulatory Flood (feet)	Other Hazards*
	Culvert 2	1,994.4	1,986.1	8.3	
	Culvert 3 (tie-in to existing culvert only)	1,995.2	1,989.5	5.7	
	Culvert 4	1,996.4	1,990.6	5.9	
	Culvert 5	2,009.9	2,003.8	6.1	Average velocity = 2.0 ft/sec Average shear = 0.3 lb/sq. ft.
	Culvert 6	2,010.7	2,004.7	6.1	Average velocity = 2.0 ft/sec Average shear = 0.3 lb/sq. ft.
	Culvert 7	2,012.9	2,007.9	5.0	
	Culvert 8	2,028.6	2,026.4	2.2	

AEP – Annual Exceedance Probability; **ft/sec** – feet per second; **lb/sq. ft.** – pounds per square foot

*Values presented are for the 100-year flood, not the regulatory flood; nevertheless, describing hazards at a high-flow event provides important context for risks to human life and potential structural effects.

- Trail widening and grade raises: Imported fill would widen the trail tread to 8 to 10 feet (edge to edge) and raise grades (from 6 inches to approximately 5 feet above the existing grade in the eroding riverbank section west of Blue Ridge Parkway). Fill material in the floodplain is required to avoid impacts on archaeological sites. Trail resurfacing will use a combination of gravel, asphalt, and concrete.
- Multiuse recreational access plaza (northern end, near Oconaluftee Visitor Center): Concrete tread would be placed on imported fill elevated to approximately 2,030 feet; short rock-retaining wall and railing near river edge.
- Saunooke Bridge Connector trail (southern connector): Fill would raise tread (up to approximately 8 feet above grade) to FVA elevation and would include two 18-inch-diameter reinforced concrete pipe culverts with mortared stone headwalls for rare flooding events.

2 JUSTIFICATION FOR USE OF THE FLOODPLAIN

The trail is topographically constrained to the Oconaluftee River valley. Relocation outside the floodplain is not feasible due to the impracticality of using other sites due to roads, steep slopes, rare plants, bat habitat, and wetlands, as well as meeting the trail objectives to bring visitors in proximity to cultural resources (Oconaluftee Archeological District and Mountain Farm Museum). Following the existing Oconaluftee River Trail alignment and staying within the previously disturbed trail areas to the maximum extent practicable would minimize disturbance of undeveloped and sensitive areas of GRSM. The existing alignment provides the only direct, low-impact connection between the Oconaluftee Visitor Center and the EBCI Qualla Boundary.

Development of potential alternatives for the trail tread surface, footbridge type, riverbank stabilization, and multiuse recreational access plaza were all assessed using a choosing-by-advantages value methodology. Efforts to reduce flood risk included proposing a larger span for Footbridge #1 compared to the existing span, considering use of a trail in the Saunooke Bridge Road area that would use bridges to reduce fill, and upsizing culverts to improve local drainage. Flood risk was considered in the context of each streambank treatment. This project would not change the facility use type, as the trail is currently a multiuse trail that allows pedestrians and bicycles. This project would provide increased connectivity and accessibility, which may increase the volume of trail use and may result in additional visitors to the adjacent Oconaluftee Visitor Center. Improvements or additions to the trail would be kept with the design intent of the existing trail. The project would not include formalizing or adding any additional parking areas for trail users.

Nonfloodplain alternatives were evaluated but rejected because they would cause substantially greater overall environmental and cultural impacts. The proposed project minimizes new floodplain encroachment through targeted elevation of structures such as Footbridge #1, bioengineering (i.e., riverbank stabilization elements), and minor alignment shifts.

3 DETAILED FLOOD HAZARD AND FLOOD RISK ANALYSIS

3.1 DESCRIPTION OF SITE-SPECIFIC FLOOD HAZARD

The Oconaluftee River is subject to flooding driven by orographic precipitation. The 1 percent annual chance discharge is approximately 18,000 cubic feet per second (cfs) (U.S. Geological Survey

StreamStats regression equations). Hydraulic modeling shows high velocities within the channel bed and banks capable of scour and debris transport, with substantially decreased velocities when floodwater surface elevations reach the elevation of the trail (Table 2; Appendix A).

Stantec completed hydrologic and hydraulic analysis on behalf of NPS using HEC-RAS 2D (v. 6.5) and 1D (v. 6.5/6.6) models to evaluate potential impacts on proposed actions within the NPS regulatory floodplain. The two-dimensional (2D) model was used to support design of the riverbank stabilization area only. The one-dimensional (1D) steady-state model was used to evaluate the 1 percent annual-chance (100-year) WSE impacts. Pre-project and post-project conditions were compared at all regulatory cross sections within the study area and tied into the effective FEMA Letter of Map Revision model at stations 57,096 and 48,090 (Stantec 2026b; see Table 4, Appendix A).

The 2D model estimates at the eroding bank found that there would be an average velocity of 2.0 feet per second with an average shear stress of 0.3 pounds per square foot. These values were used to size and design the riverbank stabilization features. Further, a separate scour analysis for the proposed pedestrian bridge estimated a 1 percent event scour depth of up to 15.3 feet at the left abutment, and a 10 percent event scour depth up to 2.4 feet. These results would guide foundation design and would not affect floodplain elevations.

3.2 DESCRIPTION OF SITE-SPECIFIC FLOOD RISK

Human Health and Safety: Inundation depth and water velocities as described in Table 2 pose flood risks to trail users. Water depths and, where available, velocities shown for all proposed action locations are sufficient to knock down or sweep away adults, children, and pets. Even shallow water, such as is expected at some of the fill locations, can create enough force to destabilize a person walking across these areas. The Oconaluftee River Trail is a high-risk area and is actively managed for flood risk by GRSM using cutting-edge artificial intelligence (AI)-based flood prediction models. Egress is constrained along the trail and adjacent roads, making escape from floodwater on the trail potentially difficult depending on the specific location.

Property: Flood risks to trail tread, bridges, fill embankments, and stabilization measures from scour, debris impact, and erosion is moderate to high, as all these features would be fully immersed or overtopped during the regulatory flood event (Table 2). Design standard varies by specific element (e.g., culverts were designed to 10 percent AEP event; river stabilization/repair and Footbridge #1 were designed to 1 percent Annual Exceedance Probability [AEP] event); all are in accordance with current best engineering practice. The final structures are designed to account for modeled hazards (Appendices A and B). Note that construction of all proposed elements to meet or exceed a design standard of the regulatory flood is not required or appropriate. However, following PM 77-2, flood risk mitigations for these NPS project elements to the level of the regulatory flood are described below (see Section 4).

Floodplain Values: Floodplains associated with Appalachian Mountain streams and rivers provide a range of ecological, hydrological, and social functions that contribute to watershed health and community resilience. These systems, such as the Oconaluftee River, are typically narrow, forested corridors shaped by steep terrain, high-gradient channel networks, and seasonally variable flow regimes. Floodplain processes in these settings remain essential for maintaining water quality, supporting native biodiversity, and mitigating the effects of storm events.

Overall risks to floodplain function associated with the project are low. Risk associated with replacement of Footbridge #1 on floodplain values is minimal; the new bridge is not expected to affect riparian, geomorphic, or aquatic function and is built to be overtopped during a regulatory flood. Total fill actions as part of the project will cover an additional 14,072 square feet of land area, which will theoretically affect groundwater recharge, although the remaining floodplain area is more than sufficient to compensate for these potential losses. Land stabilization project elements may have a very small effect on microscale riparian processes, but again, a sufficient extent of unmanipulated riparian and floodplain areas exists to offset these very small risks.

4 FLOODPLAIN IMPACT MITIGATION MEASURES

Flood risk mitigation measures and monitoring activities will be integrated into construction design and specifications.

Measures to reduce risk to human life, health, and safety include:

- Reduced depth of floodwaters over the trail surface compared to the previous Footbridge #1.
- Signage providing information to trail users about the potential flood conditions and flood warning integration used by GRSM to close the trail during flooding will be installed at the southern Oconaluftee Trail terminus and the Oconaluftee Visitor Center.
- Use of AI-based flood prediction models to provide site-specific evacuation warnings for visitors and staff.

These mitigations reduce the overall risk such that risk to human life, health, and safety associated with the project is moderate to low.

Measures to reduce risk to NPS infrastructure and capital investment property include:

- Scour-resistant abutments, wingwalls, and mortared stone riprap.
- Although an excepted component of the proposed action, upsized culverts will prevent or reduce flow constriction, reducing flow velocity at the confluence with the Oconaluftee mainstem.
- Bioengineered/nature-based solutions (i.e., woody debris reuse, native revegetation, plant salvage) at bank stabilization areas, which reduce the velocity and erosive capacity of floodwaters.

Structures are designed to be consistent with National Flood Insurance Program standards (44 Code of Federal Regulations Part 60). These mitigations reduce the overall risk such that risk to infrastructure and capital investment associated with the project is moderate.

Measures to reduce adverse impacts to site-specific natural and beneficial floodplain values include:

- Post-construction monitoring (hydrology and erosion) for three years.
- Full restoration of disturbed areas.

- Integrating best management practices into construction activities (e.g., minimizing erosion, discouraging disturbance, replanting with native plants, monitoring for invasive plants).

These mitigations reduce the overall risk such that risk to floodplain function and values associated with the project is low.

5 SUMMARY

The NPS has determined that the Oconaluftee River Trail Improvements Project is necessary to provide safe, accessible multiuse trail access; resolve chronic flood and erosion damage; and maintain connectivity to the EBCI Qualla Boundary. NPS concludes there is no practicable nonfloodplain alternative that exists due to topographic, cultural, infrastructure, and connectivity constraints. Further, while the proposed project features do encourage increased use in a higher risk area, robust mitigation measures are in place to offset these risks. The long-term benefits include improved visitor safety, better recreational access, and resource protection. Therefore, NPS finds the proposed action would be consistent with EO 11988, *Floodplain Management*, and NPS DO 77-2, *Floodplain Management*.

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Appendix A. Hydrologic and Hydraulic Report

Hydrologic and Hydraulic Report

Oconaluftee Transportation Trail Corridor Design
Great Smoky National Park
Contract No. 140P2021D0021

Date:
February 20, 2026

Prepared for:
National Park Service

Prepared by:
Stantec

Project/File:
234364224



Revision Record

Revision	Description	Author	Date	Quality Check	Date	Independent Review	Date

Disclaimer

The conclusions in the Report titled Hydrologic and Hydraulic Report are Stantec's professional opinion, as of the time of the Report, and concerning the scope described in the Report. The opinions in the document are based on conditions and information existing at the time the scope of work was conducted and do not take into account any subsequent changes. The Report relates solely to the specific project for which Stantec was retained and the stated purpose for which the Report was prepared. The Report is not to be used or relied on for any variation or extension of the project, or for any other project or purpose, and any unauthorized use or reliance is at the recipient's own risk.

Stantec has assumed all information received from National Park Service (the "Client") and third parties in the preparation of the Report to be correct. While Stantec has exercised a customary level of judgment or due diligence in the use of such information, Stantec assumes no responsibility for the consequences of any error or omission contained therein.

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1 Site and project Description

The upstream limit of study is approximately 1,300 feet upstream of the confluence of Raven Fork, at effective cross section 571. The downstream limit of study is approximately 1,400 feet downstream of US-441, downstream of effective cross section 484. The stream reach in question is contained on two Flood Insurance Rate Map (FIRM) panels: 3700761600J and 3700762600J.

The project includes repair of the riverbank erosion area, construction of a multi-purpose recreational area, design and construction of improved/more accessible trail, and construction of a spur trail to Saunooke Bridge.

Two separate HEC-RAS v6.5 models and one v6.6 model were developed as part of this analysis. The primary purpose of the 2D model was to support the design of the stream bank erosion repair, while the 1D model was used to assess water surface elevation (WSE) impacts due to the proposed projects within FEMA's Special Flood Hazard Area (SFHA) and floodway. A second, separate 1D model was used to assess the scour potential of the proposed footbridge in the potential reroute project area.



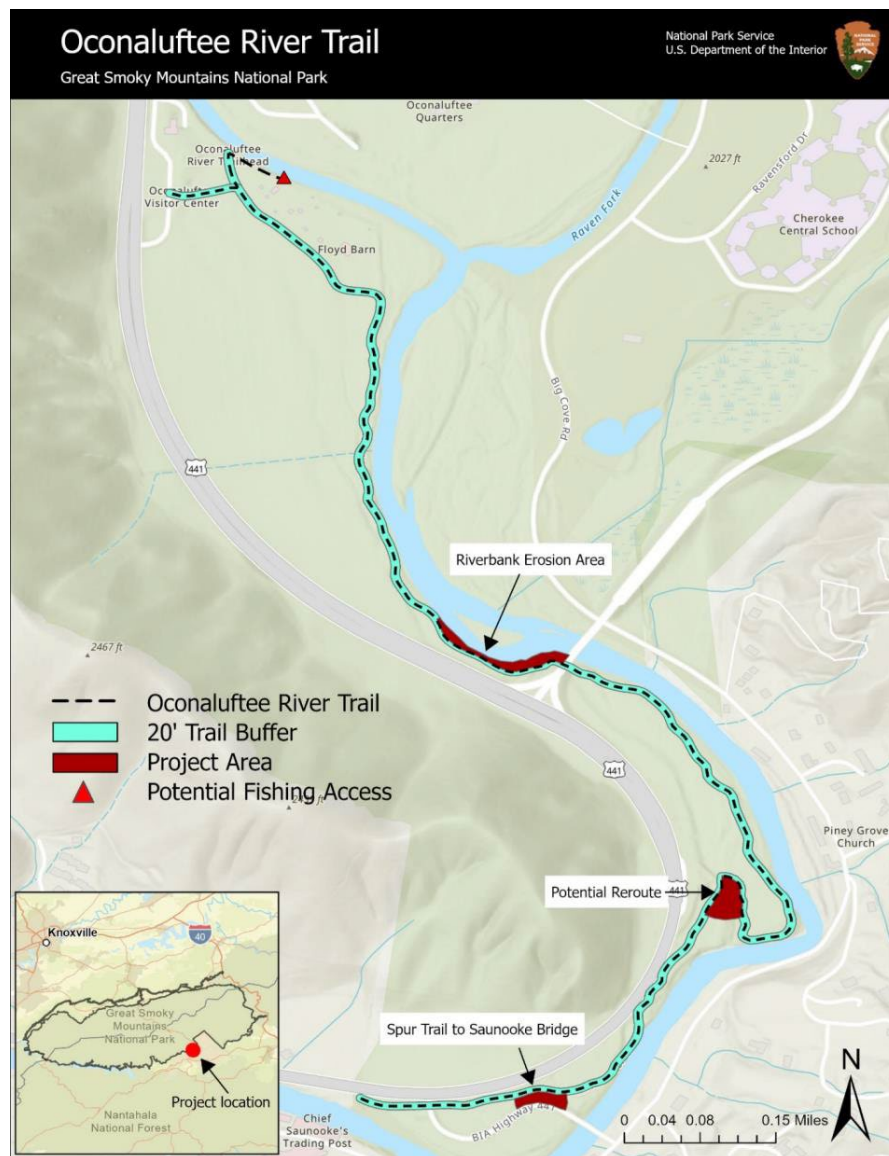


Figure 1. Project Vicinity (source NPS)

2 Source Data

The following data were used in developing the models:

- 2017 Light detection and ranging (LiDAR) data for Swain County was obtained from the North Carolina Spatial Data Download.
- The National Park Service (NPS) acquired the effective and Letter of Map Revision (LOMR) 21-04-5780P HEC-RAS models, effective date 11/13/2023, from FEMA's Engineering Library and provided it to Stantec.



- Field survey performed by Stantec in November 2024, to collect topographic information of the existing trail and the riverbank erosion area. Limited cross-section data was collected to supplement the LiDAR data and capture the below-water portion of the channel in the vicinity of the riverbank erosion area.
- 95% design drawings developed by Stantec
- Esri aerial imagery basemap data as a web service.
- Geotechnical Engineering Report revised November 18, 2025, developed by DMY Engineering Consultants Inc.

3 2D analysis

The 2D quasi-steady state HEC-RAS model was developed to provide flow characteristics needed to design the stream bank erosion repair. Because the 2D model was developed for the sole purpose of assisting with the riverbank erosion area design, only one flow was utilized for the full extent of the model. Model results upstream and downstream of the erosion area should not be used for other purposes/analyses.

3.1 Terrain development

Multiple sources of terrain and topographic data were utilized and merged to develop the model terrain. Most of the model terrain is derived from the 2017 Quality Level (QL)1 LiDAR. In the areas where Stantec collected field survey data, the field survey was used to replace the 2017 LiDAR. Additionally, Stantec extracted the channel geometry from LOMR 21-04-5780P model and used it to add below-water channel data to the terrain.

3.2 Hydrology

The U.S. Geological Survey's (USGS) published new regression equations for North Carolina in 2023, USGS Scientific Investigations Report (SIR) 2023-5006. To support development of the riverbank erosion area using the latest available flow data, peak flow estimates for the 1-percent-annual-chance (1%AC) event were acquired using the USGS Streamstats program. Streamstats calculated an estimate of 18,000 cubic feet per second (CFS) using the regression equations from USGS Scientific Investigations Report (SIR) 2023-5006. The location chosen for flow calculation was approximately 200 feet downstream of Blue Ridge Parkway bridge.

In the absence of historical site-specific flow hydrograph data, a constant discharge flow hydrograph was developed and utilized in the modeling. The constant discharge flow hydrograph is intended to capture flow characteristics at the peak flow estimate, allowing assumptions around hydrograph volume and the timing of the peak to be omitted.



The downstream boundary condition of normal depth was utilized, and a friction slope 0.0072 ft/ft was measured from the channel slope in the LOMR 21-04-5789P model.

To maintain model stability, the flow hydrograph starts at 1,000 cfs and ramps up to 18,000 cfs over a duration of 7 hours.

3.3 Hydraulics

3.3.1 Existing Conditions

A base computation mesh was created within the study area using a 100 feet x 100 feet grid cell size. The mesh was modified by adding refinement regions and breaklines to capture channels and other topological features in the underlying terrain.

Breaklines were incorporated into the 2D mesh to better capture the high and low points within the 2D area, such as road embankments, channel thalweg, and channel banks. These breaklines were developed using the model terrain and aerial imagery data. Grid cell sizes ranged from 10 feet x 10 feet to 75 feet x 75 feet along the breaklines, depending on the level of detail necessary to capture the features.

A refinement region polygon was developed to capture two spilt flow channels. These refinement regions were incorporated into the 2D mesh along with the breaklines.

A Manning's n roughness layer was developed from aerial imagery, for the entire 2D area. Based on the aerial imagery Stantec assigned a landuse and then used the HEC-RAS 2D NLCD Manning's n Values reference table and Chow (1959) to assign a Manning's n.

Table 1. Final Model Manning's n values

Description	n Value
Channel*	0.040
Developed, Medium Intensity	0.160
Developed, Low Intensity	0.090
Impervious*	0.015
Pasture Grassland	0.038
Deciduous Forest	0.150

*adapted from Chow (1959)

Blue Ridge Parkway bridge data was extracted from the LOMR model and added to the 2D model as an SA/2D connection.

The model was run using the Shallow Water equation due to the fact it better accounts for energy losses in and around structures (HEC-RAS 2D User's Manual). A computation interval of 0.5 seconds was used to ensure that the maximum Courant number within the vicinity of the riverbank erosion area did not exceed 1.0.



The model WSE's were validated against the effective LOMR elevations. Manning's n values were adjusted until the model WSE's were within 0.5 feet of the effective LOMR elevations along the full extent of the riverbank erosion area.

3.3.2 Proposed Conditions

The Proposed Conditions geometry is a duplicate of the Existing Conditions geometry, except that the terrain and Manning's n values in the vicinity of the riverbank scour area have been updated based on Stantec's design.

The Manning's n value for the repair was set to 0.150 for Deciduous Forest.

3.4 Results Summary

Table 2 provides a comparison of the Effective regulatory WSE and the 2D HEC-RAS Existing Conditions WSE at each cross section with the limits of study. Within the study area 1%AC WSEs were within 0.5 feet at all locations, except the downstream most cross section (511).

Table 2. Effective and 2D Existing Conditions WSE Comparisons

Cross Section	Effective WSE (feet NAVD88)	2D HEC-RAS Existing Conditions WSE (feet NAVD88)	Difference (feet)
511	1995.8	1997.2	1.4
513	1998.9	1999.1	0.2
518	2001.6	2001.9	0.3
525	2005.3	2004.8	-0.5
529	2007.3	2007.0	-0.3
531	2008.5	2008.1	-0.4
541	2011.0	2011.1	0.1
549	2014.9	2015.0	0.1

The average velocity (feet per second) at the bank, through the riverbank erosion area, is 2.0 ft/sec, while the average shear (pounds per square feet) at the bank is 0.3 lb/sq. ft. The final proposed riverbank erosion repair has been designed to account for this average velocity and average shear.

4 1D analyses

4.1 WSE impact model

This 1D steady state HEC-RAS model was developed to assess 1%AC WSE impacts due to the proposed projects within FEMA's SFHA and floodway.



4.1.1 Hydrology

Stantec reviewed the effective LOMR model that NPS acquired from FEMA and discovered that the model flows did not match the flows published in the effective FEMA FIS report. After reviewing the model WSEs and confirming they match the effective FWDT to the nearest tenth of a foot at all cross sections, Stantec decided to continue development of the 1D HEC-RAS model using the model discharges. Discharge values and flow change location are listed in Table 3.

Table 3. Discharge & Flow Change Locations

Cross Section	Station	1%AC Discharge (cfs)
598	59,828	9,660
558	55,774	13,100
541	54,056	13,500

4.1.2 Hydraulics

Stantec used HEC-RAS version 6.5 to develop the *Pre-Project Conditions* and *Post-Project Conditions* plans. All plans were developed assuming unobstructed flow at all cross sections and bridges. Unless otherwise noted, the vertical datum for this project is the North American Vertical Datum of 1988 (NAVD88) and the horizontal datum is the North Carolina State Plane Zone, North American Datum of 1983 (NAD83) with units of U.S. feet.

4.1.2.1 Pre-Project Conditions

Within the project area the LOMR model (*Duplicate Effective*) cross section layout was revised/updated in order to better capture the impacts of the development projects. The tie-in cross sections for this analysis are stations 48,090 and 57,096. The attachments include a plan view workmap including the *Pre-Project Conditions* cross section layout.

Bridge geometry for Blue Ridge Parkway, US-441, and downstream pedestrian bridge was copied from the LOMR model.

Ineffective areas were placed where needed to define areas not actively conveying flow and conveyance obstructions were added to represent buildings within the floodplain.

The expansion and contraction coefficients were set to 0.1 and 0.3 for all non-bridge cross section, while coefficients for cross sections associated with bridges—two cross sections upstream and one cross section downstream—were assigned coefficients of 0.3 and 0.5.

Manning's n values were extrapolated from adjacent LOMR cross sections.



4.1.2.2 Post-Project Conditions

The *Post-Project Conditions* plan is a copy of the *Pre-Project Conditions* with all of the projects incorporated.

For portions of cross sections impacted by the development projects, geometry was updated using the proposed design data.

4.1.3 Results Summary

Table 4 presents *Post-Project Conditions* WSEs versus the LOMR WSEs at the upstream and downstream cross sections, which tie-in within 0.5 feet.

Table 4. LOMR and Post-Project Conditions WSE comparisons at tie-ins

Station	LOMR WSE (feet NAVD88)	Post-Project Conditions WSE (feet NAVD88)
57,096	2027.0	2027.2
48,090	1987.2	1987.2

Table 5 provides a comparison of the LOMR and *Pre-Project Conditions* WSEs at each cross section within the limit of study for the 1%AC event.



Table 5. LOMR and Pre-Project Conditions WSE comparisons

Station	LOMR WSE (feet NAVD88)	Pre-Project Conditions WSE (feet NAVD88)	Change (Pre-Project minus LOMR)
57,096	2027.0	2027.2	0.2
56,305	2021.9	2022.4	0.5
55,774	2019.2	2018.5	-0.7
54,853	2014.9	2014.6	-0.3
54,056	2011.0	2011.3	0.3
53,144	2008.5	2008.6	0.1
53,036	Blue Ridge Pkwy		
52,949	2007.3	2007.4	0.1
52,504	2005.3	2005.3	0.0
51,838	2001.6	2001.6	0.0
51,290	1998.9	1998.9	0.0
51,097	1995.8	1995.8	0.0
50,544	1994.2	1994.2	0.0
50,336	1993.8	1993.8	0.0
50,096	1993.0	1992.9	0.0
49,837	1992.6	1992.6	0.0
49,686	1992.5	1992.5	0.0
49,597	Saunooke Bridge		
49,518	1990.9	1990.9	0.0
49,228	1989.7	1989.7	0.0
48,964	1988.8	1988.8	0.0
48,625	1987.8	1987.8	0.0
48,416	1987.6	1987.6	0.0
48,191	1987.4	1987.4	0.0
48,147	Ped Bridge		
48,124	1987.2	1987.2	0.0
48,090	1987.2	1987.2	0.0

Table 6 provides a comparison of the *Pre-Project* and *Post-Project Conditions* WSEs at each cross section within the limits of study, demonstrating a maximum increase of 0.03 feet due to the proposed project.



Table 6. Pre-Project and Post-Project Conditions WSE comparisons

Station	Pre-Project Conditions WSE (feet NAVD88)	Post-Project Conditions WSE (feet NAVD88)	Change* (Post-Project minus Pre-Project)
57,096	2027.17	2027.17	0.00
57,062	2026.45	2026.45	0.00
57,037	2026.26	2026.26	0.00
57,014	2026.07	2026.07	0.00
56,973	2026.01	2026.01	0.00
56,958	2025.99	2025.99	0.00
56,905	2025.32	2025.32	0.00
56,874	2025.26	2025.26	0.00
56,305	2022.43	2022.43	0.00
55,774	2018.48	2018.48	0.00
55,680	2018.11	2018.11	0.01
55,569	2017.87	2017.88	0.01
54,853	2014.58	2014.59	0.00
54,276	2012.15	2012.15	0.00
54,180	2011.93	2011.93	0.01
54,056	2011.29	2011.30	0.00
53,876	2010.79	2010.79	0.00
53,836	2010.75	2010.76	0.00
53,736	2010.40	2010.40	0.00
53,722	2010.36	2010.36	0.00
53,578	2009.63	2009.64	0.00
53,523	2009.34	2009.36	0.02
53,419	2009.36	2009.39	0.03
53,204	2008.69	2008.70	0.01
53,144	2008.59	2008.60	0.02
53,036	Blue Ridge Pkwy		
52,949	2007.35	2007.36	0.01
52,801	2006.64	2006.65	0.01
52,759	2006.42	2006.44	0.01
52,504	2005.29	2005.30	0.01
51,838	2001.59	2001.59	0.00
51,290	1998.93	1998.93	0.00
51,097	1995.82	1995.82	0.00
50,544	1994.22	1994.23	0.01
50,336	1993.78	1993.78	0.01
50,096	1992.94	1992.95	0.01
49,837	1992.56	1992.57	0.01



Table 6. Pre-Project and Post-Project Conditions WSE comparisons (continued)

Station	Pre-Project Conditions WSE (feet NAVD88)	Post-Project Conditions WSE (feet NAVD88)	Change* (Post-Project minus Pre-Project)
49,786	1992.59	1992.60	0.01
49,686	1992.45	1992.44	-0.01
49,597	Saunooke Bridge		
49,518	1990.88	1990.87	-0.01
49,228	1989.67	1989.67	0.00
48,964	1988.77	1988.78	0.01
48,625	1987.81	1987.81	0.00
48,416	1987.60	1987.60	0.00
48,283	1987.51	1987.51	0.00
48,241	1987.48	1987.48	0.00
48,191	1987.40	1987.40	0.00
48,147	Ped Bridge		
48,124	1987.21	1987.21	0.00
48,090	1987.20	1987.20	0.00

*Change using unrounded model values.

The proposed projects increase the 1%AC WSEs up to 0.03 feet within the study area. The area of maximum increase is between the riverbank erosion area and the Blue Ridge Parkway. The rise in the post-project condition is due to the addition of fill within the floodplain. Constructing the trail on fill is intended to reduce excavation and the potential for disturbance to archaeological resources within the project limits. In the vicinity of the Blue Ridge Parkway Bridge, fill is also needed to raise the longitudinal grade so that the trail meets ADA requirements. In the vicinity of the Saunooke Bridge, fill within the floodplain is needed to widen the roadway embankment for the trail connector alignment.

4.2 Scour potential model

This 1D steady state HEC-RAS model was developed to assess the scour potential at Footbridge #1 as part of the foundation design.

4.2.1 Hydrology

Footbridge #1 is within the right overbank floodplain of the Oconaluftee River and generally receives baseflow from the culverts underneath Newfound Gap Road. When the river experiences flood events flow leaves the bank, crosses the Oconaluftee River Trail, and flows to Footbridge #1.

Stantec used the 2D model, developed as part of the stream bank erosion repair, to quantify the peak discharges that flow from the river to Footbridge #1. Discharge values are listed in Table 7.



Table 7. Discharges

Percent-annual-chance	Discharge (cfs)
10	690
4	1,180
2	1,560
1	1,800

4.2.2 Hydraulics

Stantec used HEC-RAS version 6.6 to develop the *Post-Project Conditions* plan. The plan was developed assuming unobstructed flow at all cross sections and the bridge. Unless otherwise noted, the vertical datum for this project is the North American Vertical Datum of 1988 (NAVD88) and the horizontal datum is the North Carolina State Plane Zone, North American Datum of 1983 (NAD83) with units of U.S. feet.

Within the vicinity of Footbridge #1, cross sections were drawn in order to capture the proposed structure. Cross section geometry was extracted from the LiDAR. The attachments include a plan view workmap including the cross section layout.

Bridge geometry for Footbridge #1 was input based on the 95% design plans.

Ineffective areas were placed where needed to define areas not actively conveying flow.

The expansion and contraction coefficients were set to 0.1 and 0.3 for all non-bridge cross section, while coefficients for cross sections associated with bridges—two cross sections upstream and one cross section downstream—were assigned coefficients of 0.3 and 0.5.

Manning's n values were assigned based on the values present in the WSE impact 1D model; to ensure consistency.

A scour analysis utilizing the procedures outlined in Hydraulic Engineering Circular No. 18 "Evaluating Scour at Bridges Fifth Edition," and the soil D50 grain size provided by DMY.

4.2.3 Results Summary

Table 8 presents the potential scour depth results for the 1% and 10%AC flows.

Table 8. Potential Scour Depths

Abutment	10%AC scour depth (ft)	1%AC scour depth (ft)
Left	2.4	15.3
Right	1.3	7.3

The results of the scour analysis are being used to inform the final foundation design elevations and type.

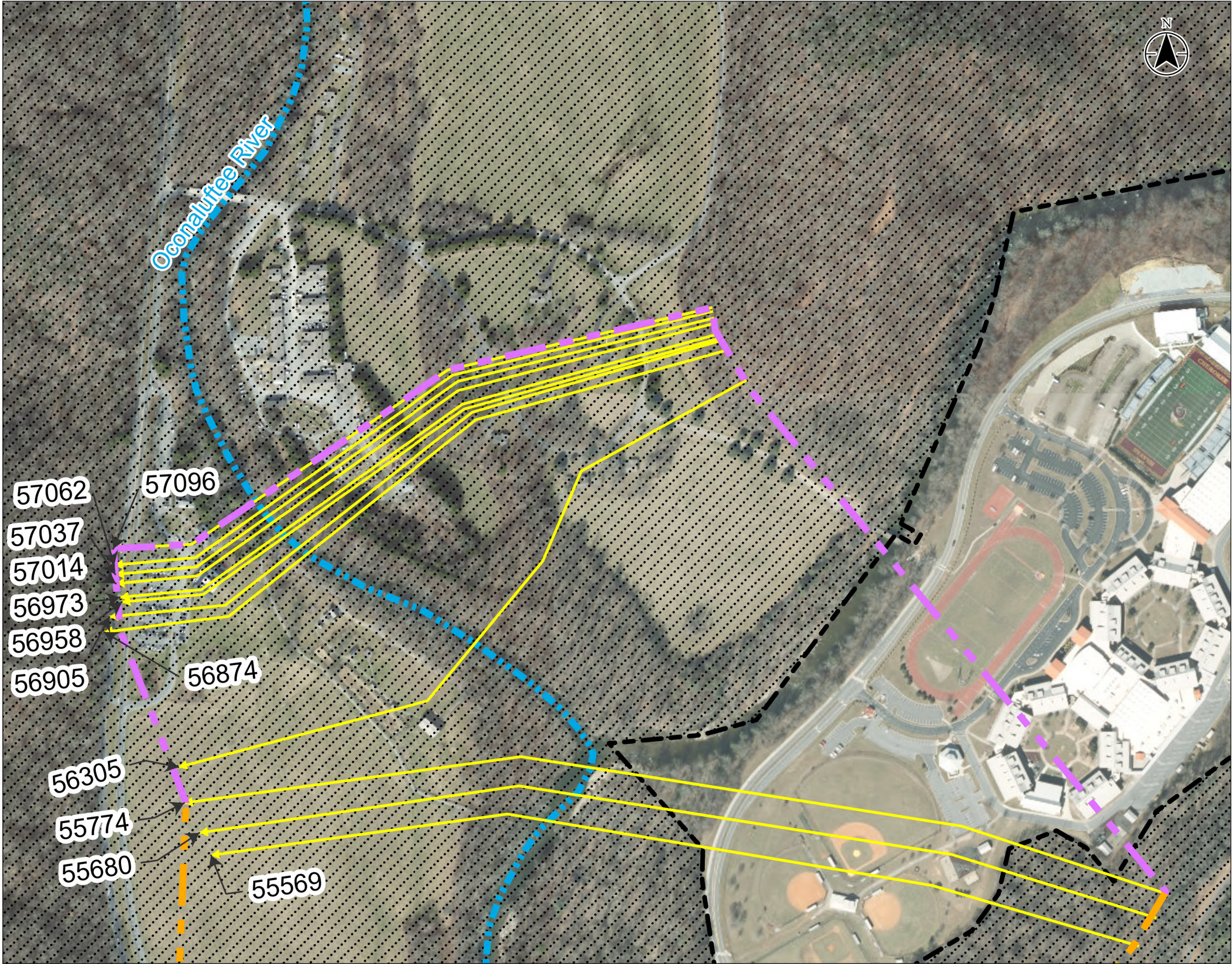




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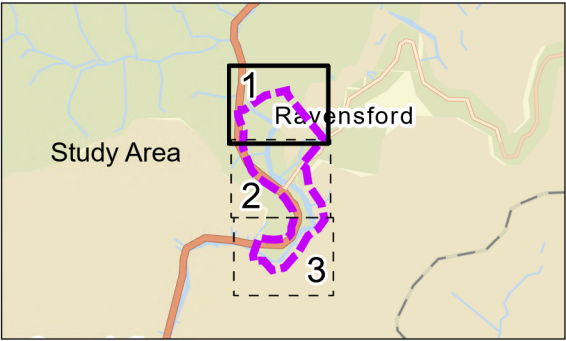


Study Area WSE Change (feet)

- 0.01
- 0.00
- 0.01
- 0.02
- 0.03
- Updated Model Cross Sections (Station)
- Bridges
- Model Baseline
- 1-percent-annual-chance inundation



Notes
1. Vertical Datum: NAVD88
2. Coordinate System: NAD 1983 StatePlane North Carolina FIPS 3200 Feet
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World Imagery: NC CGIA, Vantor



Project Location
Near
Cherokee, North Carolina
and Swain County, North Carolina

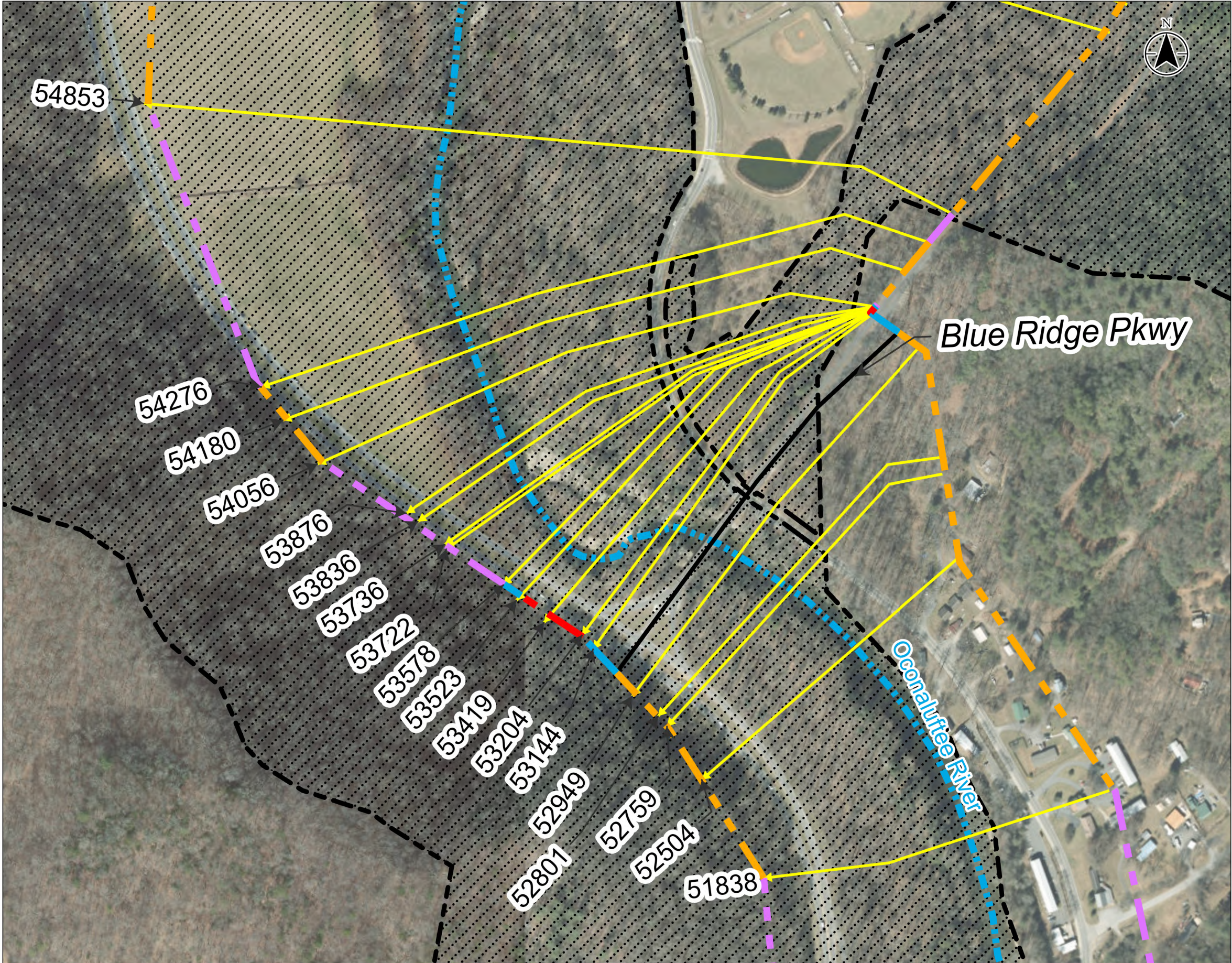
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Client/Project
National Park Service
Rehabilitate Oconaluftee River Trail at Great
Smoky Mountains National Park

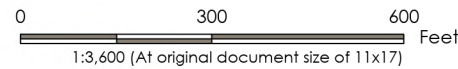
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Title
1D Model Workmaps

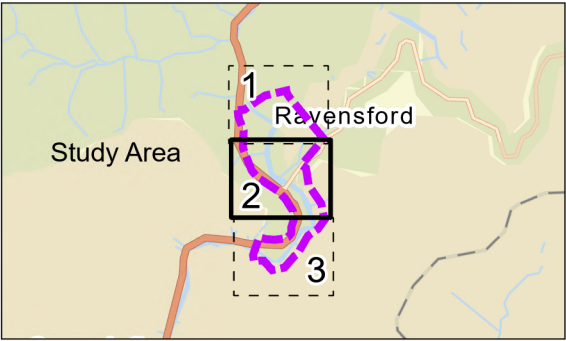
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- Study Area WSE Change (feet)
- 0.01
 - 0.00
 - 0.01
 - 0.02
 - 0.03
- Updated Model Cross Sections (Station)
- Bridges
- Model Baseline
- 1-percent-annual-chance inundation



- Notes
1. Vertical Datum: NAVD88
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- World Imagery: NC CGIA, Vantor



Project Location
Near
Cherokee, North Carolina
and Swain County, North Carolina

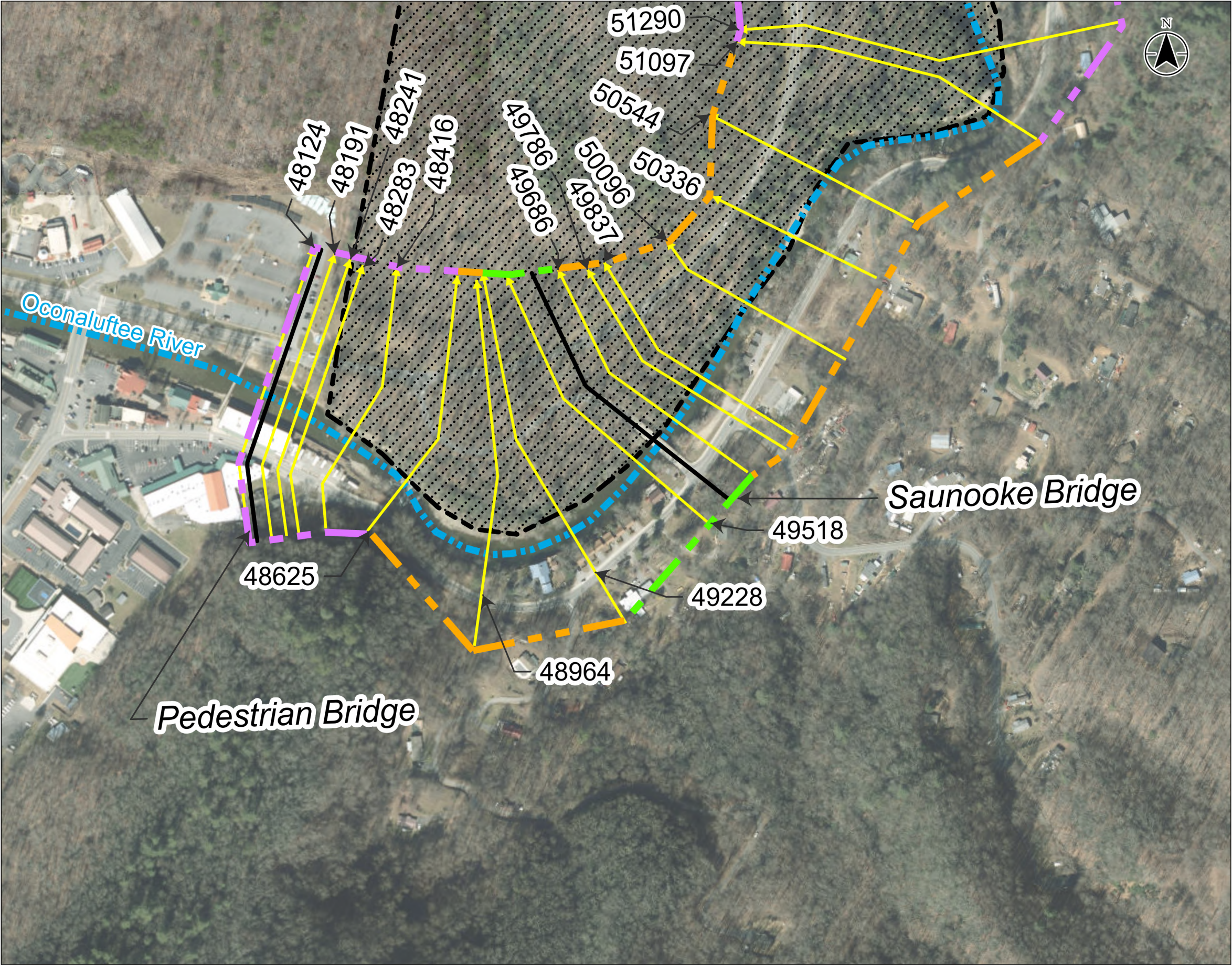
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Client/Project
National Park Service
Rehabilitate Oconaluftee River Trail at Great
Smoky Mountains National Park

Figure No.
2 of 3

Title
1D Model Workmaps

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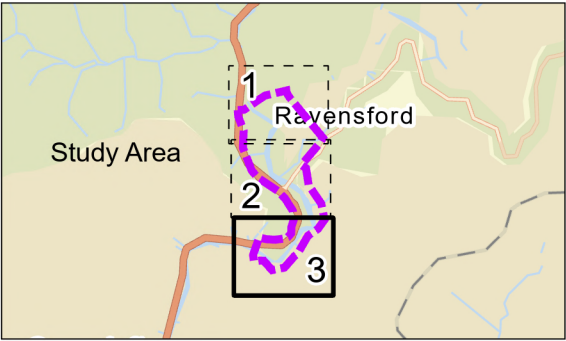


Study Area WSE Change (feet)

- 0.01
- 0.00
- 0.01
- 0.02
- 0.03
- Updated Model Cross Sections (Station)
- Bridges
- Model Baseline
- 1-percent-annual-chance inundation



Notes
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World Imagery: NC CGIA, Vantor



Project Location
Near
Cherokee, North Carolina
and Swain County, North Carolina

Prepared by MIA on 2026-02-19

Client/Project
National Park Service
Rehabilitate Oconaluftee River Trail at Great
Smoky Mountains National Park

Figure No.
3 of 3

Title
1D Model Workmaps

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 **Stantec**



 Updated Model Cross Sections (Station)



 Bridges



 Limits of Construction



 Model Baseline



 1-percent-annual-chance inundation



 Study Area



 GRSM Park Boundary

060120

Feet

1:720 (At original document size of 11x17)

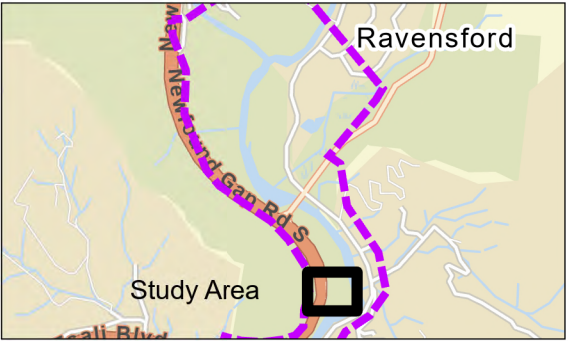
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World Imagery: NC CGIA, Microsoft, Vantor



Project Location

Near
Cherokee, North Carolina
and Swain County, North Carolina

Prepared by MIA on 2026-02-10

Client/Project

National Park Service
Rehabilitate Oconaluftee River Trail at Great
Smoky Mountains National Park

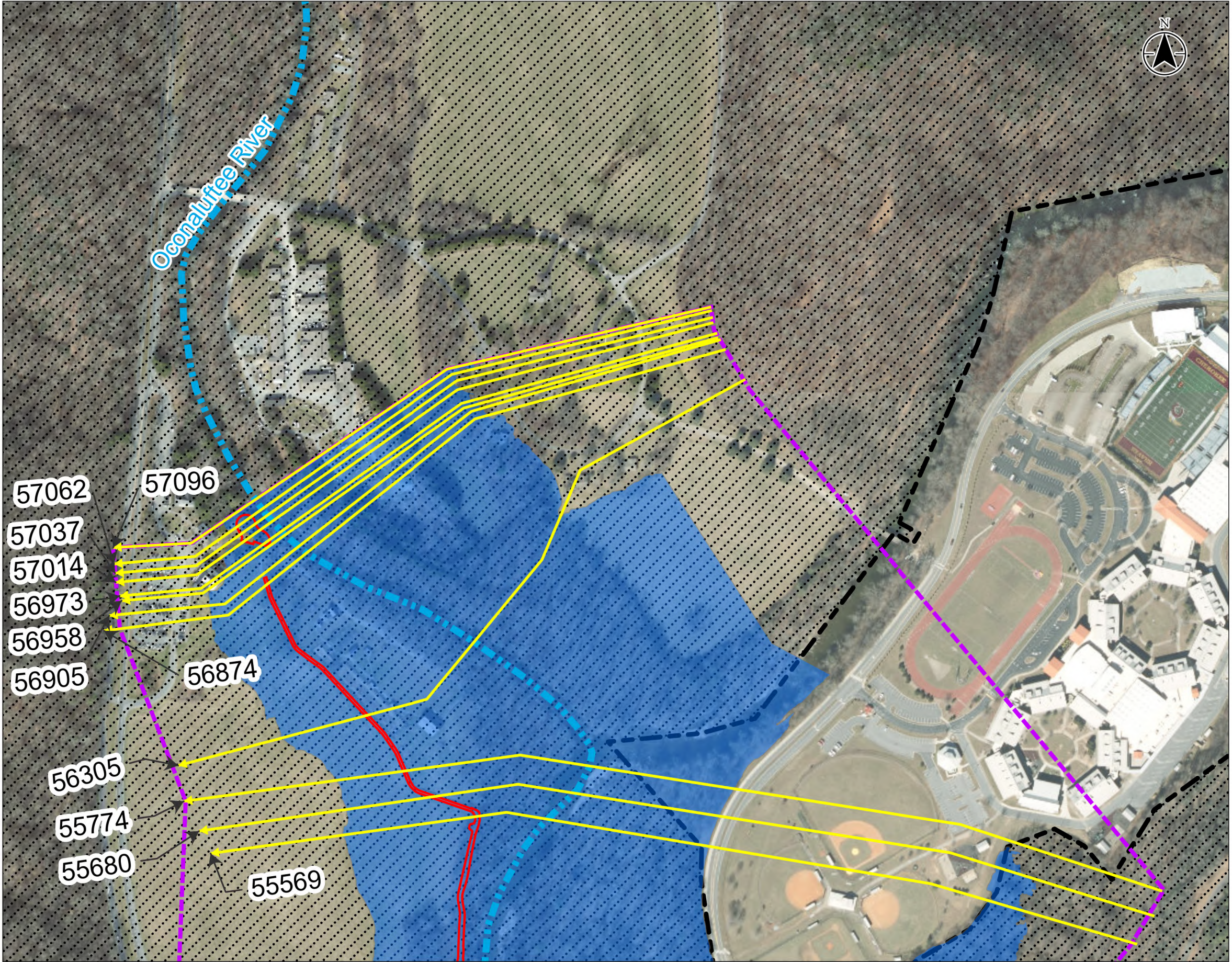
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Title

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 **Stantec**

 Updated Model Cross Sections (Station)

 Bridges

 Limits of Construction

 Model Baseline

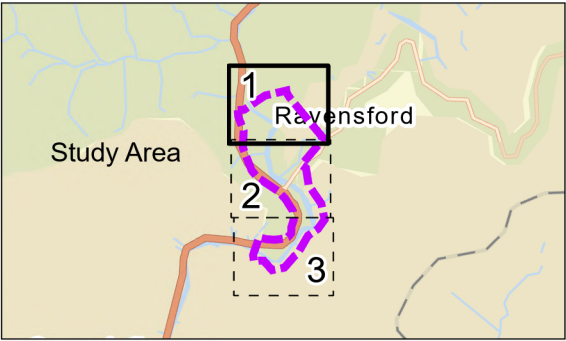
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 Study Area

 GRSM Park Boundary



Notes
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3. Base features: Service Layer Credits: World Street Map; State of North Carolina DOT; Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS
World Imagery: NC CGIA, Vantor



Project Location
Near
Cherokee, North Carolina
and Swain County, North Carolina

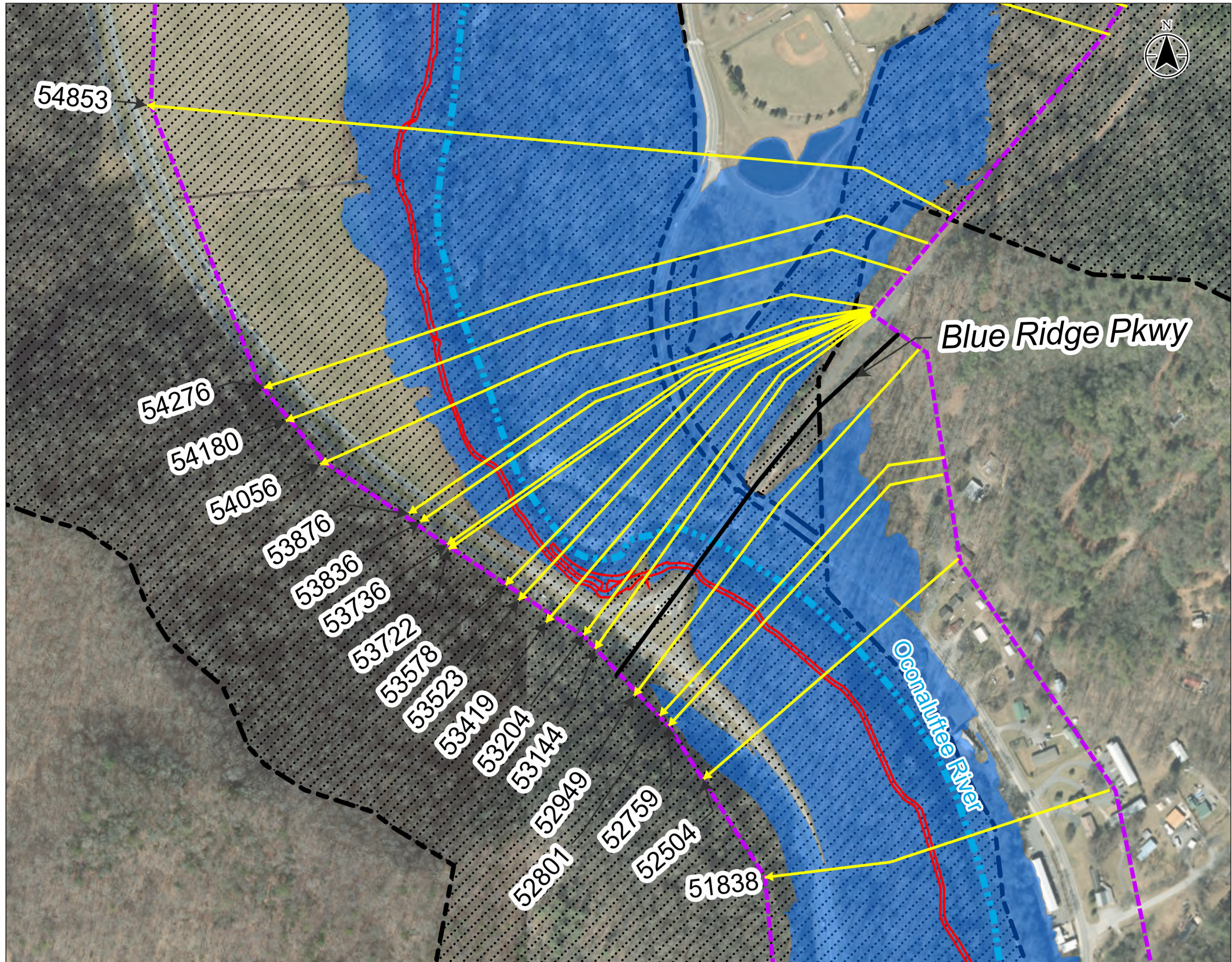
Prepared by MIA on 2026-02-19

Client/Project
National Park Service
Rehabilitate Oconaluftee River Trail at Great
Smoky Mountains National Park

Figure No.
1 of 3

Title
FEMA BFE plus 2 feet Workmaps

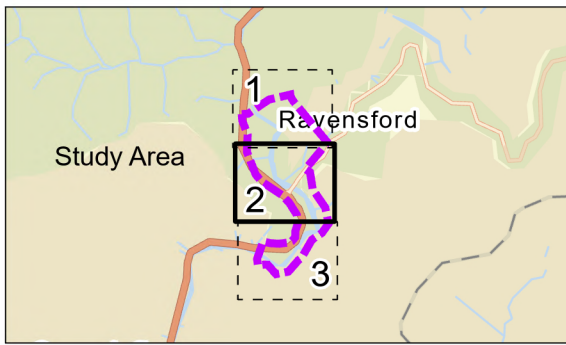
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- Updated Model Cross Sections (Station)
- Bridges
- Limits of Construction
- Model Baseline
- 1-percent-annual-chance BFE plus 2 foot
- Study Area
- GRSM Park Boundary

0 300 600 Feet
1:3,600 (At original document size of 11x17)

Notes
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World Imagery: NC CGIA, Vantor



Project Location
Near
Cherokee, North Carolina
and Swain County, North Carolina

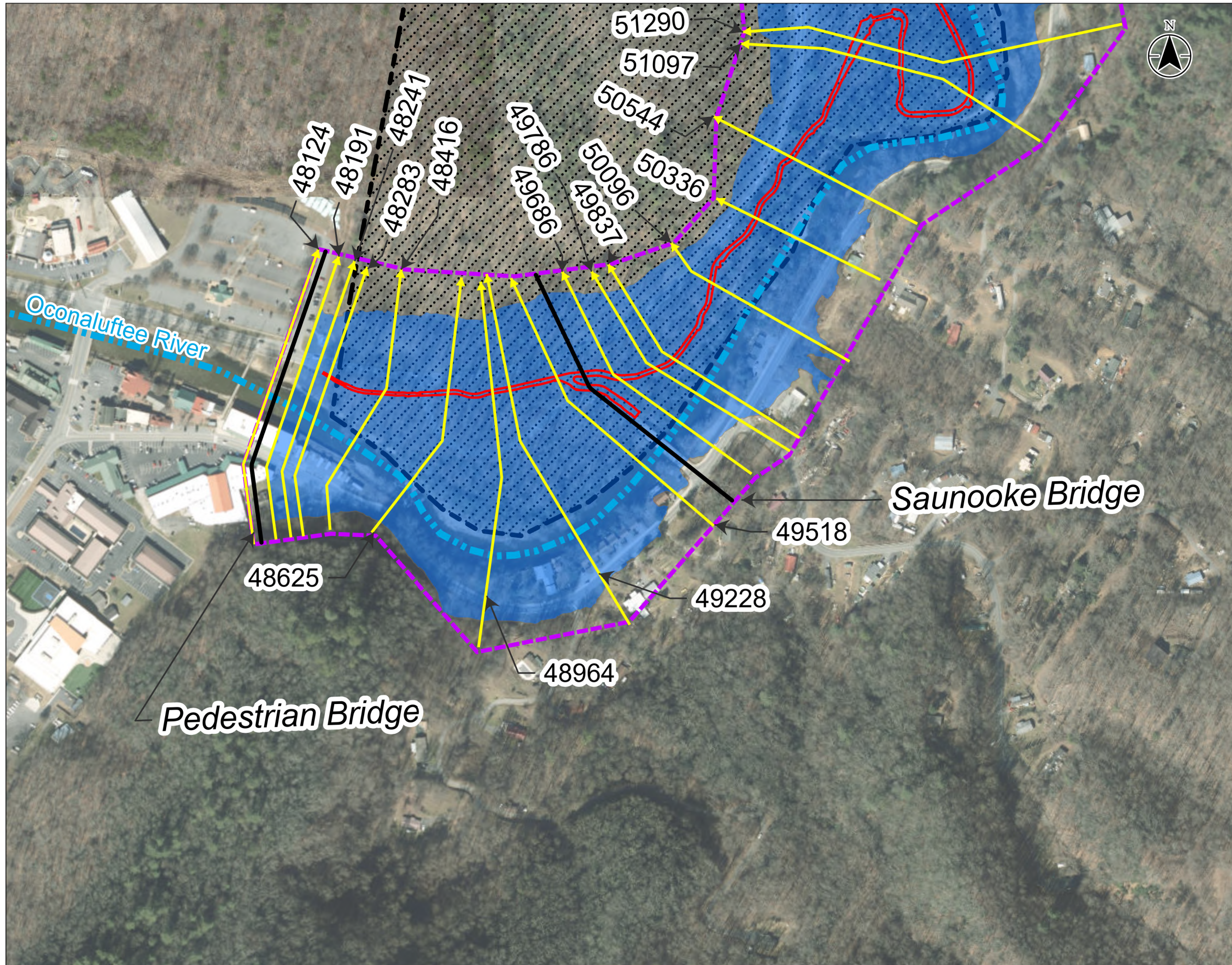
Prepared by MIA on 2026-02-19

Client/Project
National Park Service
Rehabilitate Oconaluftee River Trail at Great Smoky Mountains National Park

Figure No.
2 of 3

Title
FEMA BFE plus 2 feet Workmaps

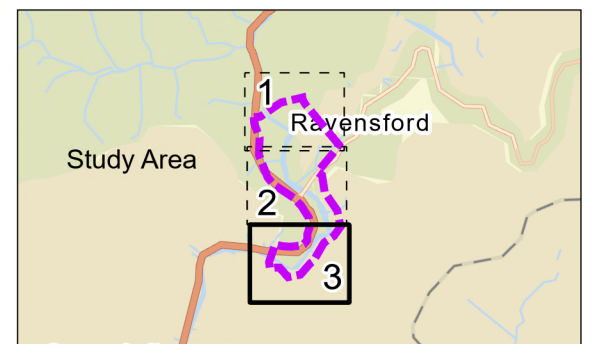
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- Updated Model Cross Sections (Station)
- Bridges
- Limits of Construction
- Model Baseline
- 1-percent-annual-chance BFE plus 2 foot
- Study Area
- GRSM Park Boundary

0 300 600 Feet
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Notes
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3. Base features: Service Layer Credits: World Street Map; State of North Carolina DOT; Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS
World Imagery: NC CGIA, Vantor



Project Location
Near
Cherokee, North Carolina
and Swain County, North Carolina

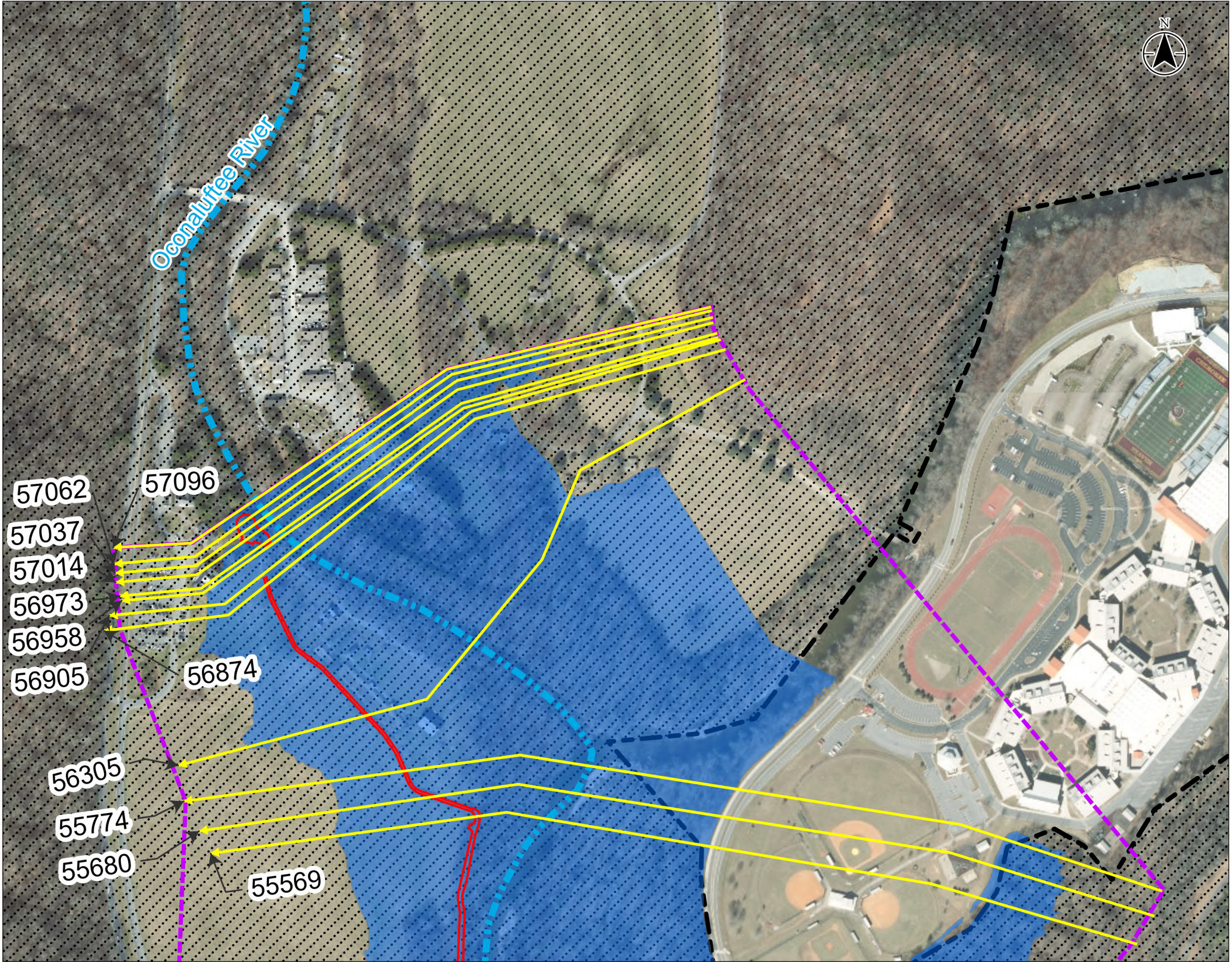
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Client/Project
National Park Service
Rehabilitate Oconaluftee River Trail at Great Smoky Mountains National Park

Figure No.
3 of 3

Title
FEMA BFE plus 2 feet Workmaps

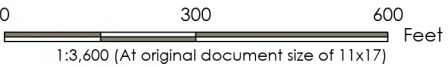
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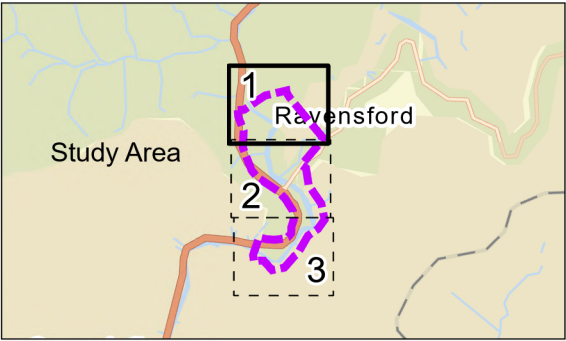


Stantec

- Updated Model Cross Sections (Station)
- Bridges
- Limits of Construction
- Model Baseline
- 1-percent-annual-chance BFE plus 3 feet
- Study Area
- GRSM Park Boundary



Notes
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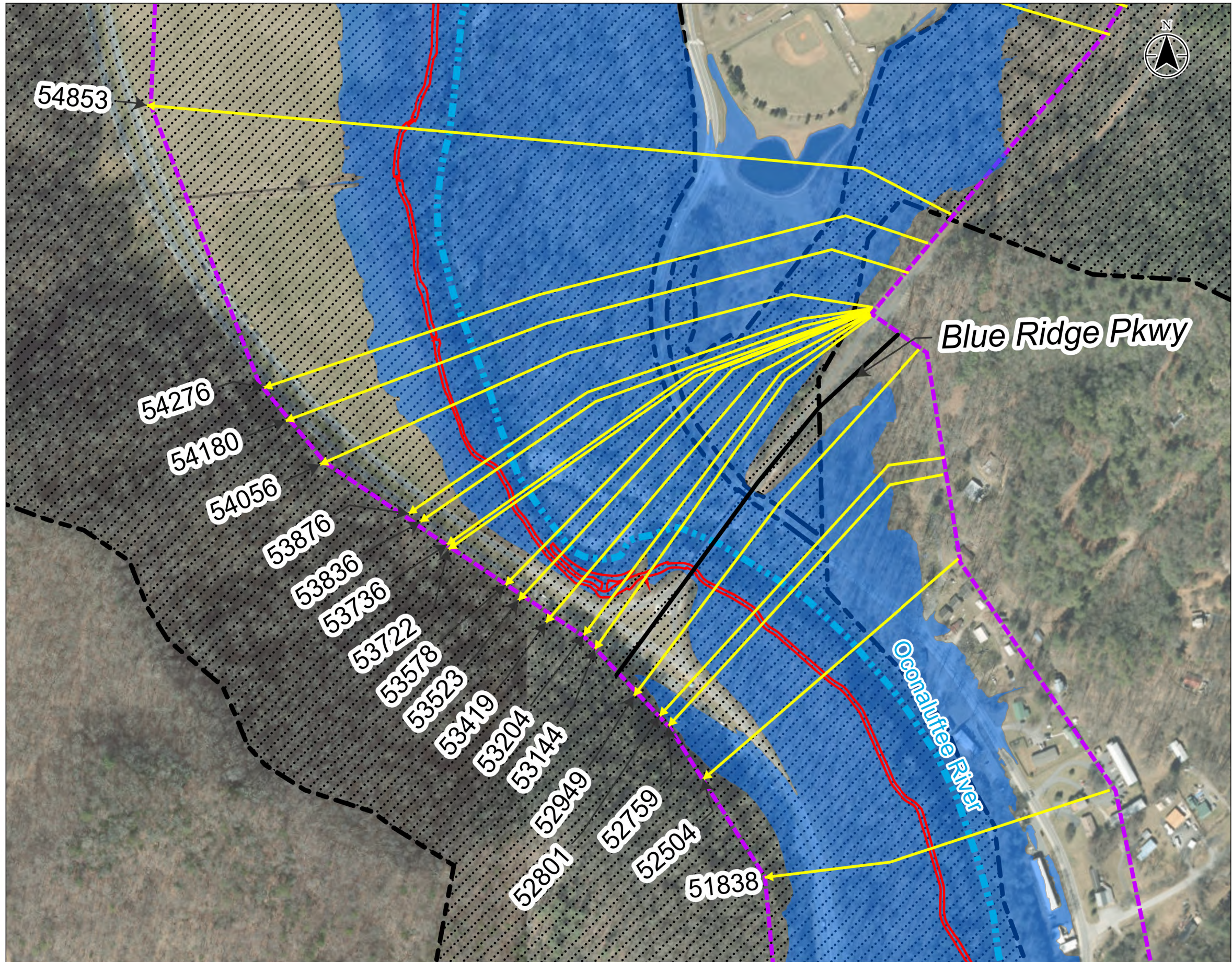
Project Location
Near
Cherokee, North Carolina
and Swain County, North Carolina

Client/Project
National Park Service
Rehabilitate Oconaluftee River Trail at Great
Smoky Mountains National Park

Figure No.
1 of 3

Title
FEMA BFE plus 3 feet Workmaps

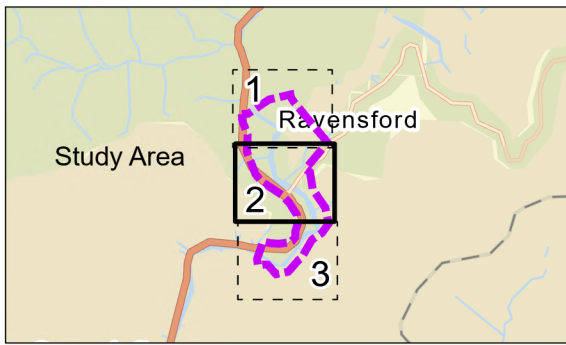
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- Updated Model Cross Sections (Station)
- Bridges
- Limits of Construction
- - - Model Baseline
- 1-percent-annual-chance BFE plus 3 feet
- Study Area
- GRSM Park Boundary

0 300 600 Feet
1:3,600 (At original document size of 11x17)

Notes
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World Imagery: NC CGIA, Vantor



Project Location
Near
Cherokee, North Carolina
and Swain County, North Carolina

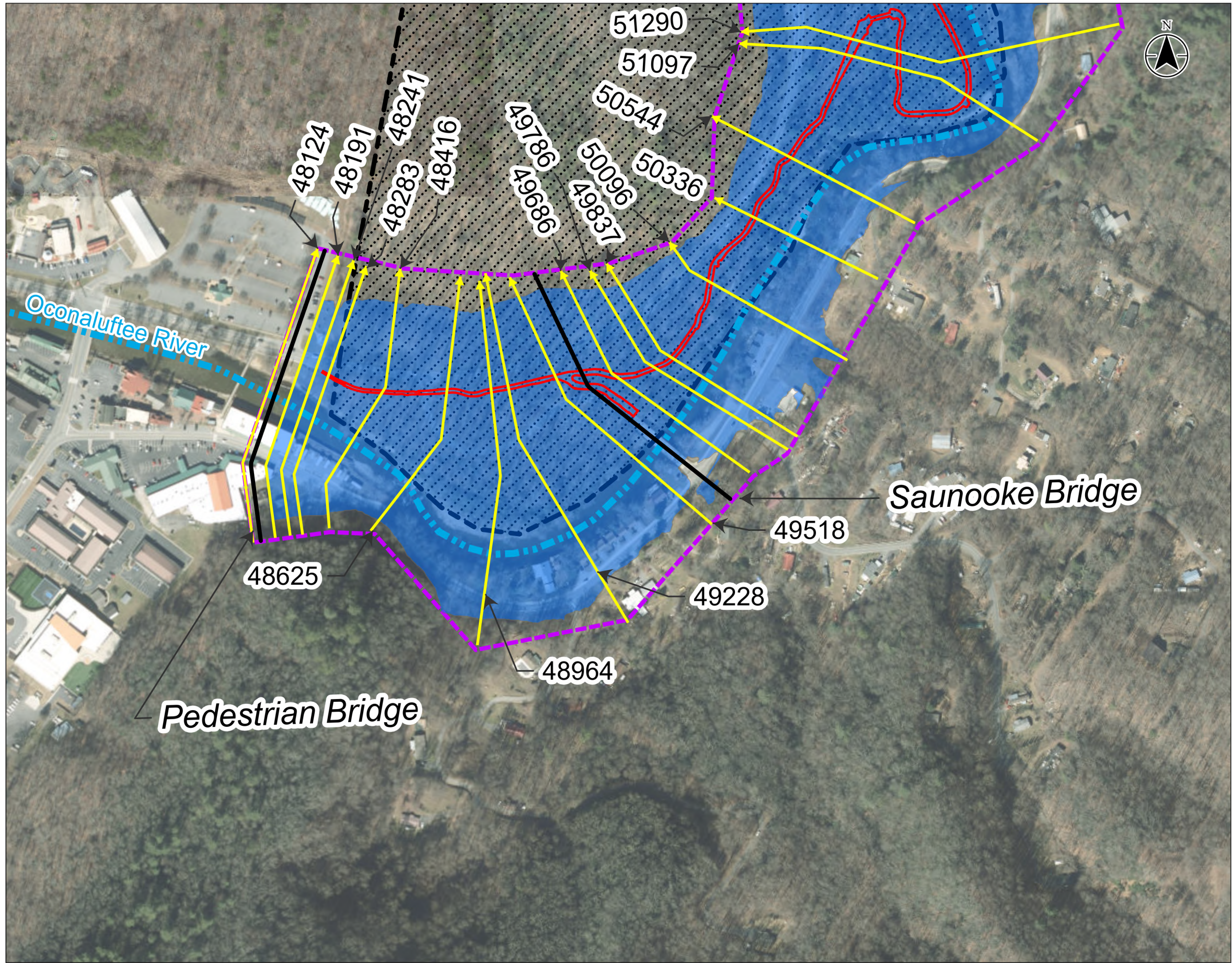
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Client/Project
National Park Service
Rehabilitate Oconaluftee River Trail at Great Smoky Mountains National Park

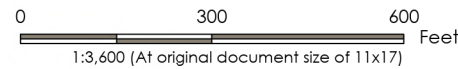
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Title
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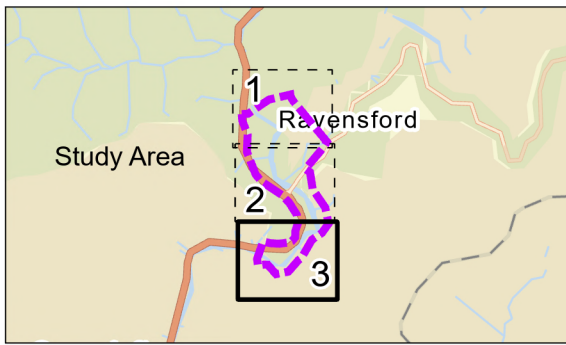
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- Updated Model Cross Sections (Station)
- Bridges
- Limits of Construction
- Model Baseline
- 1-percent-annual-chance BFE plus 3 feet
- Study Area
- GRSM Park Boundary



Notes
1. Vertical Datum: NAVD88
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World Imagery: NC CGIA, Vantor



Project Location
Near
Cherokee, North Carolina
and Swain County, North Carolina

Prepared by MIA on 2026-02-19

Client/Project
National Park Service
Rehabilitate Oconaluftee River Trail at Great Smoky Mountains National Park

Figure No.
3 of 3

Title
FEMA BFE plus 3 feet Workmaps

Appendix B. Drainage Design Report

Drainage Design Report

Oconaluftee Transportation Trail Corridor Design

Great Smoky National Park

Contract No. 140P2021D0021

February 2026

Owner/Developer:

National Park Service (NPS)

Denver Service Center

Prepared by:



Stantec

Contents

1	Project Site Description and Narrative	3
2	Methodology and Criteria	3
3	Site Assumptions	4
4	Proposed Design	4

Appendices

- Appendix A- Drainage Area Maps**
- Appendix B- Soils Mapping**
- Appendix C- Hydrology and Hydraulics**
- Appendix D- Buoyancy Computations**

1 Project Site Description and Narrative

The National Park Service (NPS) is improving the multi-use Oconaluftee River Trail that links the gateway community of Cherokee to the park. The trail is in Great Smoky Mountains National Park in Swain County, NC and is in the Tuckasegee subbasin (06010203) watershed.

The Oconaluftee River Trail is approximately 8,400 feet (1.6 miles) in length and extends from the Oconaluftee Visitor Center to the park boundary with Cherokee, North Carolina. Most of the trail parallels the Oconaluftee River. This trail accommodates pedestrian and bicycle traffic and connects to the larger Eastern Band of Cherokee Indians (EBCI) Qualla Boundary. It allows users to walk/bike from the Oconaluftee Visitor Center/Mountain Farm Museum to the Cherokee commercial district. Motorized vehicles are prohibited on the trail.

The existing trail varies in width from 4-10 feet of an aggregate surface and includes three small pedestrian bridges along its length. The project will widen the trail to an 8-foot travel surface and the trail will be rerouted in some locations to reduce potential archaeological impacts. This project will include improvements to the main trail and the evaluation and construction of a "spur" off the existing trail to the Saunooke Bridge, approximately 300 feet in length.

Most of the existing trail is located within the 100-year floodplain and sections of the trail have been impacted/washed out due to flooding. This project will consider minor re-alignment of the trail further away from the river to reduce potential future impacts from high water events. This project will not include formalizing or adding any additional parking areas for trail users.

There are wetlands and/or Waters of the US (WOTUS) located at the site.

USDA Natural Resources Conservation Service (NRCS) Web Soil Survey was used to determine the soil types present in the area. The site is comprised of primarily Hydrologic Soil Group (HSG) A and B soils. Soils maps depicting the various soil types present within the project limits are included in Appendix B.

2 Methodology and Criteria

The USDOT FHWA Project Development and Design Manual (PDDM) Chapter 7 was used to determine the design for the culverts that will be extended as part of the trail widening. The design storm for the trail culvert design is the 10-year storm event. Per section 7.2.3.9.2, the rainfall data that was used to determine the design flows was the NOAA Atlas 14 – Precipitation Frequency Atlas of the United States (Vol. 1 and 2, 2004). This can be found in Appendix C.

Drainage areas to each of the proposed culvert locations were delineated with the use of a combination of GIS topography contours, Google imagery, and field observations. The proposed drainage areas can be seen in the rational spreadsheets in Appendix C.

The Rational Method was used to compute 10-year peak discharges based on drainage area to the culverts. A runoff coefficient (C-Factor) was calculated for each drainage area using a value of 0.15 for wooded areas, 0.25 for open areas, 0.70 for gravel, and 0.90 for impervious roadway areas. Due to the rural and wooded nature of the project, time of concentration paths were computed for most of the drainage areas. A minimum time of concentration of six minutes was

used for the other culverts. The drainage area rational method and HY-8 culvert analysis computations can be found in Appendix C.

A minimum pipe diameter of 18" was requested by the National Park Service for design. This was used in all locations where it meets the design criteria, however culvert 8 is only a 15" culvert due to the small drainage area and the vertical profile of the proposed trail.

3 Site Assumptions

There was no data or survey of Newfound Gap Road, however it was assumed at sump areas in the LIDAR that culverts flowing from the western edge to the eastern edge of the road exist. Drainage areas to these areas and discharges for these culverts were determined and it was assumed that the culvert is sized to pass the 10-year discharge at these locations.

4 Proposed Design

There are eight culverts being proposed for the trail design. Culvert 1 is a double barrel 18" RCP culvert located at station 600+36 on the spur to Saunooke Bridge just to the south of the Oconaluftee River Trail, drainage from east to west. Culvert 2 is an 18" RCP culvert within the Culvert 1 drainage area to the northeast of Culvert 1 beneath the Oconaluftee River Trail at station 108+83, draining from northeast to southwest. A culvert beneath Newfound Gap Road that passes the 10-year design storm was assumed as part of this drainage area. Culvert 3 is an 18" RCP located at station 114+03 beneath the Oconaluftee River trail, draining from northwest to southeast. Culvert 4 is at 18" RCP located at station 119+07, draining from northwest to southeast. A culvert beneath Newfound Gap Road that passes the 10-year design storm was assumed as part of this drainage area. Culvert 5 is an 18" RCP culvert to the west of Blue Ridge Parkway on the Oconaluftee Trail at station 147+22, draining from south to north. Culvert 6 is an existing 24" RCP culvert in current conditions beneath Newfound Gap Road. As part of this project, the trail will be relocated to the current outfall and the culvert will be extended using a manhole and another 24" RCP pipe at station 149+90, draining from south to north. Culvert 7 is an 18" RCP located at station 156+92, draining from west to east. Culvert 8 is a 15" RCP located at station 184+26, draining a small area trapped by the proposed compliant walkway at the multi-use recreational access location, from northwest to southeast.

The HY-8 calculations can be found in Appendix C. Due to the large drainage area of the river and different peak times between the culvert drainage areas and the rivershed, the 2-year water-surface elevation of the river was used as the starting tailwater condition for the culverts. Where the downstream channel invert was higher than the water surface elevation, the channel invert was used. Culverts 2-8 pass the 10-year design discharge with this starting condition. During the 2-year river flooding event, the trail at Culvert 1 location as well as the culvert will be fully submerged. There are two computations for the culvert, one using the tailwater submerged condition and the second using the channel downstream invert as starting conditions. The culvert passes the 10-year design discharge using the channel invert as starting condition. Buoyancy computations have also been performed for Culvert 1 as it will be fully submerged to

ensure it will work as designed. These are show in in Appendix D for the culvert and the ACPA Design Data 22- Flotation of Circular Concrete Pipe guidance.

The culverts, drainage areas, and design discharges are summarized in the table below.

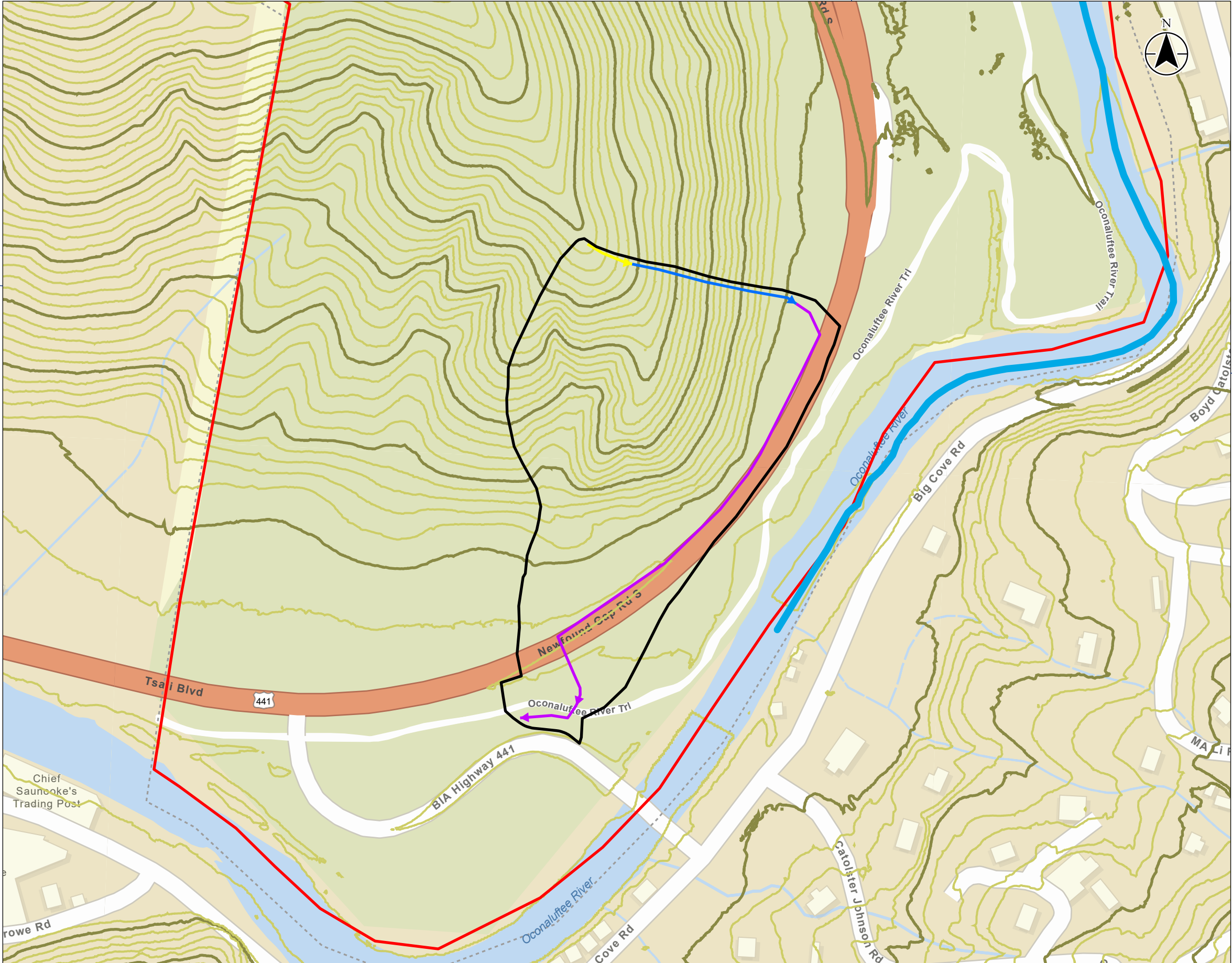
Table1. Culvert Summary Table

Culvert	Size and Type	Drainage Area (ac)	10-Year Design Discharge Q (cfs)	2-Year Water Surface Elevation (Oconaluffee River)
1	Double 18" RCP	8.93	5.98	1988.3
2	18" RCP	8.72	6.07	1988.1
3	18" RCP	0.06	0.04	1989.2
4	18" RCP	12.29	8.21	1990.4
5	18" RCP	0.34	0.87	2004.8
6	24" RCP	26.30	17.18	2005.5
7	18" RCP	1.59	1.99	2007.6
8	15" RCP	0.07	0.23	2023.3

APPENDIX A

DRAINAGE AREA MAPS

\\US0522\PF0301\shared_project\2434424\design\1_Land_in\working\report\Culvert\watershed\Oconalufee_Pipe_watershed.aprx Revised: 2024-02-17 By: sammoore





Stantec

2D Model Stream Centerlines

Pipe Drainage Basin

Park Boundary

Longest Flowpaths (Line ID)

Channel

Shallow Concentrated

Sheet

Contours

10-ft

50-ft

0200400

Feet

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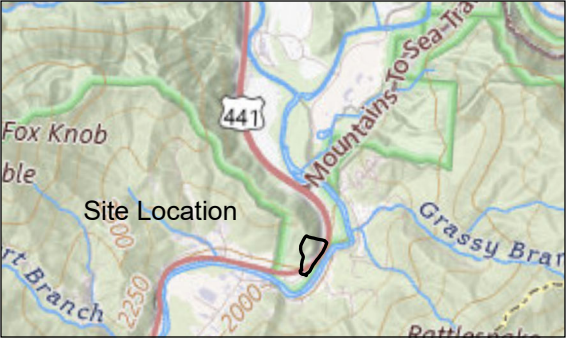
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2. Coordinate System: NAD 1983 StatePlane North Carolina FIPS 3200 Feet

3. Base features: Service Layer Credits: World Street Map: Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, (c) OpenStreetMap contributors, and the GIS User Community

USGSTopo: USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road data; Natural Earth Data; U.S. Department of State HII; NOAA National Centers for Environmental Information. Data refreshed October 27, 2025.



Project Location

Near Cherokee, North Carolina and Swain County, North Carolina

Client/Project

National Park Service
Rehabilitate Oconalufee River Trail at Great Smoky Mountains National Park

Figure No.

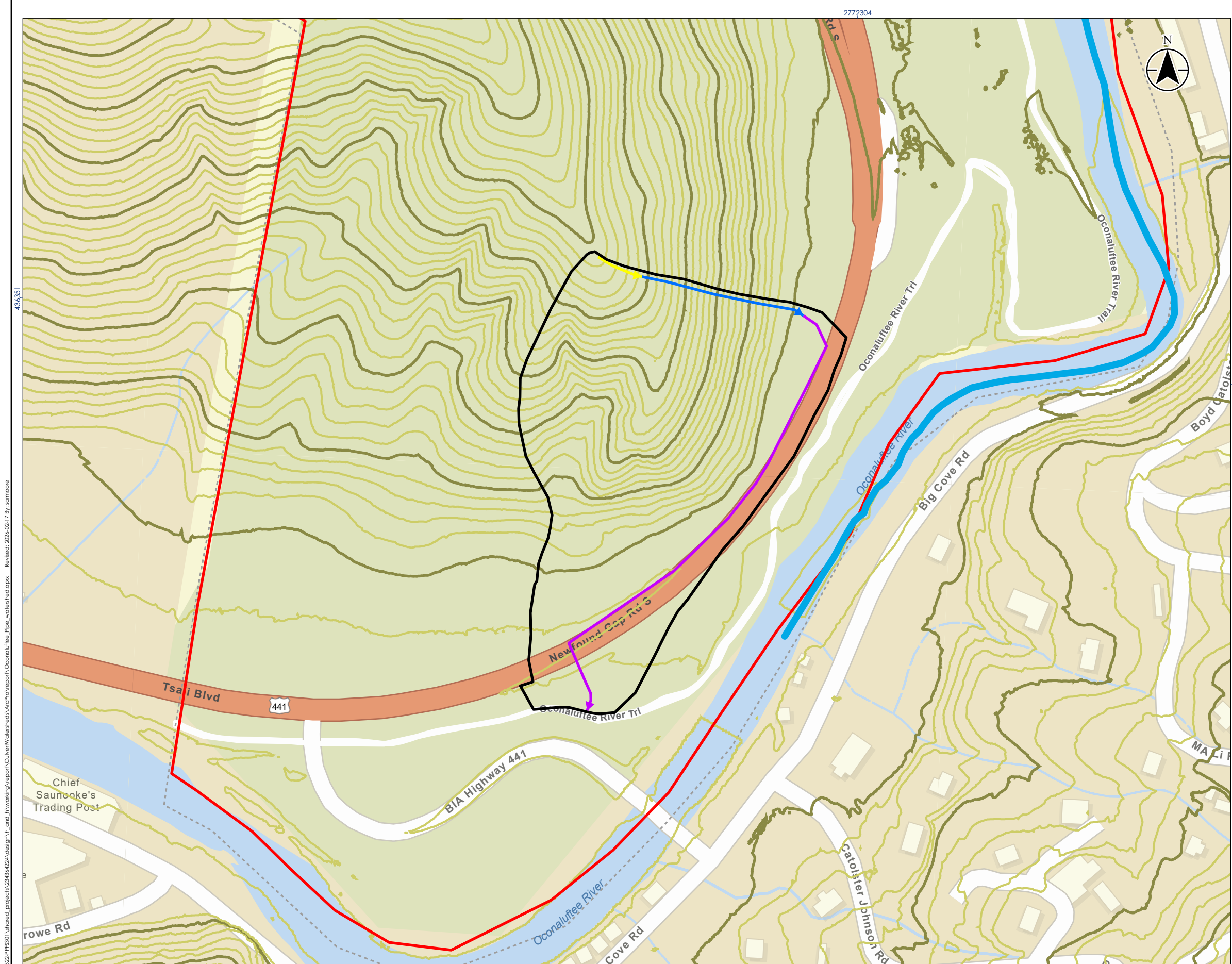
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Title

Drainage Pipe Watershed Figure (Rational Method)

Prepared by MIA on 2025-03-20

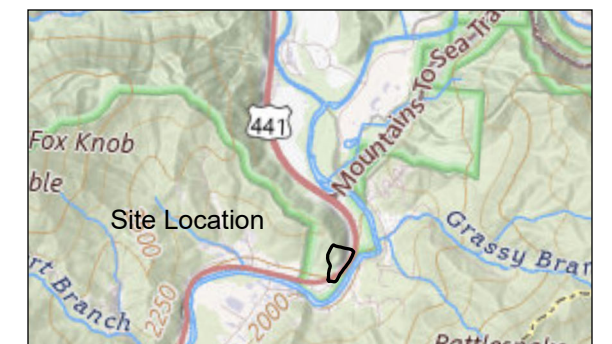
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- 2D Model Stream Centerlines
- Pipe Drainage Basin
- Park Boundary
- Longest Flowpaths (Line ID)
 - Channel
 - Shallow Concentrated
 - Sheet
- Contours
 - 10-ft
 - 50-ft



Notes
1. Vertical Datum: NAVD88
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3. Base features: Service Layer Credits: World Street Map: Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, (c) OpenStreetMap contributors, and the GIS User Community
USGSTopo: USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road data; Natural Earth Data; U.S. Department of State HII; NOAA National Centers for Environmental Information. Data refreshed October 27, 2025.



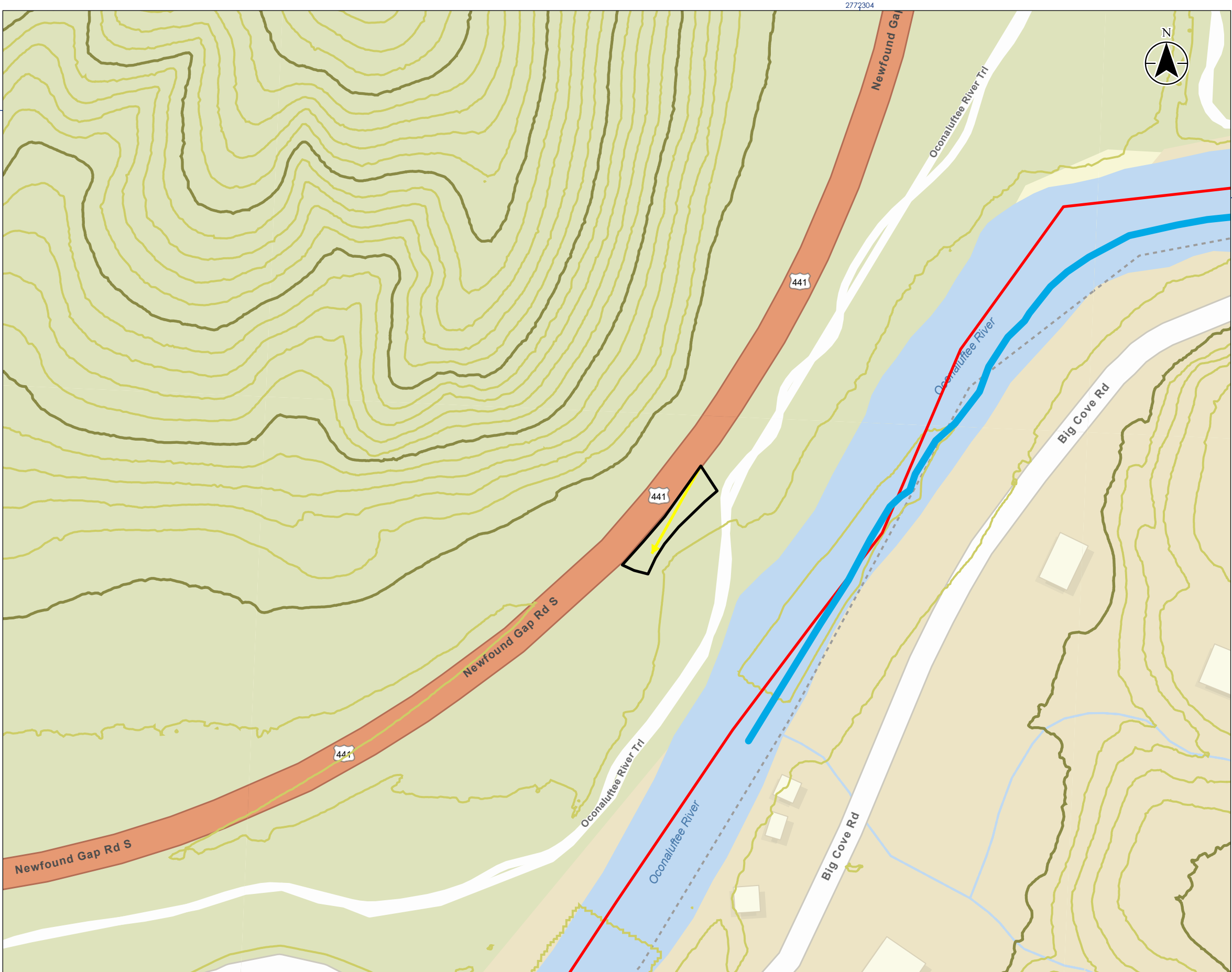
Project Location
Near
Cherokee, North Carolina
and Swain County, North Carolina
Prepared by MIA on 2025-03-20

Client/Project
National Park Service
Rehabilitate Oconaluftee River Trail at Great
Smoky Mountains National Park

Figure No.
2

Title
**Drainage Pipe Watershed Figure
(Rational Method)**

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- 2D Model Stream Centerlines
- Pipe Drainage Basin3
- Park Boundary
- Longest Flowpaths (Line ID)
 - Channel
 - Shallow Concentrated
 - Sheet
- Contours
 - 10-ft
 - 50-ft



Notes
1. Vertical Datum: NAVD88
2. Coordinate System: NAD 1983 StatePlane North Carolina FIPS 3200 Feet
3. Base features: Service Layer Credits: World Street Map: Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, (c) OpenStreetMap contributors, and the GIS User Community
USGSTopo: USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road data; Natural Earth Data; U.S. Department of State HII; NOAA National Centers for Environmental Information. Data refreshed October 27, 2025.



Project Location
Near
Cherokee, North Carolina
and Swain County, North Carolina
Prepared by MIA on 2025-03-20

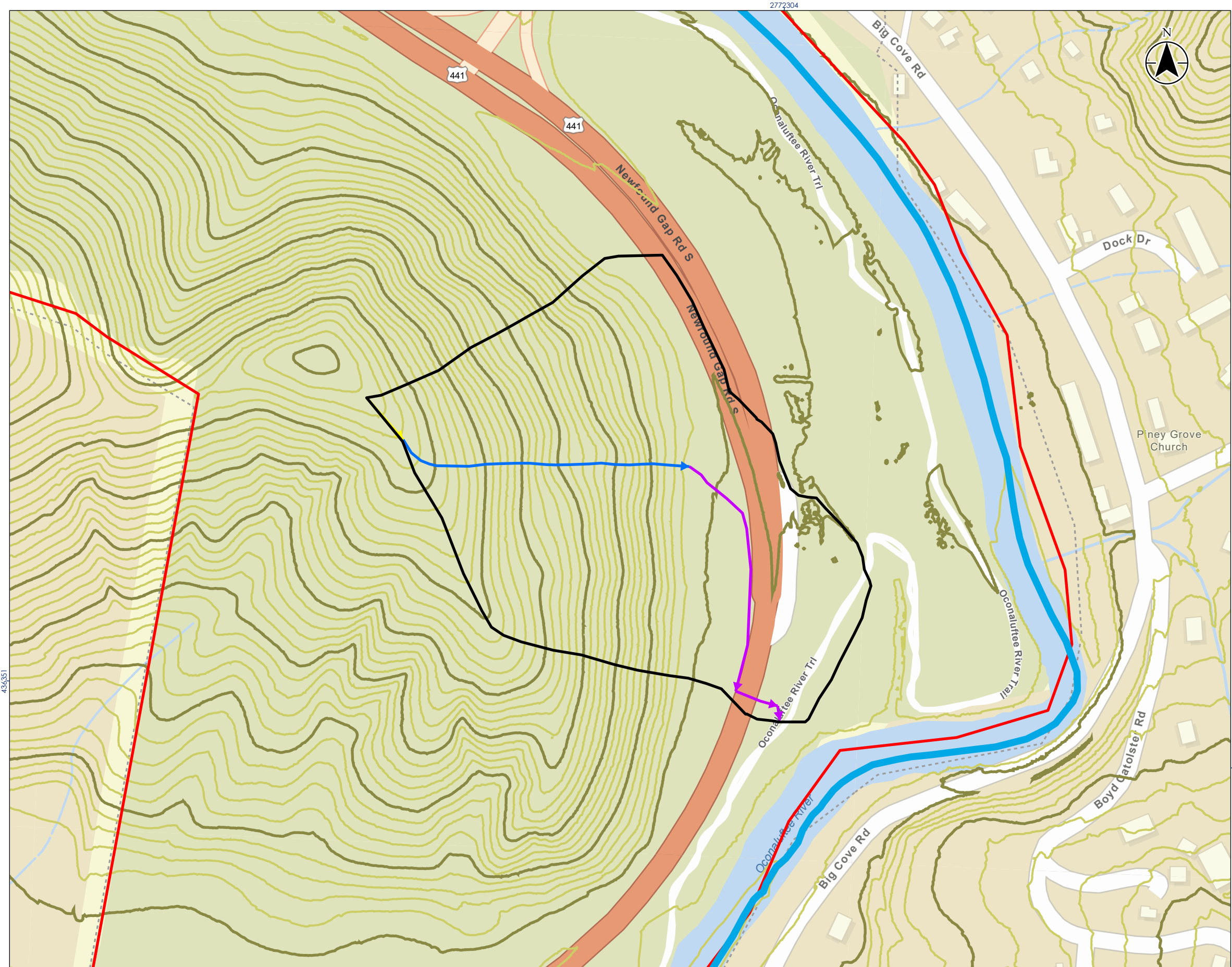
Client/Project
National Park Service
Rehabilitate Oconaluftee River Trail at Great
Smoky Mountains National Park

Figure No.
3

Title
**Drainage Pipe Watershed Figure
(Rational Method)**

Disclaimer: Stantec assumes no responsibility for data supplied in electronic format. The recipient accepts full responsibility for verifying the accuracy and completeness of the data. The recipient releases Stantec, its officers, employees, consultants and agents, from any and all claims arising in any way from the content or provision of the data.

\\US0522-PFFS301\shared_projects\234344224\design\1_and_1\working\report\Culvert\Watersheds\Macro\Report\Oconaluftee_Pipe_watershed.aprx Revised: 2026-02-17 By: sammoore



- 2D Model Stream Centerlines
- Pipe Drainage Basin
- Park Boundary
- Longest Flowpaths (Line ID)
 - Channel
 - Shallow Concentrated
 - Sheet
- Contours
 - 10-ft
 - 50-ft



Notes
1. Vertical Datum: NAVD88
2. Coordinate System: NAD 1983 StatePlane North Carolina FIPS 3200 Feet
3. Base features: Service Layer Credits; World Street Map; Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, (c) OpenStreetMap contributors, and the GIS User Community
USGSTopo: USGS The National Map; National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road data; Natural Earth Data; U.S. Department of State HUI; NOAA National Centers for Environmental Information. Data refreshed October 27, 2025.



Project Location
Near
Cherokee, North Carolina
and Swain County, North Carolina

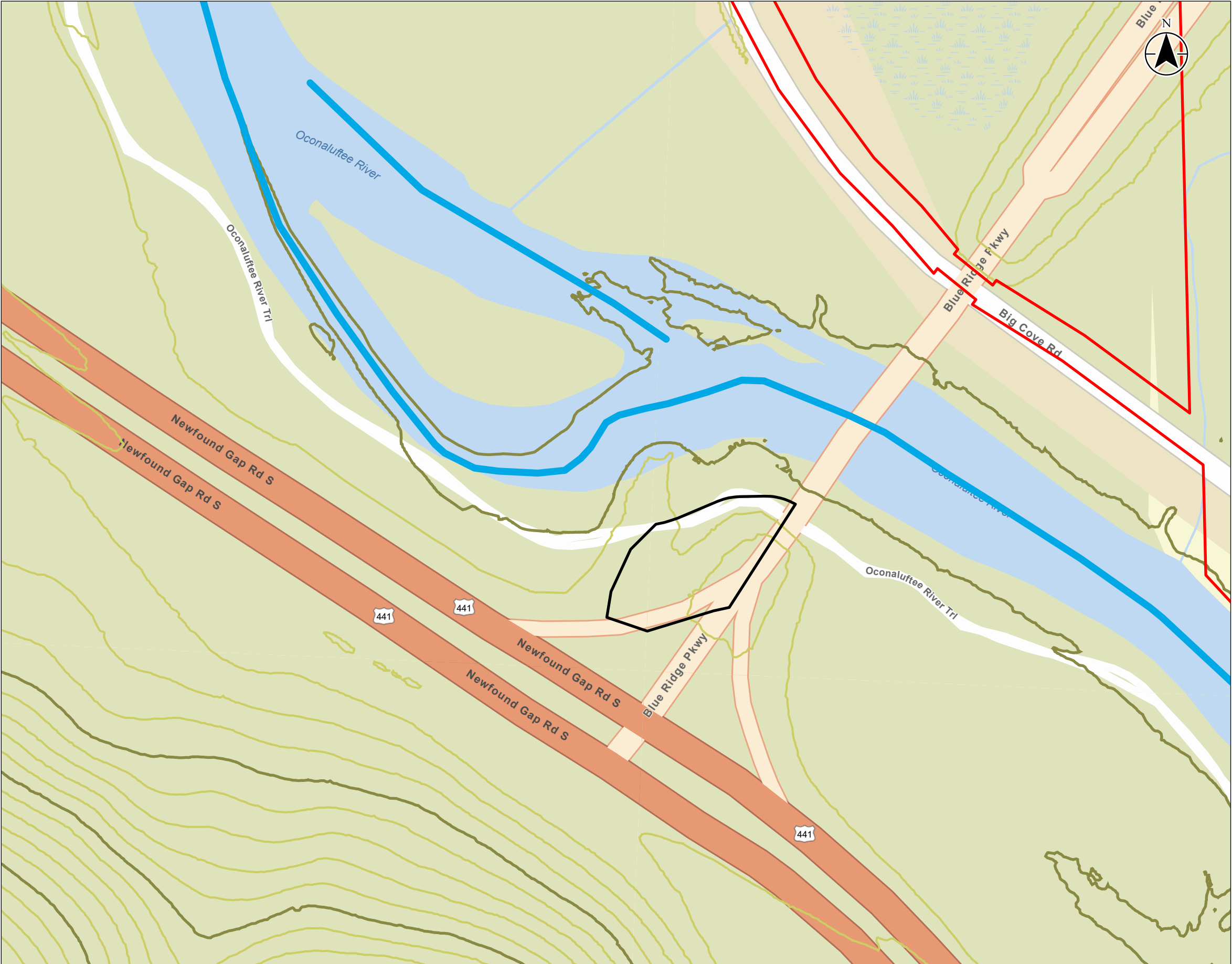
Prepared by MIA on 2025-03-20

Client/Project
National Park Service
Rehabilitate Oconaluftee River Trail at Great
Smoky Mountains National Park

Figure No.
4

Title
**Drainage Pipe Watershed Figure
(Rational Method)**

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Stantec

2D Model Stream Centerlines

Pipe Drainage Basin

Park Boundary

Longest Flowpaths (Line ID)

Channel

Shallow Concentrated

Sheet

Contours

10-ft

50-ft

* Minimum Time of Concentration of 6 minutes was used for Culvert 5, so no longest flowpaths were developed

0

200

Feet

1:1,200 (At original document size of 11x17)

Notes

1. Vertical Datum: NAVD88

2. Coordinate System: NAD 1983 StatePlane North Carolina FIPS 3200 Feet

3. Base features: Service Layer Credits; World Street Map; Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, (c) OpenStreetMap contributors, and the GIS User Community

USGSTopo: USGS The National Map; National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road data; Natural Earth Data; U.S. Department of State HUI; NOAA National Centers for Environmental Information. Data refreshed October 27, 2025.



Project Location

Near
Cherokee, North Carolina
and Swain County, North Carolina

Prepared by MIA on 2025-03-20

Client/Project

National Park Service
Rehabilitate Oconaluftee River Trail at Great
Smoky Mountains National Park

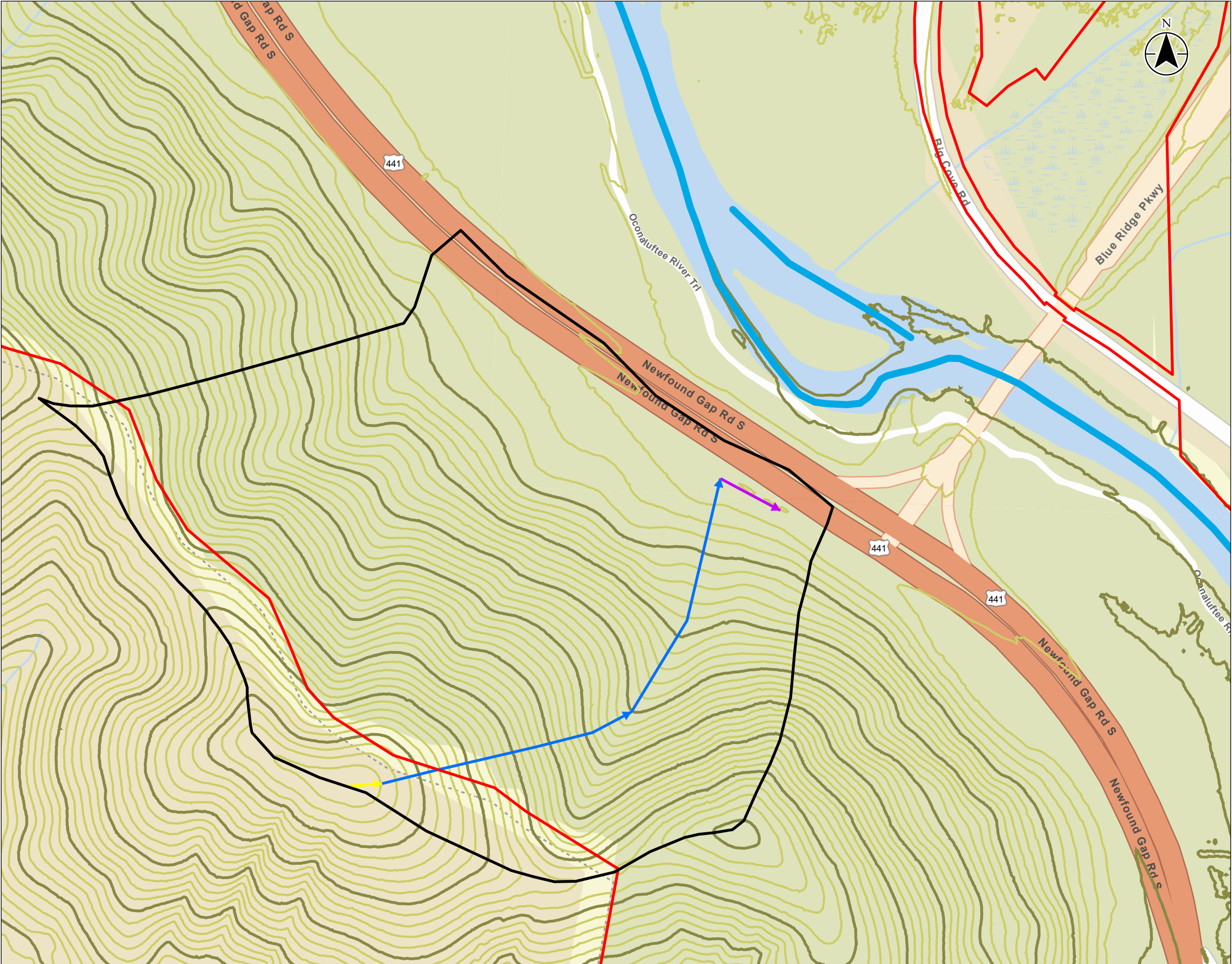
Figure No.

5

Title

Drainage Pipe Watershed Figure
(Rational Method)

\\US05222\FPS30\shared_projects\23434424\design\1_Land_in\working\report\Culvert\watershed\Oconalufee_Pipe_watershed.aprx Revised: 2026-02-17 By: sammoore





Stantec

2D Model Stream Centerlines

Pipe Drainage Basin

Park Boundary

Longest Flowpaths (Line ID)

Channel

Shallow Concentrated

Sheet

Contours

10-ft

50-ft

0

200

400

Feet

1:2,400 (At original document size of 11x17)

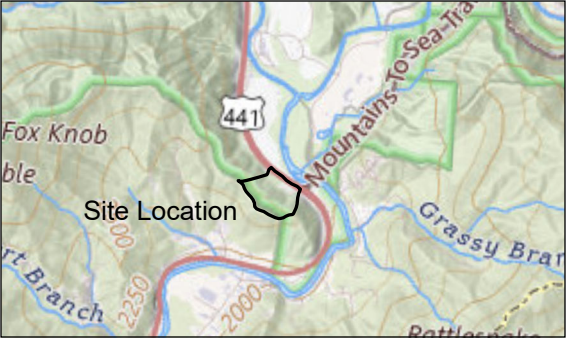
Notes

1. Vertical Datum: NAVD88

2. Coordinate System: NAD 1983 StatePlane North Carolina FIPS 3200 Feet

3. Base features: Service Layer Credits; World Street Map; Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, (c) OpenStreetMap contributors, and the GIS User Community

USGSTopo: USGS The National Map; National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road data; Natural Earth Data; U.S. Department of State HII; NOAA National Centers for Environmental Information. Data refreshed October 27, 2025.



Project Location

Near Cherokee, North Carolina and Swain County, North Carolina

Prepared by MIA on 2025-03-20

Client/Project

National Park Service
Rehabilitate Oconalufee River Trail at Great Smoky Mountains National Park

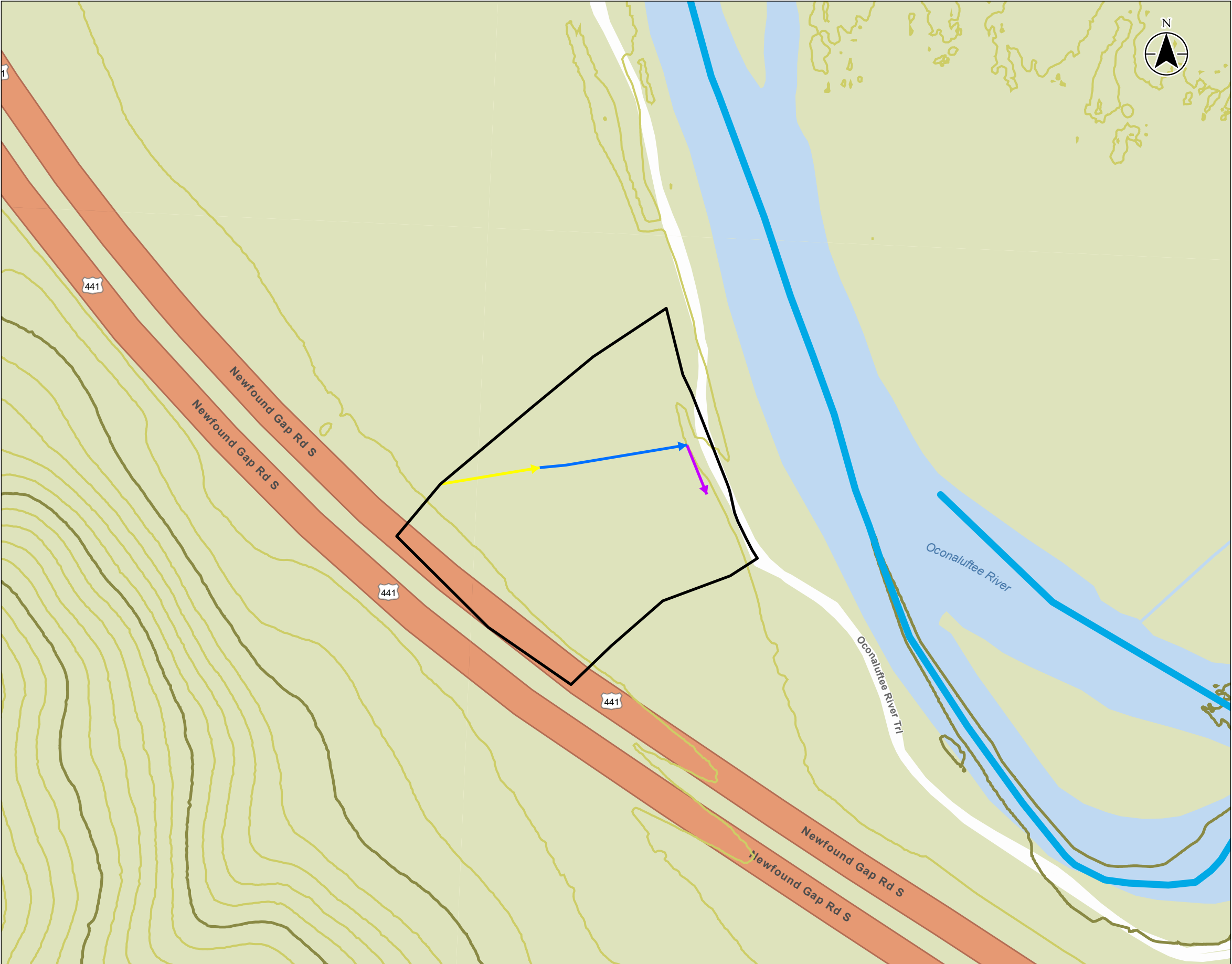
Figure No.

6

Title

Drainage Pipe Watershed Figure (Rational Method)

\\US0522-PF0301\shared_projects\24344224\design\1_and_1\working\report\Culvert\Watershed\Oconaluftee_Pipe_watershed.aprx Revised: 2024-02-17 By: sammoore





Stantec

2D Model Stream Centerlines

Pipe Drainage Basin

Park Boundary

Longest Flowpaths (Line ID)

Channel

Shallow Concentrated

Sheet

Contours

10-ft

50-ft

0

200

Feet

1:1,200 (At original document size of 11x17)

Notes

1. Vertical Datum: NAVD88
2. Coordinate System: NAD 1983 StatePlane North Carolina FIPS 3200 Feet
3. Base features: Service Layer Credits: World Street Map: Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, (c) OpenStreetMap contributors, and the GIS User Community
USGSTopo: USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road data; Natural Earth Data; U.S. Department of State HUI; NOAA National Centers for Environmental Information. Data refreshed October 27, 2025.



Project Location

Near
Cherokee, North Carolina
and Swain County, North Carolina

Prepared by SBM on 2024-02-12

Client/Project

National Park Service
Rehabilitate Oconaluftee River Trail at Great
Smoky Mountains National Park

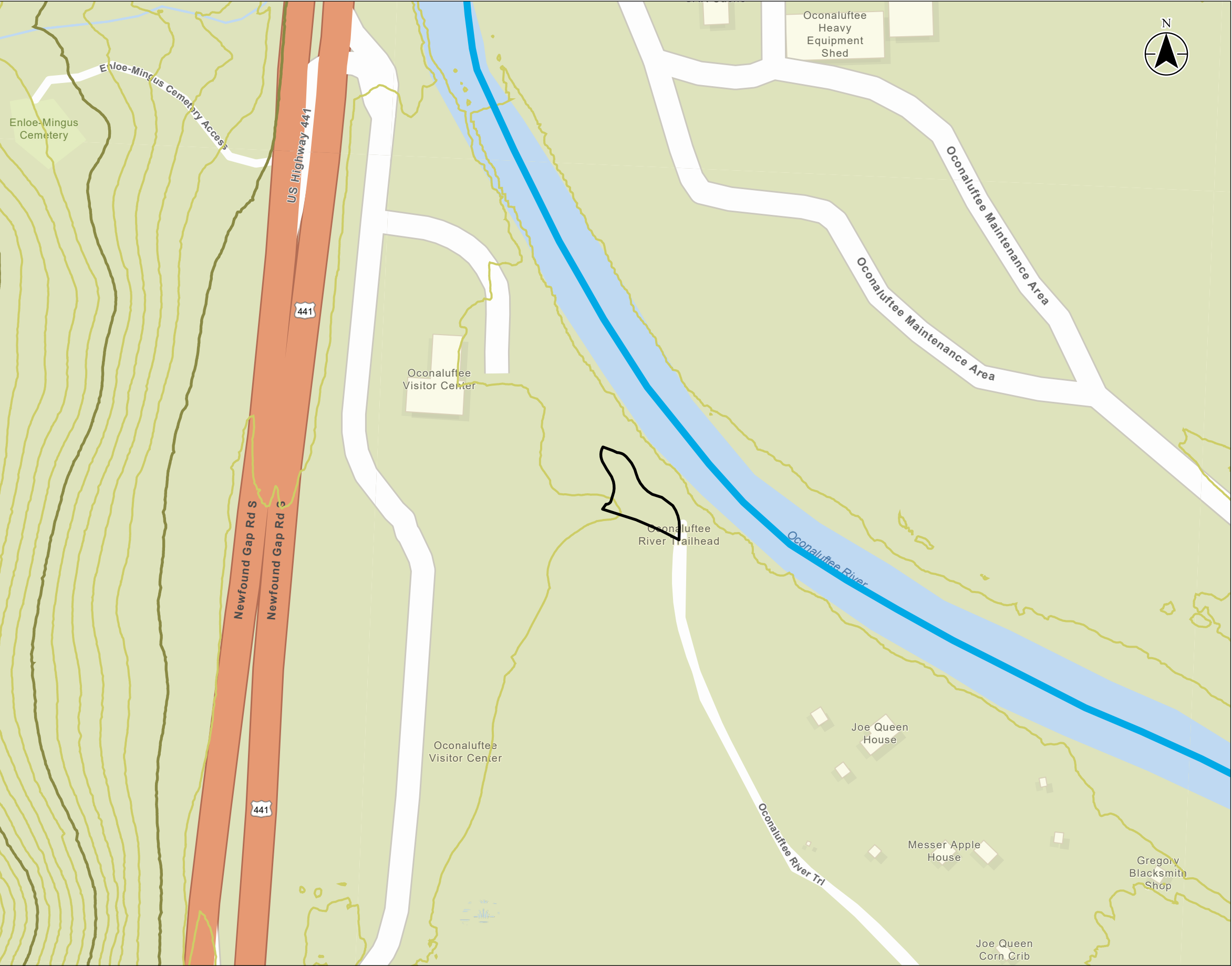
Figure No.

7

Title

Drainage Pipe Watershed Figure
(Rational Method)

\\US0522\PFPS01\shared_project\23434424\design\1 and 1\working\report\Culvert\waterheds\AcPro\report\Oconaluftee_Pipe_watershed.aprx Revised: 2026-02-17 By: sammore



2D Model Stream Centerlines

Pipe Drainage Basin

Park Boundary

Longest Flowpaths (Line ID)

Channel

Shallow Concentrated

Sheet

Contours

10-ft

50-ft

* Minimum Time of Concentration of 6 minutes was used for Culvert 8, so no longest flowpaths were developed

0 200 Feet

1:1,200 (At original document size of 11x17)

Notes

1. Vertical Datum: NAVD88

2. Coordinate System: NAD 1983 StatePlane North Carolina FIPS 3200 Feet

3. Base features: Service Layer Credits: World Street Map: Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, (c) OpenStreetMap contributors, and the GIS User Community

USGSTopo: USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road data; Natural Earth Data; U.S. Department of State HUI; NOAA National Centers for Environmental Information. Data refreshed October 27, 2025.

Site Location

Project Location

Near Cherokee, North Carolina and Swain County, North Carolina

Prepared by SBM on 2026-02-12

Client/Project

National Park Service

Rehabilitate Oconaluftee River Trail at Great Smoky Mountains National Park

Figure No.

8

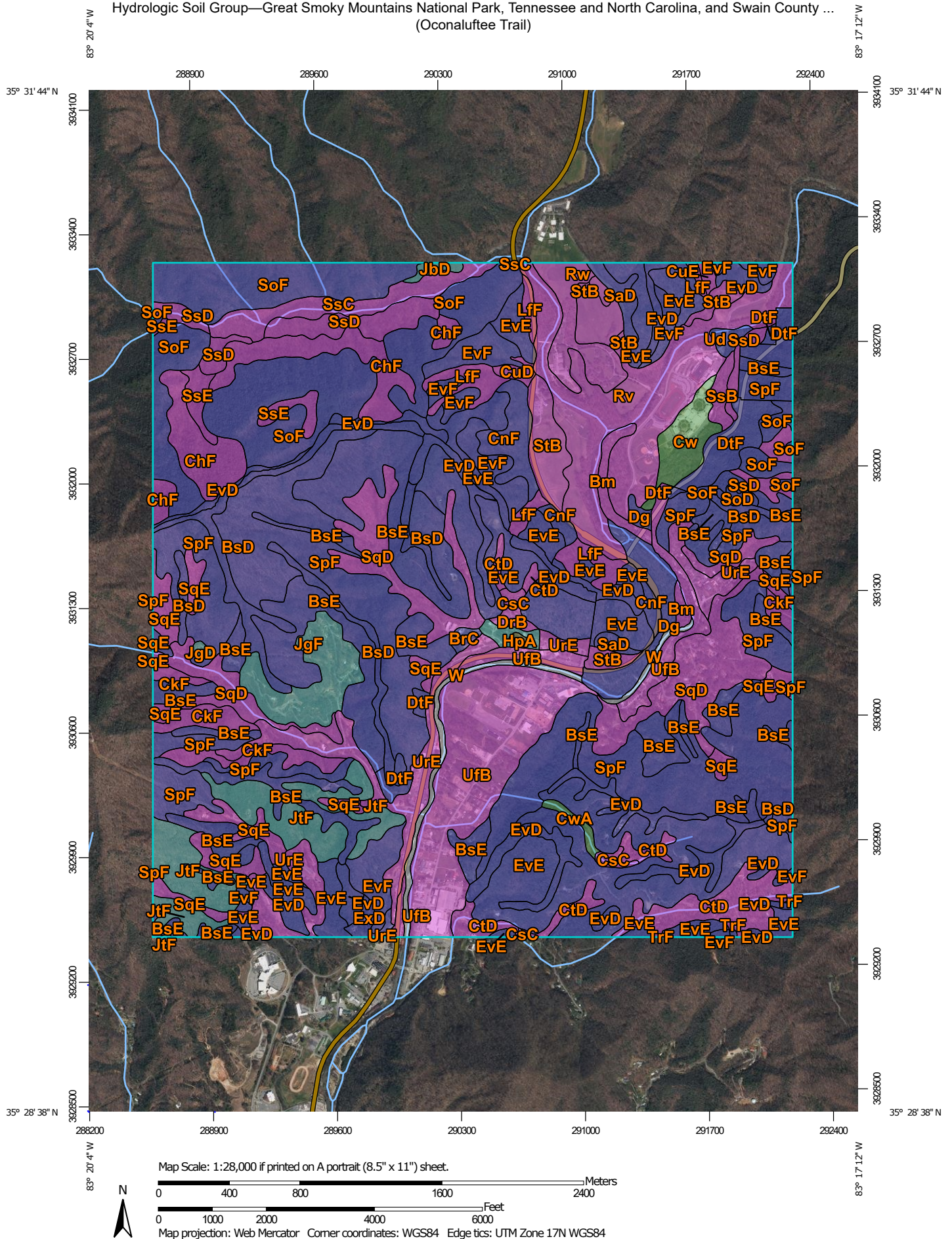
Title

Drainage Pipe Watershed Figure (Rational Method)

APPENDIX B

NRCS SOILS MAPPING

Hydrologic Soil Group—Great Smoky Mountains National Park, Tennessee and North Carolina, and Swain County ...
(Oconaluftee Trail)



MAP LEGEND

Area of Interest (AOI)

 Area of Interest (AOI)

Soils

Soil Rating Polygons

 A
 A/D
 B
 B/D
 C
 C/D
 D
 Not rated or not available

Soil Rating Lines

 A
 A/D
 B
 B/D
 C
 C/D
 D
 Not rated or not available

Soil Rating Points

 A
 A/D
 B
 B/D

 C
 C/D
 D
 Not rated or not available

Water Features

 Streams and Canals

Transportation

 Rails
 Interstate Highways
 US Routes
 Major Roads
 Local Roads

Background

 Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at scales ranging from 1:12,000 to 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service

Web Soil Survey URL:

Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Great Smoky Mountains National Park, Tennessee and North Carolina

Survey Area Data: Version 18, Sep 12, 2024

Soil Survey Area: Swain County Area, North Carolina

Survey Area Data: Version 19, Sep 9, 2024

Your area of interest (AOI) includes more than one soil survey area. These survey areas may have been mapped at different scales, with a different land use in mind, at different times, or at different levels of detail. This may result in map unit symbols, soil properties, and interpretations that do not completely agree across soil survey area boundaries.

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Mar 30, 2021—Apr 4, 2021

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Hydrologic Soil Group

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
Bm	Biltmore sand, 0 to 3 percent slopes, frequently flooded	A	15.7	0.5%
ChF	Cheoah channery loam, 30 to 95 percent slopes, stony	A	92.4	2.7%
CnF	Clifton clay loam, 50 to 95 percent slopes	B	36.8	1.1%
CuD	Cullasaja-Tuckasegee complex, 15 to 30 percent slopes, very stony	A	5.1	0.1%
CuE	Cullasaja-Tuckasegee complex, 30 to 50 percent slopes, very stony	A	2.8	0.1%
Cw	Culowhee-Ela complex, 0 to 2 percent slopes, frequently flooded	A/D	29.3	0.9%
Dg	Dellwood-Smokemont complex, 0 to 5 percent slopes, frequently flooded	B	38.2	1.1%
DtF	Ditney-Unicoi complex, 30 to 95 percent slopes, very rocky	B	29.0	0.9%
EvD	Evard-Cowee complex, 15 to 30 percent slopes, stony	B	35.2	1.0%
EvE	Evard-Cowee complex, 30 to 50 percent slopes, stony	B	93.1	2.7%
EvF	Evard-Cowee complex, 50 to 95 percent slopes, stony	B	60.0	1.8%
JbD	Junaluska-Brasstown complex, 15 to 30 percent slopes, stony	C	4.4	0.1%
LfF	Leatherwood cobbly clay, 50 to 95 percent slopes, stony	A	37.8	1.1%
Rv	Rosman-Reddies complex, 0 to 5 percent slopes, frequently flooded	A	198.6	5.9%

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
Rw	Rosman-Reddies-Urban land complex, 0 to 5 percent slopes, occasionally flooded	A	37.3	1.1%
SaD	Saunook loam, 15 to 30 percent slopes, stony	B	14.9	0.4%
SoD	Soco-Stecoah complex, 15 to 30 percent slopes, stony	B	4.2	0.1%
SoF	Soco-Stecoah complex, 30 to 95 percent slopes, stony	B	297.9	8.8%
SsB	Spivey-Santeetlah-Nowhere complex, 2 to 8 percent slopes, very stony	A	8.9	0.3%
SsC	Spivey-Santeetlah-Nowhere complex, 8 to 15 percent slopes, very stony	A	40.3	1.2%
SsD	Spivey-Santeetlah complex, 15 to 30 percent slopes, very stony	A	61.3	1.8%
SsE	Spivey-Santeetlah complex, 30 to 50 percent slopes, very stony	A	19.8	0.6%
StB	Statler loam, 0 to 5 percent slopes	A	46.5	1.4%
Ud	Udorthents-loamy	B	5.6	0.2%
Subtotals for Soil Survey Area			1,215.2	35.8%
Totals for Area of Interest			3,392.9	100.0%

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
BrC	Braddock-Urban land complex, 2 to 15 percent slopes	B	3.9	0.1%
BsD	Brasstown-Junaluska complex, 15 to 30 percent slopes	B	71.2	2.1%
BsE	Brasstown-Junaluska complex, 30 to 50 percent slopes	B	313.7	9.2%
CkF	Cheoah-Jeffrey complex, 50 to 95 percent slopes, very rocky	A	41.5	1.2%

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
CsC	Cullasaja-Tuckasegee-Cruso complex, 8 to 15 percent slopes, very stony	A	11.7	0.3%
CtD	Cullasaja-Tuckasegee complex, 15 to 30 percent slopes, very stony	A	70.8	2.1%
CwA	Culowhee-Ela complex, 0 to 3 percent slopes, occasionally flooded	A/D	5.2	0.2%
DrB	Dillard loam, 1 to 5 percent slopes, rarely flooded	C	7.1	0.2%
DtF	Ditney-Unicoi-Rock outcrop complex, 50 to 95 percent slopes, very stony	B	18.4	0.5%
EvD	Evard-Cowee complex, 15 to 30 percent slopes, stony	B	102.5	3.0%
EvE	Evard-Cowee complex, 30 to 50 percent slopes, stony	B	283.4	8.4%
EvF	Evard-Cowee complex, 50 to 95 percent slopes, stony	B	25.3	0.7%
ExD	Evard-Cowee-Urban land complex, 15 to 30 percent slopes	B	6.7	0.2%
HpA	Hemphill clay loam, 0 to 3 percent slopes, rarely flooded	C/D	1.3	0.0%
JgD	Junaluska-Brasstown-Tsali-Urban land complex, 15 to 30 percent slopes	C	2.2	0.1%
JgF	Junaluska-Brasstown-Tsali-Urban land complex, 30 to 95 percent slopes	C	53.7	1.6%
JtF	Junaluska-Tsali complex, 50 to 95 percent slopes	C	102.6	3.0%
SpF	Soco-Stecoah complex, 50 to 95 percent slopes, rocky	B	486.4	14.3%
SqD	Spivey-Santeetlah complex, 15 to 30 percent slopes, very stony	A	165.4	4.9%

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
SqE	Spivey-Santeetlah complex, 30 to 50 percent slopes, very stony	A	72.6	2.1%
TrF	Trimont gravelly loam, 50 to 95 percent slopes, stony	B	0.6	0.0%
UfB	Udorthents-Urban land complex, 0 to 5 percent slopes, rarely flooded	A	201.7	5.9%
UrE	Udorthents-Urban land complex, 2 to 50 percent slopes	A	108.7	3.2%
W	Water		20.8	0.6%
Subtotals for Soil Survey Area			2,177.5	64.2%
Totals for Area of Interest			3,392.9	100.0%

Description

Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

The soils in the United States are assigned to four groups (A, B, C, and D) and three dual classes (A/D, B/D, and C/D). The groups are defined as follows:

Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.

Rating Options

Aggregation Method: Dominant Condition

Component Percent Cutoff: None Specified

Tie-break Rule: Higher

APPENDIX C

HYDROLOGY AND HYDRAULICS



NOAA Atlas 14, Volume 2, Version 3
Location name: Cherokee, North Carolina, USA*
Latitude: 35.5137°, Longitude: -83.3064°
Elevation: 2037 ft**
* source: ESRI Maps
** source: USGS



POINT PRECIPITATION FREQUENCY ESTIMATES

G.M. Bonnín, D. Martin, B. Lin, T. Parzybok, M. Yekta, and D. Riley

NOAA, National Weather Service, Silver Spring, Maryland

[PF_tabular](#) | [PF_graphical](#) | [Maps & aerals](#)

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches) ¹										
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.359 (0.326-0.396)	0.422 (0.383-0.465)	0.496 (0.449-0.546)	0.569 (0.515-0.627)	0.653 (0.587-0.719)	0.723 (0.646-0.798)	0.793 (0.704-0.878)	0.863 (0.758-0.960)	0.951 (0.824-1.07)	1.03 (0.883-1.17)
10-min	0.573 (0.521-0.633)	0.675 (0.613-0.744)	0.794 (0.720-0.875)	0.909 (0.823-1.00)	1.04 (0.935-1.15)	1.15 (1.03-1.27)	1.26 (1.12-1.40)	1.37 (1.20-1.52)	1.50 (1.30-1.69)	1.62 (1.39-1.84)
15-min	0.716 (0.651-0.791)	0.848 (0.770-0.935)	1.00 (0.910-1.11)	1.15 (1.04-1.27)	1.32 (1.18-1.45)	1.46 (1.30-1.61)	1.59 (1.41-1.76)	1.73 (1.52-1.92)	1.89 (1.64-2.12)	2.04 (1.75-2.31)
30-min	0.982 (0.893-1.08)	1.17 (1.06-1.29)	1.43 (1.29-1.57)	1.67 (1.51-1.84)	1.95 (1.76-2.15)	2.20 (1.96-2.42)	2.44 (2.16-2.70)	2.69 (2.36-2.99)	3.01 (2.61-3.38)	3.30 (2.83-3.74)
60-min	1.22 (1.11-1.35)	1.47 (1.34-1.62)	1.83 (1.66-2.02)	2.17 (1.96-2.39)	2.60 (2.34-2.86)	2.98 (2.66-3.29)	3.36 (2.98-3.72)	3.77 (3.31-4.19)	4.32 (3.75-4.85)	4.82 (4.13-5.46)
2-hr	1.44 (1.31-1.58)	1.72 (1.56-1.89)	2.13 (1.94-2.34)	2.52 (2.28-2.77)	3.02 (2.72-3.32)	3.46 (3.10-3.81)	3.92 (3.48-4.33)	4.40 (3.87-4.88)	5.06 (4.38-5.66)	5.66 (4.83-6.39)
3-hr	1.56 (1.43-1.72)	1.86 (1.71-2.04)	2.29 (2.10-2.51)	2.71 (2.47-2.96)	3.26 (2.95-3.56)	3.76 (3.38-4.12)	4.28 (3.81-4.71)	4.84 (4.25-5.35)	5.63 (4.87-6.27)	6.35 (5.40-7.15)
6-hr	2.01 (1.86-2.18)	2.37 (2.19-2.58)	2.86 (2.64-3.11)	3.36 (3.08-3.64)	4.03 (3.67-4.37)	4.64 (4.19-5.04)	5.28 (4.72-5.75)	5.98 (5.28-6.55)	6.98 (6.04-7.71)	7.90 (6.71-8.82)
12-hr	2.63 (2.44-2.84)	3.10 (2.88-3.36)	3.72 (3.45-4.02)	4.33 (4.00-4.67)	5.09 (4.68-5.50)	5.77 (5.27-6.24)	6.44 (5.84-7.00)	7.15 (6.42-7.81)	8.11 (7.19-8.93)	8.96 (7.85-9.97)
24-hr	3.09 (2.90-3.32)	3.70 (3.47-3.98)	4.55 (4.26-4.89)	5.23 (4.89-5.62)	6.17 (5.74-6.62)	6.94 (6.43-7.45)	7.74 (7.12-8.31)	8.57 (7.83-9.23)	9.74 (8.79-10.5)	10.7 (9.56-11.6)
2-day	3.74 (3.50-3.99)	4.46 (4.18-4.78)	5.43 (5.09-5.82)	6.21 (5.81-6.65)	7.28 (6.78-7.80)	8.15 (7.56-8.74)	9.04 (8.35-9.71)	9.97 (9.15-10.7)	11.3 (10.2-12.2)	12.3 (11.1-13.4)
3-day	4.04 (3.80-4.30)	4.81 (4.52-5.13)	5.81 (5.46-6.19)	6.60 (6.20-7.04)	7.68 (7.18-8.20)	8.54 (7.95-9.12)	9.42 (8.73-10.1)	10.3 (9.52-11.1)	11.6 (10.6-12.5)	12.6 (11.4-13.6)
4-day	4.35 (4.10-4.62)	5.16 (4.87-5.49)	6.18 (5.83-6.57)	6.99 (6.58-7.42)	8.08 (7.58-8.59)	8.93 (8.35-9.51)	9.80 (9.12-10.4)	10.7 (9.90-11.4)	11.9 (10.9-12.8)	12.8 (11.7-13.8)
7-day	5.26 (4.93-5.62)	6.24 (5.85-6.67)	7.48 (7.00-7.98)	8.46 (7.91-9.04)	9.80 (9.13-10.5)	10.9 (10.1-11.6)	12.0 (11.1-12.8)	13.1 (12.1-14.0)	14.6 (13.4-15.8)	15.8 (14.4-17.1)
10-day	6.06 (5.67-6.52)	7.16 (6.70-7.70)	8.50 (7.93-9.13)	9.56 (8.91-10.3)	11.0 (10.2-11.8)	12.1 (11.2-13.1)	13.3 (12.3-14.3)	14.5 (13.3-15.6)	16.1 (14.6-17.4)	17.3 (15.7-18.8)
20-day	8.32 (7.85-8.83)	9.78 (9.22-10.4)	11.3 (10.7-12.0)	12.6 (11.8-13.3)	14.1 (13.3-15.0)	15.3 (14.4-16.3)	16.5 (15.4-17.5)	17.6 (16.5-18.8)	19.1 (17.7-20.4)	20.2 (18.7-21.6)
30-day	10.2 (9.66-10.7)	11.9 (11.3-12.5)	13.6 (12.9-14.4)	14.9 (14.2-15.7)	16.6 (15.7-17.5)	17.8 (16.8-18.8)	18.9 (17.9-20.0)	20.0 (18.8-21.2)	21.4 (20.0-22.7)	22.3 (20.9-23.7)
45-day	13.0 (12.4-13.6)	15.2 (14.5-15.9)	17.1 (16.3-17.9)	18.5 (17.6-19.3)	20.2 (19.2-21.1)	21.4 (20.3-22.3)	22.4 (21.3-23.5)	23.4 (22.2-24.6)	24.6 (23.3-25.9)	25.4 (24.0-26.8)
60-day	15.6 (14.9-16.3)	18.2 (17.4-19.0)	20.3 (19.4-21.2)	21.9 (20.9-22.8)	23.7 (22.6-24.7)	25.0 (23.8-26.1)	26.1 (24.9-27.3)	27.1 (25.8-28.4)	28.3 (26.9-29.7)	29.1 (27.6-30.6)

¹ Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

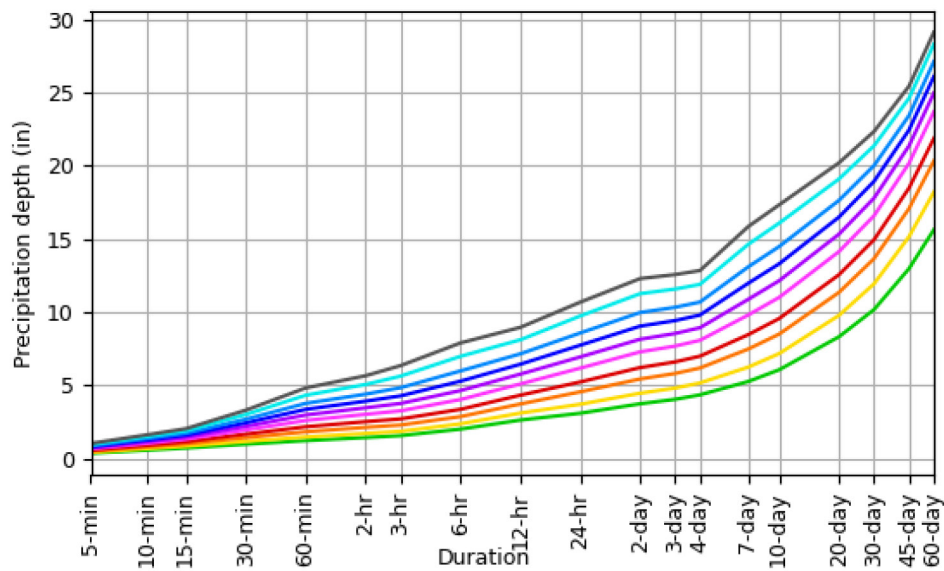
Please refer to NOAA Atlas 14 document for more information.

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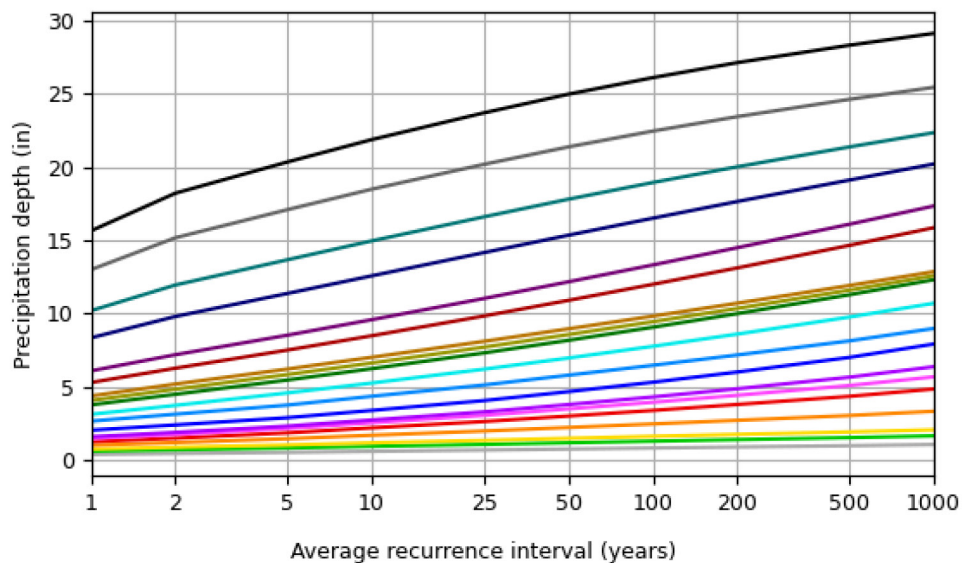
PF graphical

PDS-based depth-duration-frequency (DDF) curves

Latitude: 35.5137°, Longitude: -83.3064°



Average recurrence interval (years)
1
2
5
10
25
50
100
200
500
1000

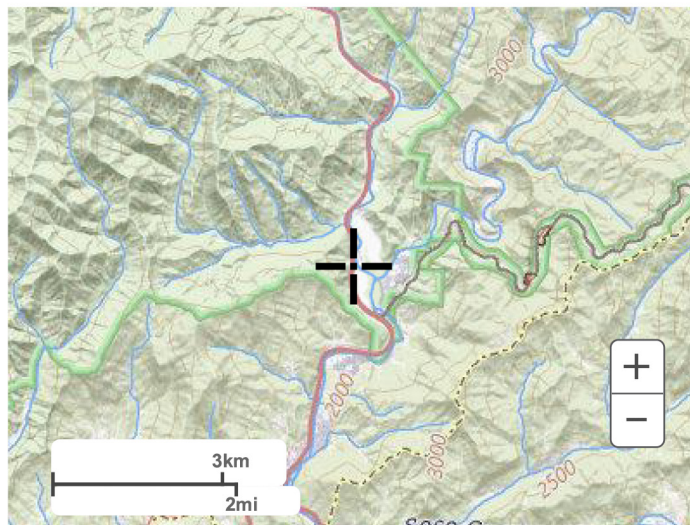


Duration	
5-min	2-day
10-min	3-day
15-min	4-day
30-min	7-day
60-min	10-day
2-hr	20-day
3-hr	30-day
6-hr	45-day
12-hr	60-day
24-hr	

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Maps & aerials

Small scale terrain



Large scale terrain



Large scale map



Large scale aerial



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[National Water Center](#)
1325 East West Highway
Silver Spring, MD 20910
Questions?: HDSC.Questions@noaa.gov

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STANTEC

PROJECT: OCONALUFTEE

STANTEC JOB #: 234364224

		BY	DATE
CULVERT 1			
INCLUDES CULVERT 2		COMPUTED	SMH
		CHECKED	

SOIL TYPE	% SLOPE	LANDUSE	AREA (SF)	2, 10-YR STORM	25-YR STORM		
				C	CA	C	CA
B	---	Gravel	2389.00	0.70	1672.30	0.70	1672.30
---	---	IMPERVIOUS	24480.00	0.90	22032.00	0.90	22032.00
B	---	WOODED AREAS	362084.00	0.15	54312.60	0.15	54312.60
TOTALS			388953.00		78016.90		78016.90

COMPOSITE C FACTOR (2, 10-YR): 0.20

COMPOSITE C FACTOR (25-YR): 0.20

TIME OF CONCENTRATION

Tc = 30.9 MIN

STORM EVENT (YR)	RAINFALL INTENSITY	DISCHARGE (CFS)
2	2.34	4.19
10	3.34	5.98
25	3.90	6.98

Project: Oconaluftee	Project #: 234264224
Subwatershed: Culvert 1	County: Swain
Calculations By: Remington Cross	8/19/2025
Checked By: Matthew Armstrong	8/19/2025

Channel Flow	Segment 4	Estimated Channel Bottom Width (ft):	12
		Estimated Channel Side Slope (xH:1V):	1
		Estimated Water Depth (ft):	0.12
		Estimated Cross-sectional Area (sq ft):	1.45
		Estimated Wetted Perimeter (ft):	12.34
		Estimated Hydraulic Radius (ft):	0.12
		Channel Slope (ft/ft):	0.005
		Manning's Roughness Coefficient, n:	0.035
		Velocity (ft/s):	0.75
		Flow (cu ft/s):	1.09
Channel Flow Length (ft):	126		
Travel Time (hrs):	0.05		

TOTAL TRAVEL TIME (HRS) = 0.52
TOTAL TRAVEL TIME (MIN) = 30.90

SHEET FLOW ROUGHNESS EQUATIONS				
Manning's roughness coefficients for sheet flow (flow depth generally <0.1 ft)		$T_1 = \frac{0.007(n/f)^{0.58}}{(P_1^2) S^{0.54}} \quad (\text{eq. 15-8})$	where:	$T_1 = \text{travel time, h}$ $n = \text{Manning's roughness coefficient (table 15-1)}$ $f = \text{sheet flow length, ft}$ $P_1 = 2\text{-year, 24-hour rainfall, in}$ $S = \text{slope of land surface, ft/ft}$
Surface Description	n			
Smooth surface (concrete, asphalt, gravel, or bare soil)	0.013			
Fallow (no residue)	0.05			
Cultivated Soils with residue cover < 20%	0.06			
Cultivated Soils with residue cover > 20%	0.17			
Short-Grass Prairie	0.15			
Dense Grasses	0.24			
Bermudagrass	0.41			
Range (natural)	0.13			
Woods with light underbrush	0.40			
Woods with dense underbrush	0.80			
*source: National Engineering Handbook Table 15-1				

[illegible]

CHANNEL FLOW EQUATIONS	
Manning's equation is: $V = \frac{1.49 R^{2/3} S^{1/2}}{n} \quad (\text{eq. 15-10})$ where: V = average velocity, ft/s r = hydraulic radius, ft a = area P_w = wetted perimeter, ft s = slope of the hydraulic grade line (channel slope), ft/ft n = Manning's n value for open channel flow is assumed to occur. Open channels are assumed to begin where surveyed cross-sectional information has been obtained, where channels are visible on aerial photographs, or where bluelines (indicating streams) appear on U.S. Geological Survey (USGS) quadrangle sheets. may have a large variation. In practice, calculations are typically based on the 2-year frequency discharge event since it is normally assumed that the time of concentration computed using these characteristics is representative of travel time conditions for a wide	
Table B.2. Manning's Roughness Coefficients for Various Boundaries.	
Rigid Boundary Channels	Manning's n
Very smooth concrete and planed timber	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Wood	0.014
Verified clay	0.015
Shot concrete, untroweled, and earth channels in best condition	0.017
Straight unlined earth canals in good condition	0.020
Streambeds with rocky beds	0.040–0.050
MINOR STREAMS (top width at flood stage < 30 m)	
Streams on Plain	
1. Clean, straight, full stage, no rills or deep pools	0.025–0.033
2. Same as above, but more stones and weeds	0.030–0.040
3. Clean, winding, some pools and shoals	0.033–0.045
4. Same as above, but some weeds and stones	0.035–0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040–0.055
6. Same as 4, but more stones	0.045–0.060
7. Sluggish reaches, weedy, deep pools	0.050–0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075–0.150
Mountain Streams, no Vegetation in Channel, Banks Usually Steep, Trees and Brush Along Banks Submerged at High Stages	
1. Bottom: gavel, cobbles and few boulders	0.030–0.050
2. Bottom: cobbles with large boulders	0.040–0.070

HY-8 Culvert 1 Analysis Report- Tailwater Condition

Crossing Discharge Data

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 0.00 cfs

Design Flow: 5.98 cfs

Maximum Flow: 10.00 cfs

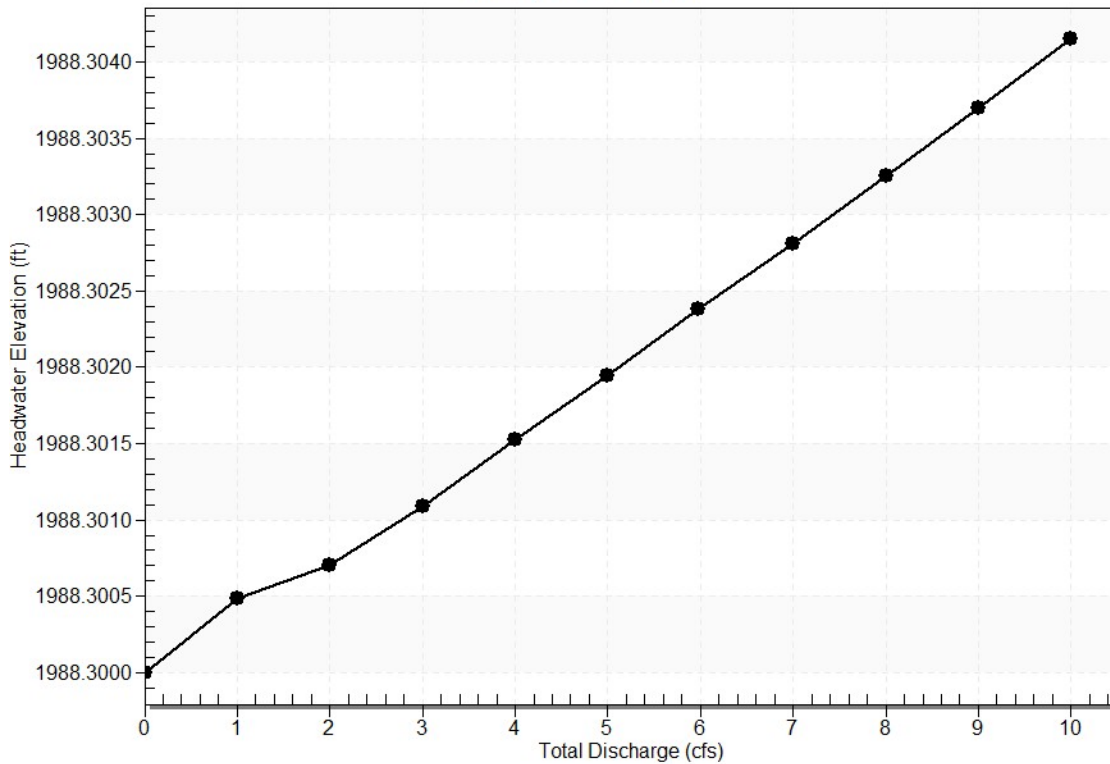
Table 1 - Summary of Culvert Flows at Crossing: Culvert 1 Tailwater

Headwater Elevation (ft)	Total Discharge (cfs)	Culvert 1 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
1988.30	0.00	0.00	0.00	1
1988.30	1.00	0.00	0.98	3
1988.30	2.00	0.63	1.45	4
1988.30	3.00	0.76	2.24	3
1988.30	4.00	0.88	3.15	2
1988.30	5.00	0.98	4.01	3
1988.30	5.98	1.08	4.91	2
1988.30	7.00	1.17	5.84	2
1988.30	8.00	1.26	6.76	2
1988.30	9.00	1.34	7.68	2
1988.30	10.00	1.41	8.60	2
1986.93	0.00	0.00	0.00	Overtopping

Rating Curve Plot for Crossing: Culvert 1 Tailwater

Total Rating Curve

Crossing: Culvert 1 Tailwater



Culvert Data: Culvert 1

Table 1 - Culvert Summary Table: Culvert 1

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
0.00 cfs	0.00 cfs	1988.30	0.00	3.580	0-NF	0.00	0.00	1.50	3.99	0.00	0.00
1.00 cfs	0.00 cfs	1988.30	0.00	3.580	0-NF	0.00	0.00	1.50	3.99	0.00	0.00
2.00 cfs	0.63 cfs	1988.30	0.27	3.581	4-FFf	0.13	0.21	1.50	3.99	0.18	0.00
3.00 cfs	0.76 cfs	1988.30	0.30	3.581	4-FFf	0.15	0.23	1.50	3.99	0.21	0.00
4.00 cfs	0.88 cfs	1988.30	0.33	3.582	4-FFf	0.16	0.25	1.50	3.99	0.25	0.00
5.00 cfs	0.98 cfs	1988.30	0.35	3.582	4-FFf	0.17	0.26	1.50	3.99	0.28	0.00
5.98 cfs	1.08 cfs	1988.30	0.36	3.582	4-FFf	0.17	0.27	1.50	3.99	0.31	0.00
7.00 cfs	1.17 cfs	1988.30	0.38	3.583	4-FFf	0.18	0.28	1.50	3.99	0.33	0.00
8.00 cfs	1.26 cfs	1988.30	0.39	3.583	4-FFf	0.19	0.29	1.50	3.99	0.36	0.00
9.00 cfs	1.34 cfs	1988.30	0.41	3.584	4-FFf	0.19	0.30	1.50	3.99	0.38	0.00
10.00 cfs	1.41 cfs	1988.30	0.42	3.584	4-FFf	0.20	0.31	1.50	3.99	0.40	0.00

Culvert Barrel Data

Culvert Barrel Type Straight Culvert

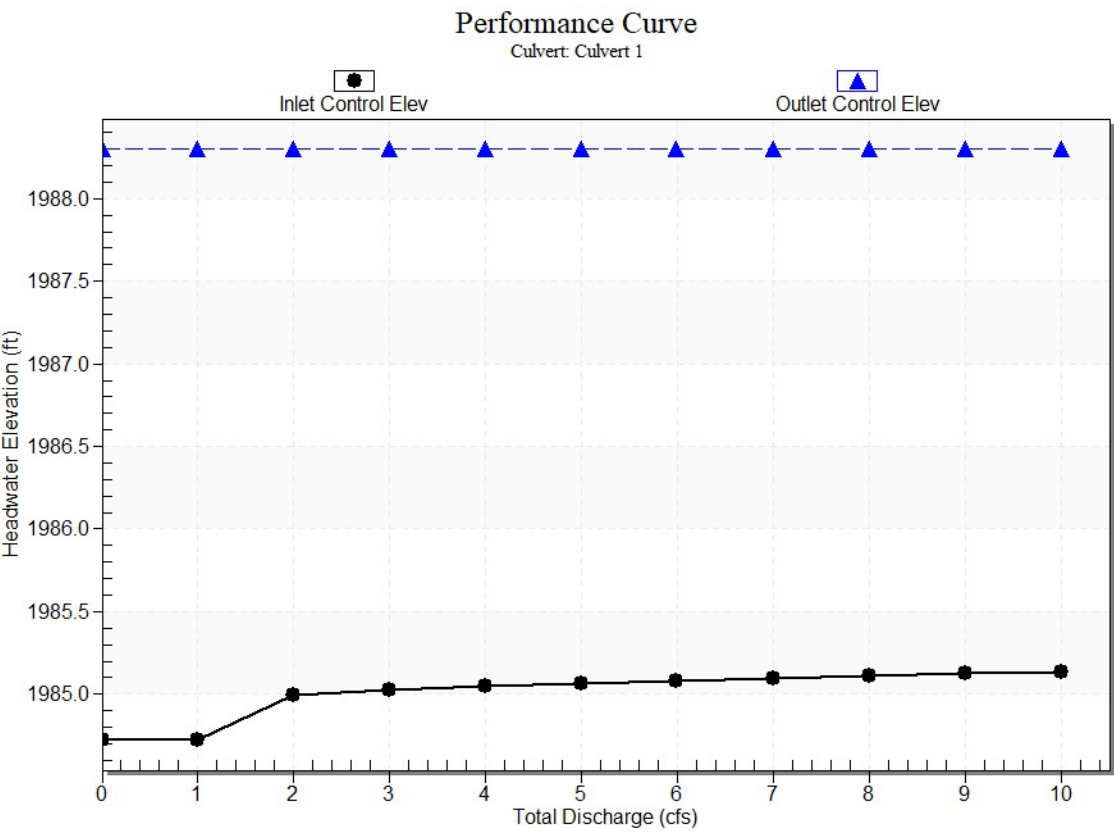
Inlet Elevation (invert): 1984.72 ft,

Outlet Elevation (invert): 1984.31 ft

Culvert Length: 15.17 ft,

Culvert Slope: 0.0270

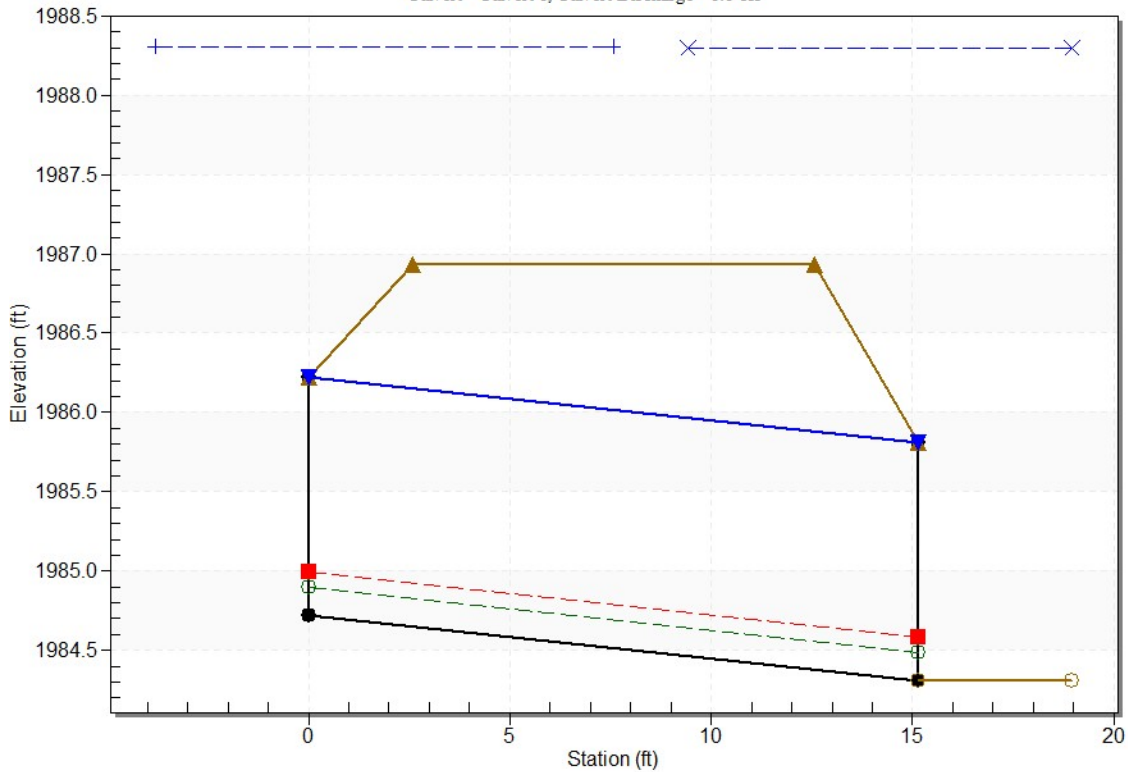
Culvert Performance Curve Plot: Culvert 1



Water Surface Profile Plot for Culvert: Culvert 1

Crossing - Culvert 1 Tailwater, Design Discharge - 6.0 cfs

Culvert - Culvert 1, Culvert Discharge - 1.1 cfs



Site Data - Culvert 1

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 1984.72 ft

Outlet Station: 15.16 ft

Outlet Elevation: 1984.31 ft

Number of Barrels: 2

Culvert Data Summary - Culvert 1

Barrel Shape: Circular

Barrel Diameter: 1.50 ft

Barrel Material: Concrete

Embedment: 0.00 in

Barrel Manning's n: 0.0120

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall

Inlet Depression: None

Tailwater Data for Crossing: Culvert 1 Tailwater

Table 2 - Downstream Channel Rating Curve (Crossing: Culvert 1 Tailwater)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)
0.00	1988.30	3.99
1.00	1988.30	3.99
2.00	1988.30	3.99
3.00	1988.30	3.99
4.00	1988.30	3.99
5.00	1988.30	3.99
5.98	1988.30	3.99
7.00	1988.30	3.99
8.00	1988.30	3.99
9.00	1988.30	3.99
10.00	1988.30	3.99

Tailwater Channel Data - Culvert 1 Tailwater

Tailwater Channel Option: Enter Constant Tailwater Elevation

Constant Tailwater Elevation: 1988.30 ft

Roadway Data for Crossing: Culvert 1 Tailwater

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 30.00 ft

Crest Elevation: 1986.93 ft

Roadway Surface: Gravel

Roadway Top Width: 10.00 ft

HY-8 Culvert 1 Analysis Report- Invert Condition

Crossing Discharge Data

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 0.00 cfs

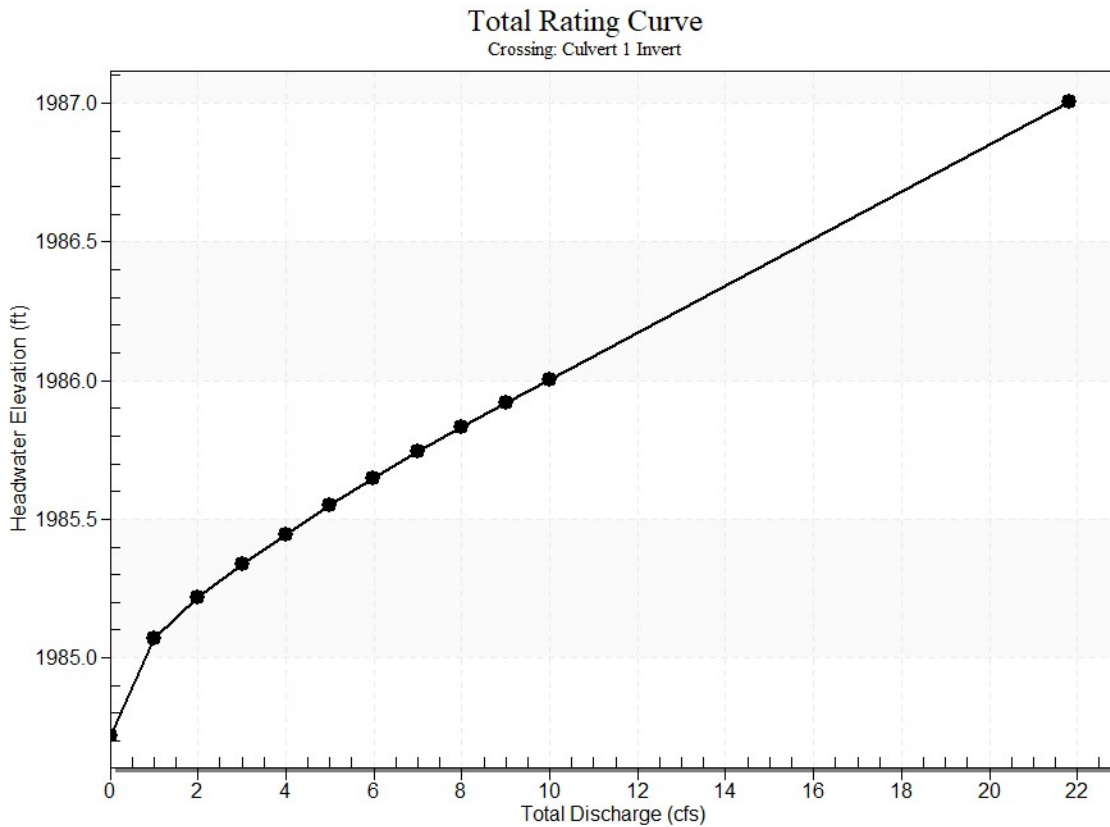
Design Flow: 5.98 cfs

Maximum Flow: 10.00 cfs

Table 1 - Summary of Culvert Flows at Crossing: Culvert 1 Invert

Headwater Elevation (ft)	Total Discharge (cfs)	Culvert 1 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
1984.72	0.00	0.00	0.00	1
1985.07	1.00	1.00	0.00	1
1985.22	2.00	2.00	0.00	1
1985.34	3.00	3.00	0.00	1
1985.44	4.00	4.00	0.00	1
1985.55	5.00	5.00	0.00	1
1985.65	5.98	5.98	0.00	1
1985.74	7.00	7.00	0.00	1
1985.83	8.00	8.00	0.00	1
1985.92	9.00	9.00	0.00	1
1986.00	10.00	10.00	0.00	1
1986.93	19.68	19.68	0.00	Overtopping

Rating Curve Plot for Crossing: Culvert 1 Invert



Culvert Data: Culvert 1

Table 1 - Culvert Summary Table: Culvert 1

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
0.00 cfs	0.00 cfs	1984.72	0.00	0.000	0-NF	0.00	0.00	0.00	0.00	0.00	0.00
1.00 cfs	1.00 cfs	1985.07	0.35	0.0*	1-S2n	0.17	0.26	0.17	0.00	4.41	0.00
2.00 cfs	2.00 cfs	1985.22	0.50	0.0*	1-S2n	0.24	0.37	0.25	0.00	5.22	0.00
3.00 cfs	3.00 cfs	1985.34	0.62	0.069	1-S2n	0.29	0.46	0.31	0.00	5.71	0.00
4.00 cfs	4.00 cfs	1985.44	0.72	0.158	1-S2n	0.33	0.53	0.36	0.00	6.06	0.00
5.00 cfs	5.00 cfs	1985.55	0.83	0.243	1-S2n	0.37	0.60	0.41	0.00	6.35	0.00
5.98 cfs	5.98 cfs	1985.65	0.93	0.324	1-S2n	0.40	0.66	0.46	0.00	6.58	0.00
7.00 cfs	7.00 cfs	1985.74	1.02	0.409	1-S2n	0.44	0.71	0.50	0.00	6.80	0.00
8.00 cfs	8.00 cfs	1985.83	1.11	0.493	1-S2n	0.47	0.77	0.54	0.00	6.99	0.00
9.00 cfs	9.00 cfs	1985.92	1.20	0.579	1-S2n	0.50	0.81	0.58	0.00	7.16	0.00
10.00 cfs	10.00 cfs	1986.00	1.28	0.666	1-S2n	0.53	0.86	0.62	0.00	7.32	0.00

* Full Flow Headwater elevation is below inlet invert.

Culvert Barrel Data

Culvert Barrel Type Straight Culvert

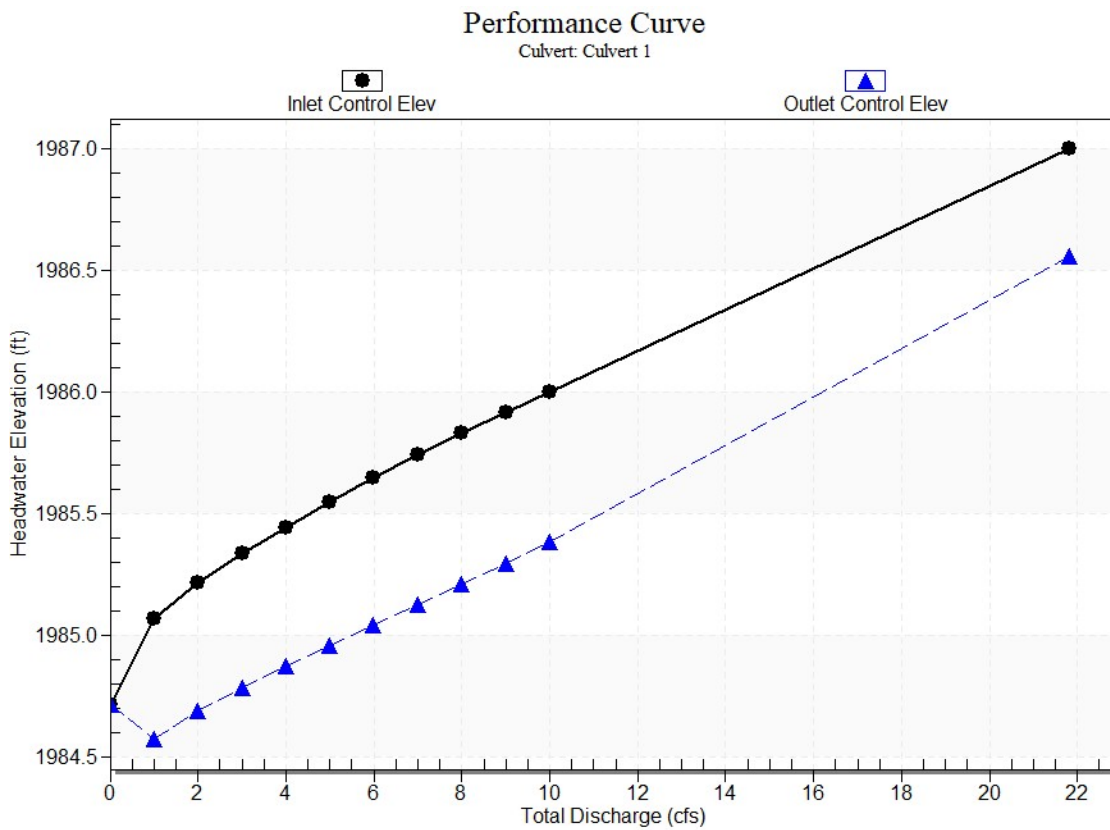
Inlet Elevation (invert): 1984.72 ft,

Outlet Elevation (invert): 1984.31 ft

Culvert Length: 15.17 ft,

Culvert Slope: 0.0270

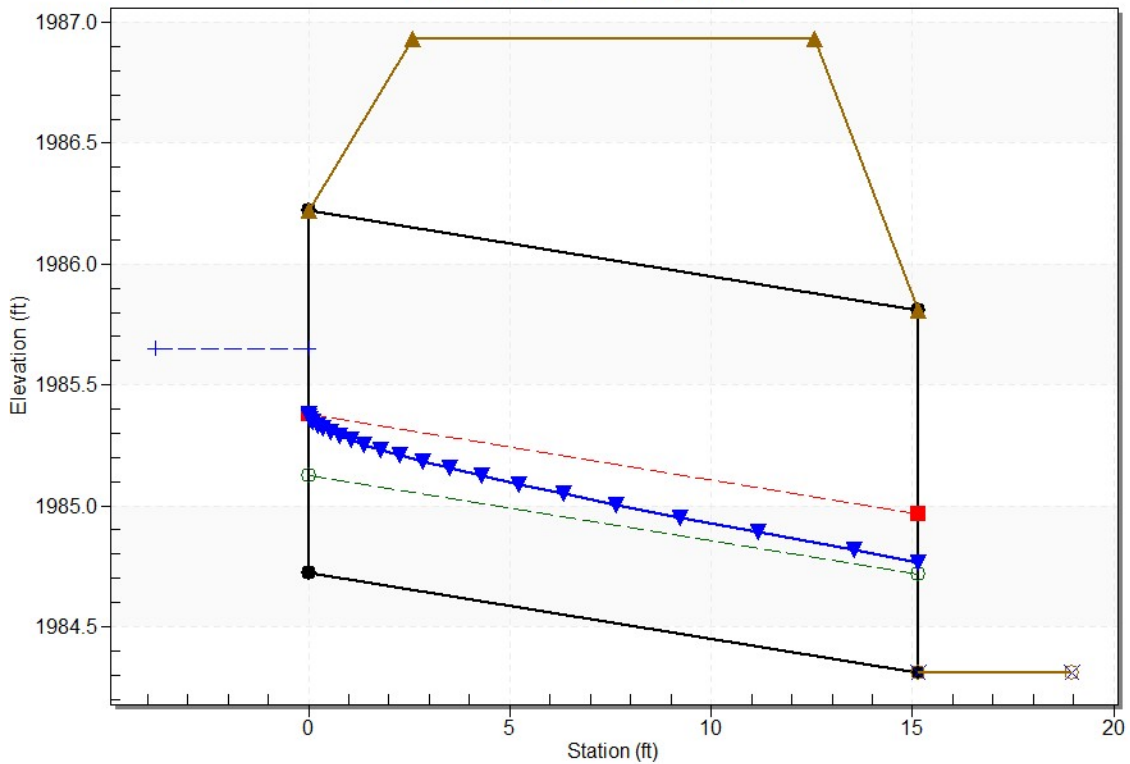
Culvert Performance Curve Plot: Culvert 1



Water Surface Profile Plot for Culvert: Culvert 1

Crossing - Culvert 1 Invert, Design Discharge - 6.0 cfs

Culvert - Culvert 1, Culvert Discharge - 6.0 cfs



Site Data - Culvert 1

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 1984.72 ft

Outlet Station: 15.16 ft

Outlet Elevation: 1984.31 ft

Number of Barrels: 2

Culvert Data Summary - Culvert 1

Barrel Shape: Circular

Barrel Diameter: 1.50 ft

Barrel Material: Concrete

Embedment: 0.00 in

Barrel Manning's n: 0.0120

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall

Inlet Depression: None

Tailwater Data for Crossing: Culvert 1 Invert

Table 2 - Downstream Channel Rating Curve (Crossing: Culvert 1 Invert)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)
0.00	1984.31	0.00
1.00	1984.31	0.00
2.00	1984.31	0.00
3.00	1984.31	0.00
4.00	1984.31	0.00
5.00	1984.31	0.00
5.98	1984.31	0.00
7.00	1984.31	0.00
8.00	1984.31	0.00
9.00	1984.31	0.00
10.00	1984.31	0.00

Tailwater Channel Data - Culvert 1 Invert

Tailwater Channel Option: Enter Constant Tailwater Elevation

Constant Tailwater Elevation: 1984.31 ft

Roadway Data for Crossing: Culvert 1 Invert

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 30.00 ft

Crest Elevation: 1986.93 ft

Roadway Surface: Gravel

Roadway Top Width: 10.00 ft

STANTEC
PROJECT: OCONALUFTEE
STANTEC JOB # : 234364224

		BY	DATE
CULVERT 2			
	COMPUTED	SMH	
	CHECKED		

SOIL TYPE	% SLOPE	LANDUSE	AREA (SF)	2, 10-YR STORM	25-YR STORM		
				C	CA	C	CA
---	---	IMPERVIOUS	24480.00	0.90	22032.00	0.90	22032.00
B	---	WOODED AREAS	355349.00	0.15	53302.35	0.15	53302.35
TOTALS			379829.00		75334.35		75334.35

COMPOSITE C FACTOR (2, 10-YR): 0.20
COMPOSITE C FACTOR (25-YR): 0.20

TIME OF CONCENTRATION

Tc = 28.1 MIN

STORM EVENT (YR)	RAINFALL INTENSITY	DISCHARGE (CFS)
2	2.48	4.29
10	3.51	6.07
25	4.08	7.06

TIME OF CONCENTRATION CALCULATIONS

Project: Oconaluftee	Project #: 234264224
Subwatershed: Culvert 2	County: Swain
Calculations By: Remington Cross	8/19/2025
Checked By: Matthew Armstrong	8/19/2025

Sheet Flow	Segment 1	Surface Description: Woods with light underbrush
		Manning's Roughness Coefficient, n: 0.4 Sheet Flow Length (ft): 100 NOAA Atlas 14, 2-year, 24-hour Rainfall (in): 3.7 Slope of Land Surface (ft/ft): 0.403 Travel Time (hrs): 0.167
Shallow Concentrated Flow	Segment 2	Flow Type: Forest with heavy ground litter and hay meadows Shallow Concentrated Flow Length (ft): 337 Slope of Land Surface (ft/ft): 0.618 Average Velocity (ft/s): 1.98 Travel Time (hrs): 0.05
Channel Flow	Segment 3	Estimated Channel Bottom Width (ft): 12 Estimated Channel Side Slope (xH:1V): 1 Estimated Water Depth (ft): 0.12 Estimated Cross-sectional Area (sq ft): 1.45 Estimated Wetted Perimeter (ft): 12.34 Estimated Hydraulic Radius (ft): 0.12 Channel Slope (ft/ft): 0.012 Manning's Roughness Coefficient, n: 0.035 Velocity (ft/s): 1.12 Flow (cu ft/s): 1.62 Channel Flow Length (ft): 1023 Travel Time (hrs): 0.25

TOTAL TRAVEL TIME (HRS) = 0.47
TOTAL TRAVEL TIME (MIN) = 28.11

FLOWPATH DATA						
Flow Type	Segment	Length (ft)	US Elev (ft)	DS Elev (ft)	Slope (ft/ft)	
Sheet Flow	AB	100	2246	2205.7	0.40300	
Shallow Concentrated Flow	BC	337	2205.7	1997.6	0.61751	
Channel Flow	CD	1023	1997.6	1985.4	0.01193	

SHEET FLOW ROUGHNESS EQUATIONS		
Manning's roughness coefficients for sheet flow (flow depth generally <0.1 ft)		
Surface Description	n	
Smooth surface (concrete, asphalt, gravel, or bare soil)	0.011	
Fallow (no residue)	0.05	
Cultivated Soils with residue cover < 20%	0.06	
Cultivated Soils with residue cover > 20%	0.17	
Short-Grass Prairie	0.15	
Dense Grasses	0.24	
Bermudagrass	0.41	
Range (natural)	0.13	
Woods with light underbrush	0.40	
Woods with dense underbrush	0.80	
*source: National Engineering Handbook Table 15-1		

$$T_t = \frac{0.007(nL)^{1.49}}{(P_2)^{0.49} S^{0.49}} \quad (\text{eq. 15-8})$$

where:
 T_t = travel time, h
 n = Manning's roughness coefficient (table 15-1)
 P_2 = 2-year, 24-hour rainfall, in
 S = slope of land surface, ft/ft

Grass:
Short-grass prairie.....0.15
Dense grasses².....0.24
Bermudagrass.....0.41
Range (natural).....0.13
Woods:³
Light underbrush.....0.40
Dense underbrush.....0.80

1 The Manning's n values are a composite of information compiled by Engman (1986).
2 Includes species such as weeping lovegrass, bluegrass, buffalograss, blue grama grass, and native grass mixtures.
3 When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

SHALLOW CONCENTRATED FLOW EQUATIONS (max depth 0.5 ft)			
Equations and assumptions developed from figure 15-4			
Flow Type	Depth (ft)	Manning's n	Velocity Equation (ft/s)
Pavement and small upland gullies	0.2	0.025	$V = 20.328(S)^{0.5}$
Grassed waterways	0.4	0.050	$V = 16.135(S)^{0.5}$
Nearly bare and untilled (overland flow), and alluvial fans in western mountains	0.2	0.051	$V = 9.965(S)^{0.5}$
Cultivated straight row crops	0.2	0.058	$V = 8.762(S)^{0.5}$
Short-grass pasture	0.2	0.073	$V = 6.962(S)^{0.5}$
Minimum tillage cultivation, contour or strip-cropped, and woodlands	0.2	0.101	$V = 5.032(S)^{0.5}$
Forest with heavy ground litter and hay meadows	0.2	0.202	$V = 2.516(S)^{0.5}$
*source: National Engineering Handbook Table 15-3			

CHANNEL FLOW EQUATIONS	
Manning's equation is:	
$V = \frac{1.49r^{2/3}s^{1/2}}{n} \quad (\text{eq. 15-10})$	
where: V = average velocity, ft/s r = hydraulic radius, ft n = Manning's n value for open channel flow	
is assumed to occur. Open channels are assumed to begin where surveyed cross-sectional information has been obtained, where channels are visible on aerial photographs, or where blue lines (indicating streams) appear on U.S. Geological Survey (USGS) quadrangle sheets.	
may have a large variation. In practice, calculations are typically based on the 2-year frequency discharge event since it is normally assumed that the time of concentration computed using these characteristics is representative of travel time conditions for a wide range of storm events. Welle and Woodward's simplifi-	
Table B.2. Manning's Roughness Coefficients for Various Boundaries.	
Rigid Boundary Channels	
Very smooth concrete and planed timber	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Wood	0.014
Vitrified clay	0.015
Shot concrete, untroweled, and earth channels in best condition	0.017
Straight unlined earth canals in good condition	0.020
Mountain streams with rocky beds	0.040 - 0.050
MINOR STREAMS (top width at flood stage < 30 m)	
Streams on Plain	
1. Clean, straight, full stage, no rifts or deep pools	0.025-0.033
2. Same as above, but more stones and weeds	0.030-0.040
3. Clean, winding, some pools and shoals	0.033-0.045
4. Same as above, but some weeds and stones	0.035-0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040-0.055
6. Same as 4, but more stones	0.045-0.060
7. Sluggish reaches, weedy, deep pools	0.050-0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075-0.150
Mountain Streams, no Vegetation in Channel, Banks Usually Steep, Trees and Brush Along Banks Submerged at High Stages	
1. Bottom: gravels, cobbles and few boulders	0.030-0.050
2. Bottom: cobbles with large boulders	0.040-0.070

HY-8 Culvert 2-Analysis Report

Crossing Discharge Data

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 0.00 cfs

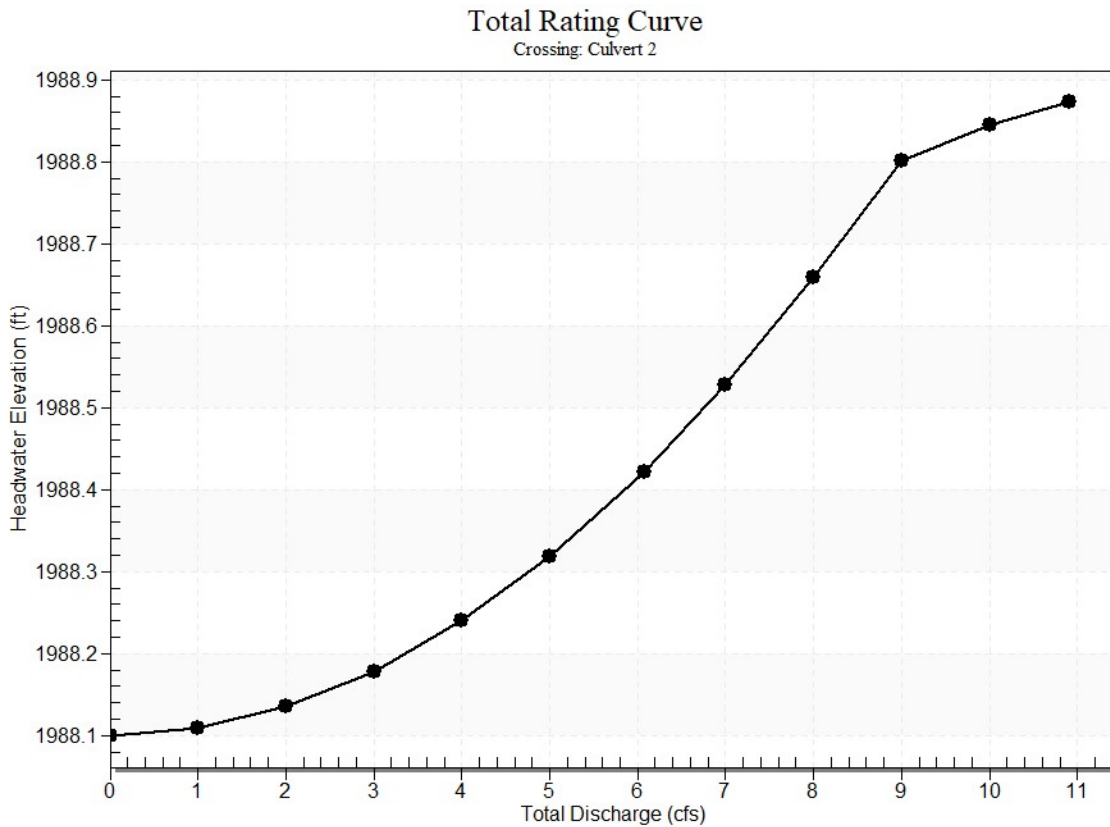
Design Flow: 6.07 cfs

Maximum Flow: 10.00 cfs

Table 1 - Summary of Culvert Flows at Crossing: Culvert 2

Headwater Elevation (ft)	Total Discharge (cfs)	Culvert 2 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
1988.10	0.00	0.00	0.00	1
1988.11	1.00	1.00	0.00	1
1988.13	2.00	2.00	0.00	1
1988.18	3.00	3.00	0.00	1
1988.24	4.00	4.00	0.00	1
1988.32	5.00	5.00	0.00	1
1988.42	6.07	6.07	0.00	1
1988.53	7.00	7.00	0.00	1
1988.66	8.00	8.00	0.00	1
1988.80	9.00	8.97	0.01	20
1988.85	10.00	9.24	0.74	6
1988.80	8.95	8.95	0.00	Overtopping

Rating Curve Plot for Crossing: Culvert 2



Culvert Data: Culvert 2

Table 1 - Culvert Summary Table: Culvert 2

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
0.00 cfs	0.00 cfs	1988.10	0.00	1.820	0-NF	0.00	0.00	1.50	2.15	0.00	0.00
1.00 cfs	1.00 cfs	1988.11	0.50	1.829	4-FFf	0.25	0.37	1.50	2.15	0.57	0.00
2.00 cfs	2.00 cfs	1988.13	0.73	1.855	4-FFf	0.36	0.53	1.50	2.15	1.13	0.00
3.00 cfs	3.00 cfs	1988.18	0.94	1.898	4-FFf	0.44	0.66	1.50	2.15	1.70	0.00
4.00 cfs	4.00 cfs	1988.24	1.12	1.960	4-FFf	0.51	0.77	1.50	2.15	2.26	0.00
5.00 cfs	5.00 cfs	1988.32	1.29	2.038	4-FFf	0.57	0.86	1.50	2.15	2.83	0.00
6.07 cfs	6.07 cfs	1988.42	1.46	2.142	4-FFf	0.64	0.95	1.50	2.15	3.43	0.00
7.00 cfs	7.00 cfs	1988.53	1.62	2.248	4-FFf	0.69	1.02	1.50	2.15	3.96	0.00
8.00 cfs	8.00 cfs	1988.66	1.81	2.379	4-FFf	0.75	1.10	1.50	2.15	4.53	0.00
9.00 cfs	8.97 cfs	1988.80	2.01	2.521	4-FFf	0.80	1.16	1.50	2.15	5.07	0.00
10.00 cfs	9.24 cfs	1988.85	2.08	2.566	4-FFf	0.81	1.18	1.50	2.15	5.23	0.00

Culvert Barrel Data

Culvert Barrel Type Straight Culvert

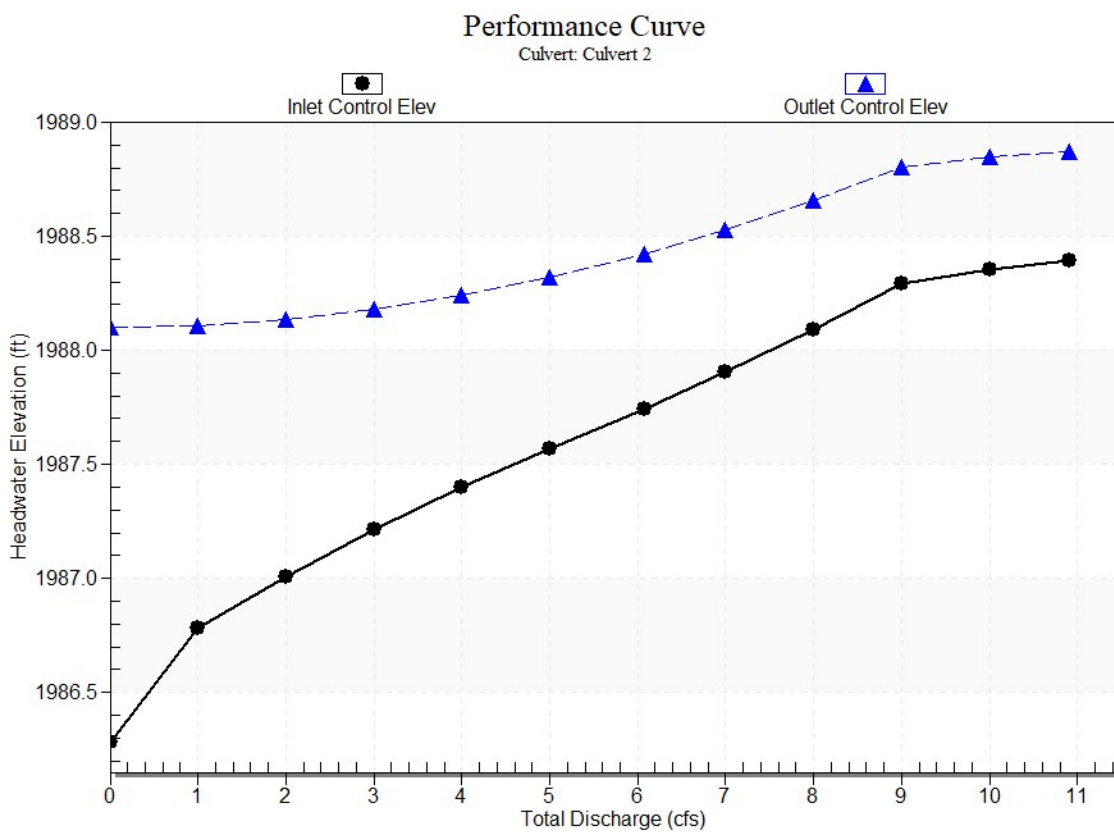
Inlet Elevation (invert): 1986.28 ft,

Outlet Elevation (invert): 1985.95 ft

Culvert Length: 16.53 ft,

Culvert Slope: 0.0200

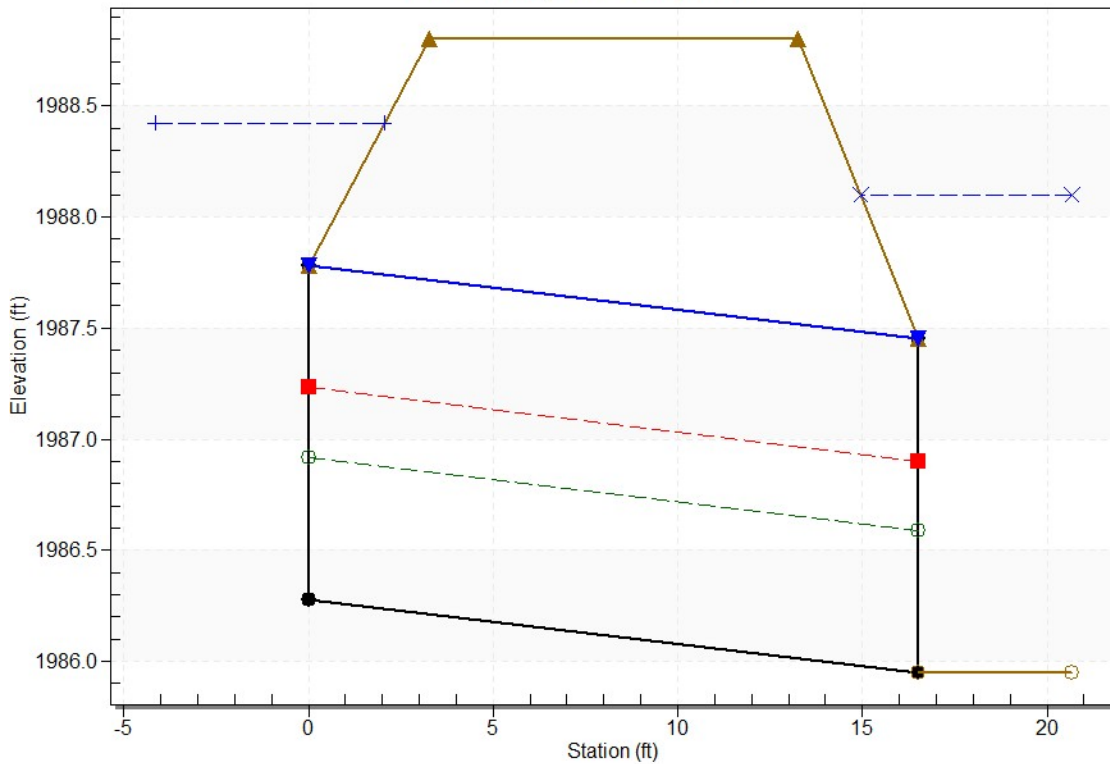
Culvert Performance Curve Plot: Culvert 2



Water Surface Profile Plot for Culvert: Culvert 2

Crossing - Culvert 2, Design Discharge - 6.1 cfs

Culvert - Culvert 2, Culvert Discharge - 6.1 cfs



Site Data - Culvert 2

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 1986.28 ft

Outlet Station: 16.53 ft

Outlet Elevation: 1985.95 ft

Number of Barrels: 1

Culvert Data Summary - Culvert 2

Barrel Shape: Circular

Barrel Diameter: 1.50 ft

Barrel Material: Concrete

Embedment: 0.00 in

Barrel Manning's n: 0.0120

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall (Ke=0.5)

Inlet Depression: None

Tailwater Data for Crossing: Culvert 2

Table 2 - Downstream Channel Rating Curve (Crossing: Culvert 2)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)
0.00	1988.10	2.15
1.00	1988.10	2.15
2.00	1988.10	2.15
3.00	1988.10	2.15
4.00	1988.10	2.15
5.00	1988.10	2.15
6.07	1988.10	2.15
7.00	1988.10	2.15
8.00	1988.10	2.15
9.00	1988.10	2.15
10.00	1988.10	2.15

Tailwater Channel Data - Culvert 2

Tailwater Channel Option: Enter Constant Tailwater Elevation

Constant Tailwater Elevation: 1988.10 ft

Roadway Data for Crossing: Culvert 2

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 30.00 ft

Crest Elevation: 1988.80 ft

Roadway Surface: Gravel

Roadway Top Width: 10.00 ft

STANTEC

PROJECT: OCONALUFTEE

STANTEC JOB #: 234364224

		BY	DATE
CULVERT 3		SMH	
		CHECKED	

SOIL TYPE	% SLOPE	LANDUSE	AREA (SF)	2, 10-YR STORM	25-YR STORM		
				C	CA	C	CA
B	---	WOODED AREAS	2459.00	0.15	368.85	0.15	368.85
TOTALS			2459.00		368.85		368.85

COMPOSITE C FACTOR (2, 10-YR): 0.15

COMPOSITE C FACTOR (25-YR): 0.15

TIME OF CONCENTRATION

Tc = 15.1 MIN

STORM EVENT (YR)	RAINFALL INTENSITY	DISCHARGE (CFS)
2	3.39	0.03
10	4.60	0.04
25	5.28	0.04

TIME OF CONCENTRATION CALCULATIONS

Project: Oconaluftee	Project #: 234264224
Subwatershed: Culvert 3	County: Swain
Calculations By: Susan Handley	8/18/2025
Checked By: Matthew Armstrong	

Sheet Flow	Segment 1	Surface Description: Woods with light underbrush	
		Manning's Roughness Coefficient, n: 0.4	
		Sheet Flow Length (ft): 100	
		NOAA Atlas 14, 2-year, 24-hour Rainfall (in): 3.7	
		Slope of Land Surface (ft/ft): 0.040	
		Travel Time (hrs): 0.252	

TOTAL TRAVEL TIME (HRS) = 0.25
TOTAL TRAVEL TIME (MIN) = 15.13

FLOWPATH DATA						
Flow Type	Segment	Length (ft)	US Elev (ft)	DS Elev (ft)	Slope (ft/ft)	
Sheet Flow	AB	100	1994	1990	0.04000	

SHEET FLOW ROUGHNESS EQUATIONS	
Manning's roughness coefficients for sheet flow (flow depth generally <0.1 ft)	n
Smooth surface (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated Soils with residue cover < 20%	0.06
Cultivated Soils with residue cover > 20%	0.17
Short-Grass Prairie	0.15
Dense Grasses	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods with light underbrush	0.40
Woods with dense underbrush	0.80
*source: National Engineering Handbook Table 15-1	

$$T_t = \frac{0.007(n\ell)^{1.49}}{(P_2)^{0.78} S^{0.48}} \quad (\text{eq. 15-8})$$

where:
 T_t = travel time, h
 n = Manning's roughness coefficient (table 15-1)
 ℓ = sheet flow length, ft
 P_2 = 2-year, 24-hour rainfall, in
 S = slope of land surface, ft/ft

Grass:	
Short-grass prairie	0.15
Dense grasses ¹	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods: ²	
Light underbrush	0.40
Dense underbrush	0.80
¹ The Manning's n values are a composite of information compiled by Engman (1986).	
² Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.	
³ When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.	

HY-8 Culvert 3- Analysis Report

Crossing Discharge Data

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 0.00 cfs

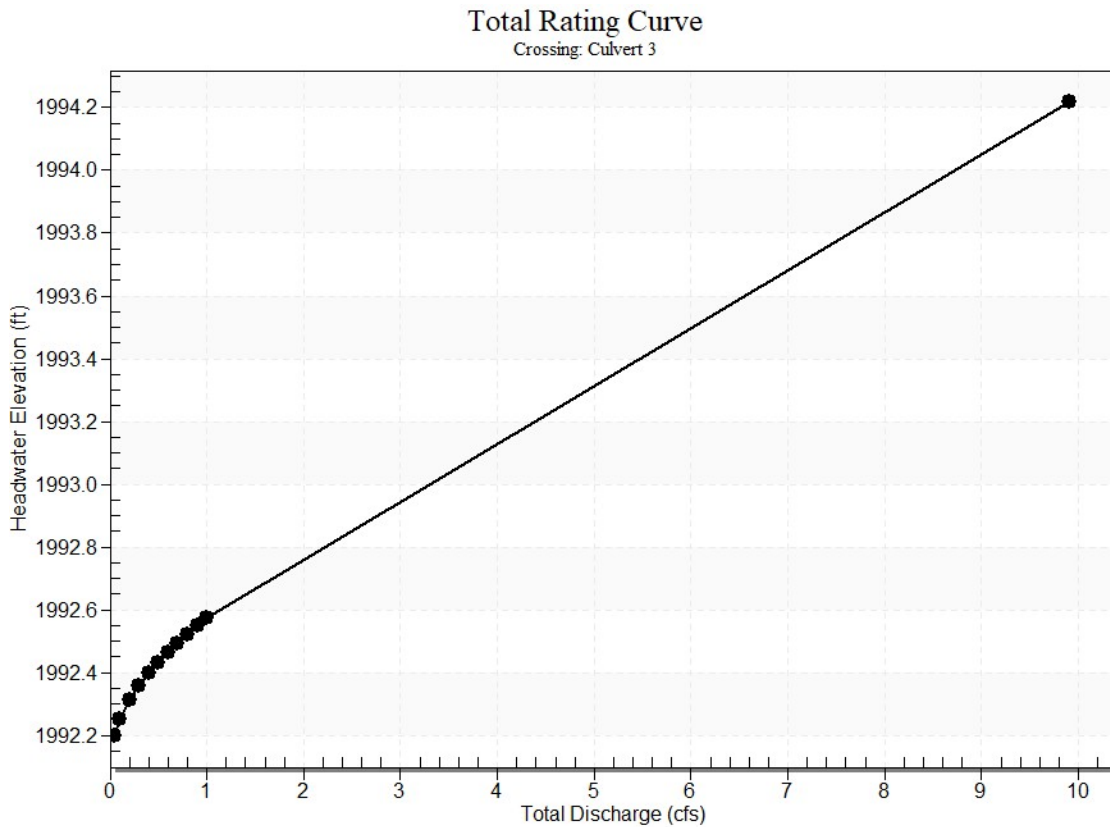
Design Flow: 0.04 cfs

Maximum Flow: 1.00 cfs

Table 1 - Summary of Culvert Flows at Crossing: Culvert 3

Headwater Elevation (ft)	Total Discharge (cfs)	Culvert 3 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
1992.20	0.04	0.04	0.00	1
1992.25	0.10	0.10	0.00	1
1992.31	0.20	0.20	0.00	1
1992.36	0.30	0.30	0.00	1
1992.40	0.40	0.40	0.00	1
1992.43	0.50	0.50	0.00	1
1992.46	0.60	0.60	0.00	1
1992.49	0.70	0.70	0.00	1
1992.52	0.80	0.80	0.00	1
1992.55	0.90	0.90	0.00	1
1992.57	1.00	1.00	0.00	1
1994.20	9.66	9.66	0.00	Overtopping

Rating Curve Plot for Crossing: Culvert 3



Culvert Data: Culvert 3

Table 1 - Culvert Summary Table: Culvert 3

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
0.04 cfs	0.04 cfs	1992.20	0.09	0.0*	1-S2n	0.03	0.07	0.03	0.00	3.87	0.00
0.10 cfs	0.10 cfs	1992.25	0.14	0.0*	1-S2n	0.05	0.12	0.05	0.00	5.15	0.00
0.20 cfs	0.20 cfs	1992.31	0.20	0.0*	1-S2n	0.07	0.16	0.07	0.00	6.04	0.00
0.30 cfs	0.30 cfs	1992.36	0.25	0.0*	1-S2n	0.09	0.20	0.09	0.00	6.93	0.00
0.40 cfs	0.40 cfs	1992.40	0.29	0.0*	1-S2n	0.10	0.23	0.10	0.00	7.52	0.00
0.50 cfs	0.50 cfs	1992.43	0.32	0.0*	1-S2n	0.12	0.26	0.12	0.00	7.94	0.00
0.60 cfs	0.60 cfs	1992.46	0.35	0.0*	1-S2n	0.13	0.29	0.13	0.00	8.46	0.00
0.70 cfs	0.70 cfs	1992.49	0.38	0.0*	1-S2n	0.13	0.31	0.13	0.00	8.87	0.00
0.80 cfs	0.80 cfs	1992.52	0.41	0.0*	1-S2n	0.14	0.33	0.14	0.00	9.21	0.00
0.90 cfs	0.90 cfs	1992.55	0.44	0.0*	1-S2n	0.15	0.35	0.15	0.00	9.48	0.00
1.00 cfs	1.00 cfs	1992.57	0.46	0.0*	1-S2n	0.16	0.37	0.16	0.00	9.82	0.00

* Full Flow Headwater elevation is below inlet invert.

Culvert Barrel Data

Culvert Barrel Type Straight Culvert

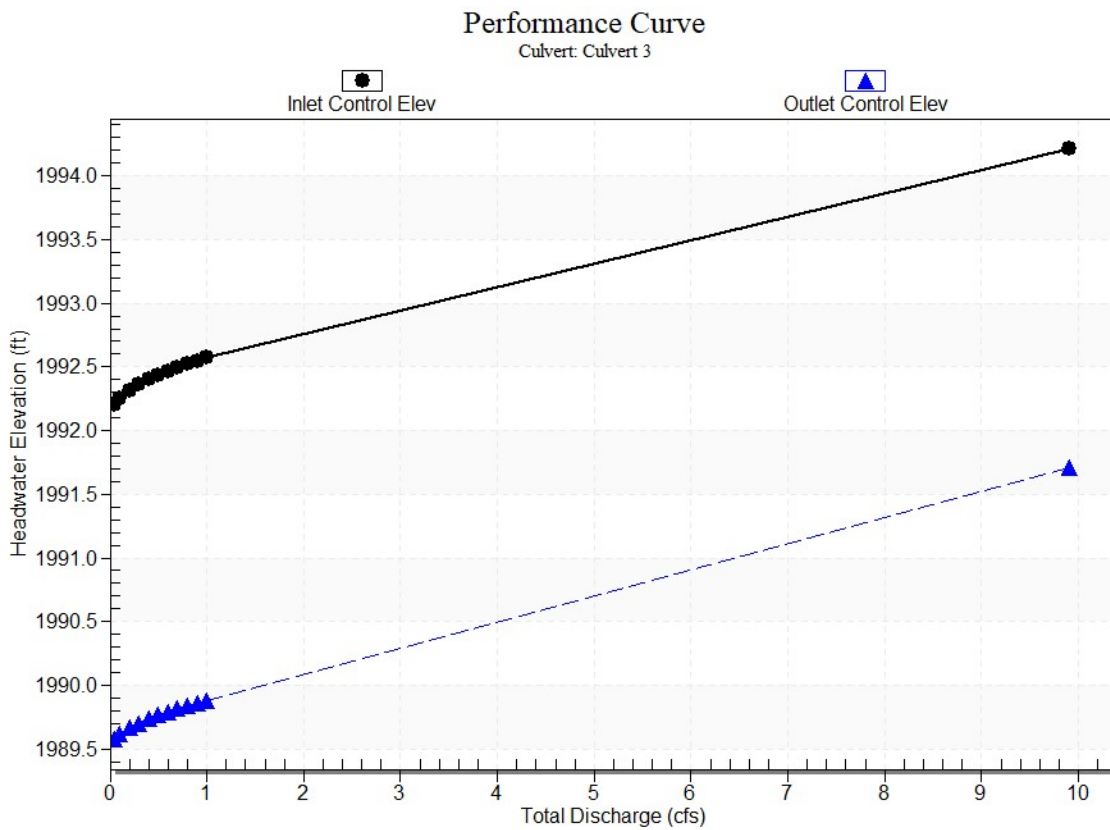
Inlet Elevation (invert): 1992.11 ft,

Outlet Elevation (invert): 1989.50 ft

Culvert Length: 20.17 ft,

Culvert Slope: 0.1305

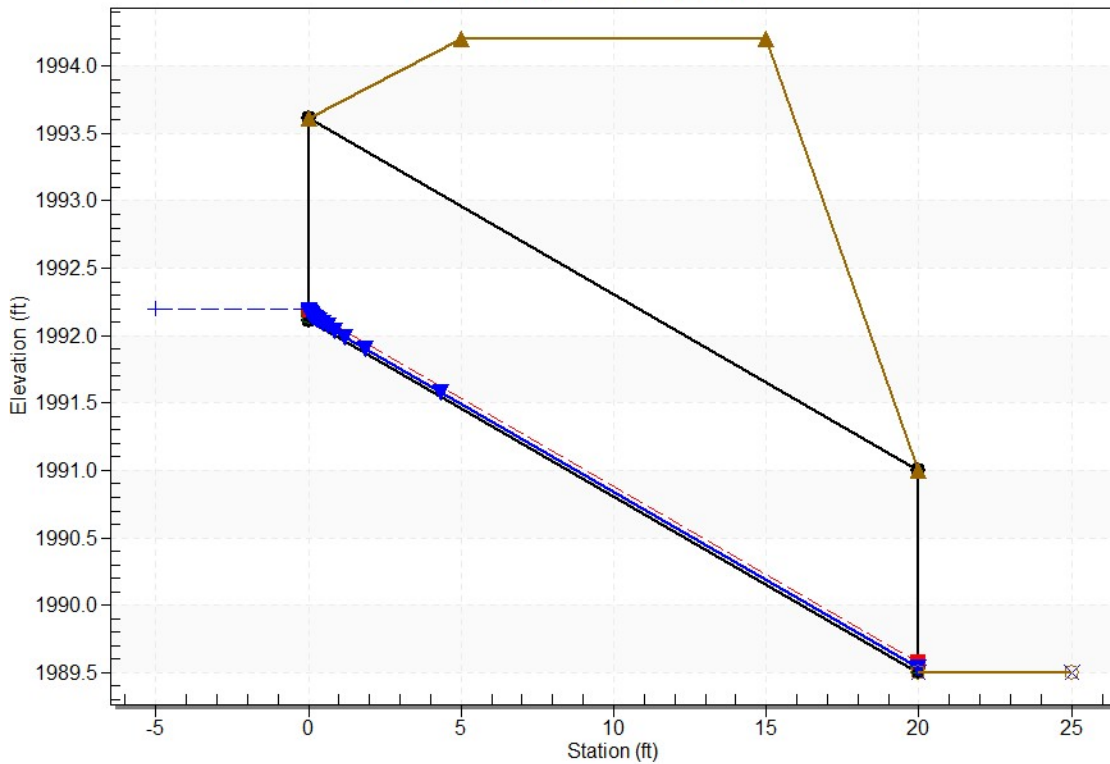
Culvert Performance Curve Plot: Culvert 3



Water Surface Profile Plot for Culvert: Culvert 3

Crossing - Culvert 3, Design Discharge - 0.0 cfs

Culvert - Culvert 3, Culvert Discharge - 0.0 cfs



Site Data - Culvert 3

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 1992.11 ft

Outlet Station: 20.00 ft

Outlet Elevation: 1989.50 ft

Number of Barrels: 1

Culvert Data Summary - Culvert 3

Barrel Shape: Circular

Barrel Diameter: 1.50 ft

Barrel Material: Concrete

Embedment: 0.00 in

Barrel Manning's n: 0.0120

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall

Inlet Depression: None

Tailwater Data for Crossing: Culvert 3

Table 2 - Downstream Channel Rating Curve (Crossing: Culvert 3)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)
0.04	1989.50	0.00
0.10	1989.50	0.00
0.20	1989.50	0.00
0.30	1989.50	0.00
0.40	1989.50	0.00
0.50	1989.50	0.00
0.60	1989.50	0.00
0.70	1989.50	0.00
0.80	1989.50	0.00
0.90	1989.50	0.00
1.00	1989.50	0.00

Tailwater Channel Data - Culvert 3

Tailwater Channel Option: Enter Constant Tailwater Elevation

Constant Tailwater Elevation: 1989.50 ft

Roadway Data for Crossing: Culvert 3

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 30.00 ft

Crest Elevation: 1994.20 ft

Roadway Surface: Gravel

Roadway Top Width: 10.00 ft

STANTEC
PROJECT: OCONALUFTEE
STANTEC JOB # : 234364224

CULVERT 4		BY	DATE
	COMPUTED	SMH	
	CHECKED		

SOIL TYPE	% SLOPE	LANDUSE	AREA (SF)	2, 10-YR STORM	25-YR STORM	
				C	CA	CA
B	---	WOODED AREAS	517607.00	0.15	77641.05	77641.05
---	---	IMPERVIOUS	15000.00	0.90	13500.00	13500.00
B	---	GRAVEL	2768.00	0.70	1937.60	1937.60
TOTALS			535375.00		93078.65	93078.65

COMPOSITE C FACTOR (2, 10-YR): 0.17
COMPOSITE C FACTOR (25-YR): 0.17

TIME OF CONCENTRATION

Tc = 24.8 MIN

STORM EVENT (YR)	RAINFALL INTENSITY	DISCHARGE (CFS)
2	2.76	5.90
10	3.84	8.21
25	4.45	9.51

Project: Oconaluftee	Project #: 234264224
Subwatershed: Culvert 4	County: Swain
Calculations By: Remington Cross	8/19/2025
Checked By: Matthew Armstrong	8/19/2025

Channel Flow	Segment 3	Estimated Channel Bottom Width (ft):	5
		Estimated Channel Side Slope (xH:1V):	1
		Estimated Water Depth (ft):	0.24
		Estimated Cross-sectional Area (sq ft):	1.25
		Estimated Wetted Perimeter (ft):	5.68
		Estimated Hydraulic Radius (ft):	0.22
		Channel Slope (ft/ft):	0.012
		Manning's Roughness Coefficient, n:	0.035
		Velocity (ft/s):	1.67
		Flow (cu ft/s):	2.10
		Channel Flow Length (ft):	1086
		Travel Time (hrs):	0.18

TOTAL TRAVEL TIME (HRS) = 0.41
TOTAL TRAVEL TIME (MIN) = 24.82

SHEET FLOW ROUGHNESS EQUATIONS			Grass:	
Manning's roughness coefficients for sheet flow (flow depth generally <0.1 ft)			Short-grass prairie	0.15
Surface Description	n	$T_1 = \frac{0.007 (u_f)^{0.48}}{(P_2)^{0.3} S^{0.4}} \quad (\text{eq. 15-8})$	Dense grasses 2	0.24
Smooth surface (concrete, asphalt, gravel, or bare soil)	0.011		Bermudagrass	0.41
Fallow (no residue)	0.05		Range (natural)	0.13
Cultivated Soils with residue cover < 20%	0.06		Woody 2	
Cultivated Soils with residue cover > 20%	0.17		Light underbrush	0.40
Short-Grass Prairie	0.15		Dense underbrush	0.80
Dense Grasses	0.24		1 The Manning's n values are a composite of information compiled by Engman (1986). 2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grama mixtures. 3 When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.	
Bermudagrass	0.41			
Range (natural)	0.13			
Woody with light underbrush	0.40			
Woody with dense underbrush	0.80			

[illegible]

CHANNEL FLOW EQUATIONS

Manning's equation is:

$$V = \frac{1.49 R^{\frac{2}{3}} S^{\frac{1}{2}}}{n} \quad (\text{eq. 15-10})$$

where:

V = average velocity, ft/s

r = hydraulic radius, ft

$$= \frac{a}{P_x}$$

a = cross-sectional flow area, ft²

P_x = wetted perimeter, ft

s = slope of the hydraulic grade line (channel slope), ft/ft

n = Manning's n value for open channel flow

is assumed to occur. Open channels are assumed to begin where surveyed cross-sectional information has been obtained, where channels are visible on aerial photographs, or where bluelines (indicating streams) appear on U.S. Geological Survey (USGS) quadrangle sheets.

may have a large variation. In practice, calculations are typically based on the 2-year frequency discharge event since it is normally assumed that the time of concentration computed using these characteristics is representative of travel time conditions for a wide

Table B.2. Manning's Roughness Coefficients for Various Boundaries.

Rigid Boundary Channels	Manning's n
Very smooth concrete and planed timber	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Wood	0.014
Vitrified clay	0.015
Shot concrete, untroweled, and earth channels in best condition	0.017
Straight unlined earth canals in good condition	0.020
Mountain streams with rocky beds	0.040 - 0.050
MINOR STREAMS (top width at flood stage < 30 m)	
Streams on Plain	
1. Clean, straight, full stage, no rifts or deep pools	0.025-0.033
2. Same as above, but more stones and weeds	0.030-0.040
3. Clean, winding, some pools and shoals	0.033-0.045
4. Same as above, but some weeds and stones	0.035-0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040-0.055
6. Same as 4, but more stones	0.045-0.080
7. Sluggish reaches, weedy, deep pools	0.050-0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075-0.150
Mountain Streams, no Vegetation in Channel, Banks Usually Steep, Trees and Brush Along Banks Submerged at High Stages	
1. Bottom: gravels, cobbles and few boulders	0.030-0.050
2. Bottom: cobbles with large boulders	0.040-0.070

HY-8 Culvert 4- Analysis Report

Crossing Discharge Data

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 0.00 cfs

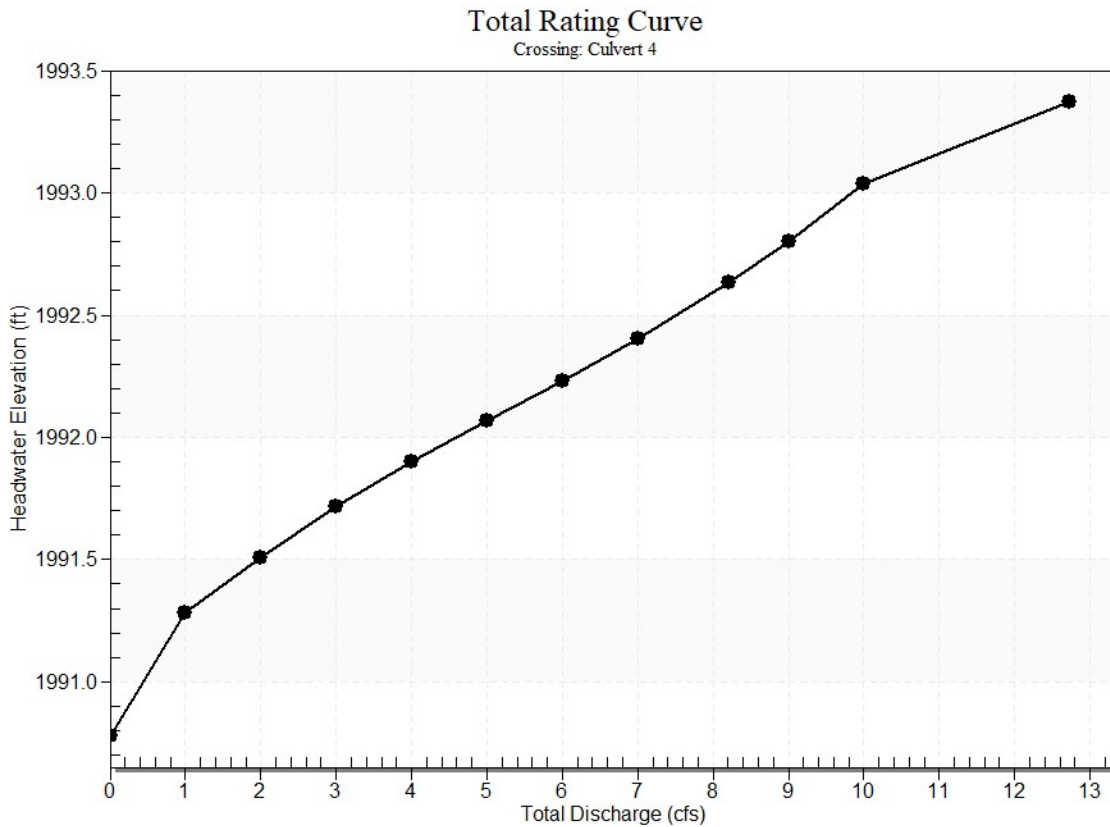
Design Flow: 8.21 cfs

Maximum Flow: 10.00 cfs

Table 1 - Summary of Culvert Flows at Crossing: Culvert 4

Headwater Elevation (ft)	Total Discharge (cfs)	Culvert 4 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
1990.78	0.00	0.00	0.00	1
1991.28	1.00	1.00	0.00	1
1991.51	2.00	2.00	0.00	1
1991.72	3.00	3.00	0.00	1
1991.90	4.00	4.00	0.00	1
1992.07	5.00	5.00	0.00	1
1992.23	6.00	6.00	0.00	1
1992.40	7.00	7.00	0.00	1
1992.63	8.21	8.21	0.00	1
1992.80	9.00	9.00	0.00	1
1993.04	10.00	10.00	0.00	1
1993.30	11.01	11.01	0.00	Overtopping

Rating Curve Plot for Crossing: Culvert 4



Culvert Data: Culvert 4

Table 1 - Culvert Summary Table: Culvert 4

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
0.00 cfs	0.00 cfs	1990.78	0.00	0.000	0-NF	0.00	0.00	0.03	0.03	0.00	0.00
1.00 cfs	1.00 cfs	1991.28	0.50	0.0*	1-S2n	0.25	0.37	0.26	0.03	4.87	0.00
2.00 cfs	2.00 cfs	1991.51	0.73	0.159	1-S2n	0.36	0.53	0.38	0.03	5.75	0.00
3.00 cfs	3.00 cfs	1991.72	0.94	0.330	1-S2n	0.44	0.66	0.47	0.03	6.29	0.00
4.00 cfs	4.00 cfs	1991.90	1.12	0.500	1-S2n	0.51	0.77	0.56	0.03	6.70	0.00
5.00 cfs	5.00 cfs	1992.07	1.29	0.676	1-S2n	0.57	0.86	0.63	0.03	7.04	0.00
6.00 cfs	6.00 cfs	1992.23	1.45	0.861	1-S2n	0.63	0.95	0.71	0.03	7.34	0.00
7.00 cfs	7.00 cfs	1992.40	1.62	1.056	5-S2n	0.69	1.02	0.77	0.03	7.61	0.00
8.21 cfs	8.21 cfs	1992.63	1.85	1.308	5-S2n	0.76	1.11	0.85	0.03	7.92	0.00
9.00 cfs	9.00 cfs	1992.80	2.02	1.651	5-S2n	0.80	1.16	0.90	0.03	8.11	0.00
10.00 cfs	10.00 cfs	1993.04	2.26	1.852	5-S2n	0.85	1.22	0.96	0.03	8.35	0.00

* Full Flow Headwater elevation is below inlet invert.

Culvert Barrel Data

Culvert Barrel Type Straight Culvert

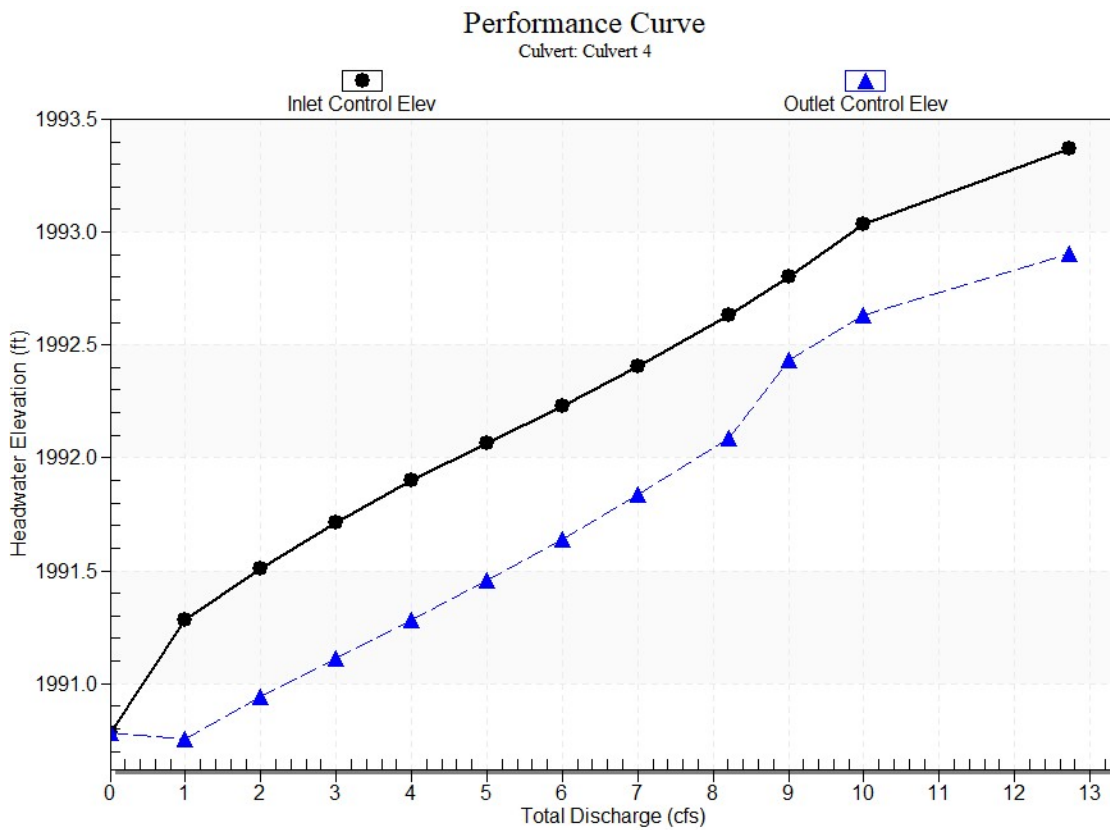
Inlet Elevation (invert): 1990.78 ft,

Outlet Elevation (invert): 1990.37 ft

Culvert Length: 20.36 ft,

Culvert Slope: 0.0201

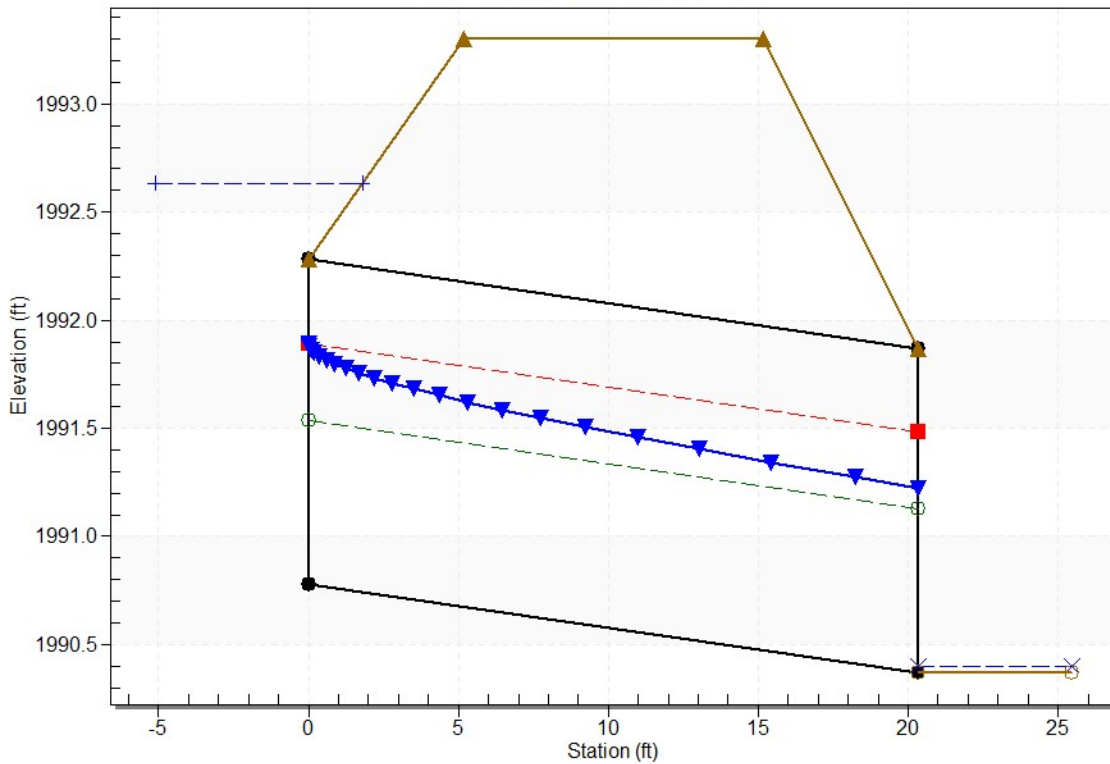
Culvert Performance Curve Plot: Culvert 4



Water Surface Profile Plot for Culvert: Culvert 4

Crossing - Culvert 4, Design Discharge - 8.2 cfs

Culvert - Culvert 4, Culvert Discharge - 8.2 cfs



Site Data - Culvert 4

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 1990.78 ft

Outlet Station: 20.36 ft

Outlet Elevation: 1990.37 ft

Number of Barrels: 1

Culvert Data Summary - Culvert 4

Barrel Shape: Circular

Barrel Diameter: 1.50 ft

Barrel Material: Concrete

Embedment: 0.00 in

Barrel Manning's n: 0.0120

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall

Inlet Depression: None

Tailwater Data for Crossing: Culvert 4

Table 2 - Downstream Channel Rating Curve (Crossing: Culvert 4)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)
0.00	1990.40	0.03
1.00	1990.40	0.03
2.00	1990.40	0.03
3.00	1990.40	0.03
4.00	1990.40	0.03
5.00	1990.40	0.03
6.00	1990.40	0.03
7.00	1990.40	0.03
8.21	1990.40	0.03
9.00	1990.40	0.03
10.00	1990.40	0.03

Tailwater Channel Data - Culvert 4

Tailwater Channel Option: Enter Constant Tailwater Elevation

Constant Tailwater Elevation: 1990.40 ft

Roadway Data for Crossing: Culvert 4

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 30.00 ft

Crest Elevation: 1993.30 ft

Roadway Surface: Gravel

Roadway Top Width: 10.00 ft

STANTEC

PROJECT: OCONALUFTEE
STANTEC JOB #: 234364224

CULVERT 5

	BY	DATE
COMPUTED	SMH	8/18/2025
CHECKED	MIA	8/19/2025

SOIL TYPE	% SLOPE	LANDUSE	AREA (SF)	2, 10-YR STORM	25-YR STORM	
				C	CA	CA
---	---	IMPERVIOUS	3827.00	0.90	3444.30	3444.30
B	---	WOODED AREAS	9670.00	0.15	1450.50	1450.50
B	---	GRAVEL	1291.00	0.70	903.70	903.70
TOTALS			14788.00		5798.50	5798.50

COMPOSITE C FACTOR (2, 10-YR): 0.39
COMPOSITE C FACTOR (25-YR): 0.39

TIME OF CONCENTRATION

T_c = 6.0 MIN

STORM EVENT (YR)	RAINFALL INTENSITY	DISCHARGE (CFS)
2	4.86	0.65
10	6.55	0.87
25	7.52	1.00

HY-8 Culvert 5- Analysis Report

Crossing Discharge Data

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 0.00 cfs

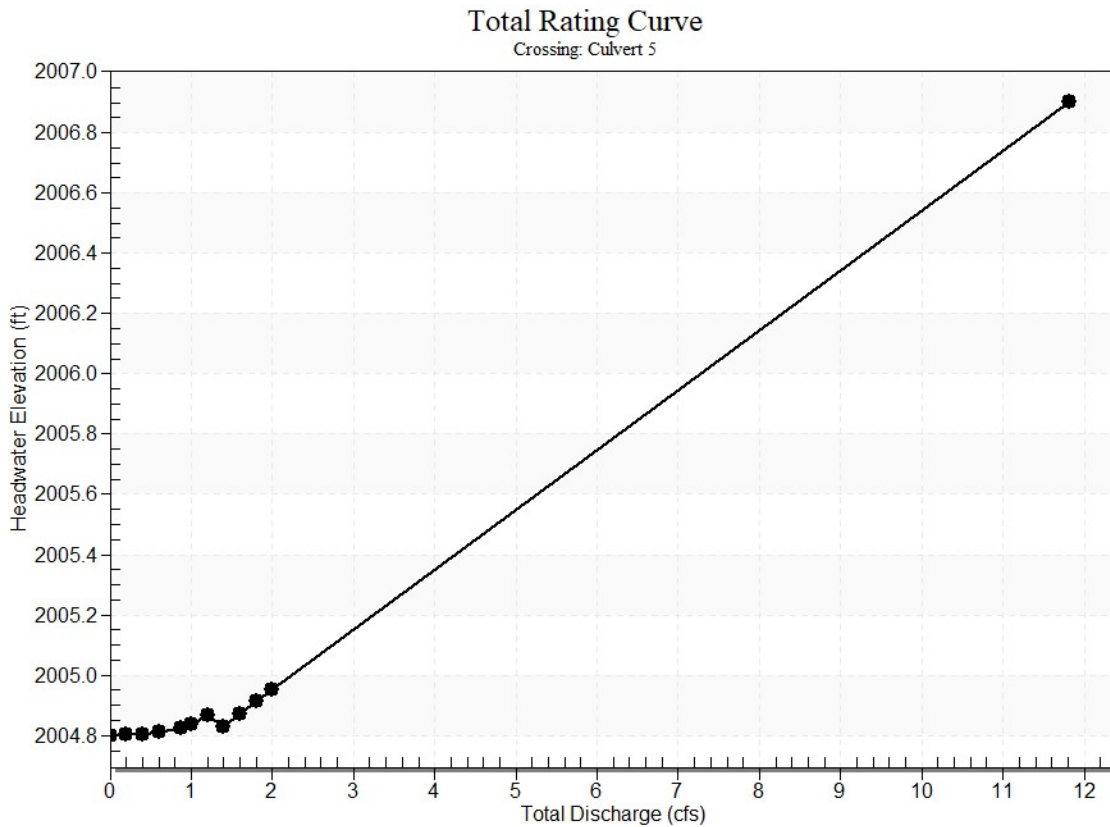
Design Flow: 0.87 cfs

Maximum Flow: 2.00 cfs

Table 1 - Summary of Culvert Flows at Crossing: Culvert 5

Headwater Elevation (ft)	Total Discharge (cfs)	Culvert 5 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
2004.80	0.00	0.00	0.00	1
2004.80	0.20	0.20	0.00	1
2004.81	0.40	0.40	0.00	1
2004.81	0.60	0.60	0.00	1
2004.83	0.87	0.87	0.00	1
2004.84	1.00	1.00	0.00	1
2004.87	1.20	1.20	0.00	1
2004.83	1.40	1.40	0.00	1
2004.87	1.60	1.60	0.00	1
2004.91	1.80	1.80	0.00	1
2004.95	2.00	2.00	0.00	1
2006.88	11.50	11.50	0.00	Overtopping

Rating Curve Plot for Crossing: Culvert 5



Culvert Data: Culvert 5

Table 1 - Culvert Summary Table: Culvert 5

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
0.00 cfs	0.00 cfs	2004.80	0.00	0.550	0-NF	0.00	0.00	1.50	1.25	0.00	0.00
0.20 cfs	0.20 cfs	2004.80	0.21	0.551	1-S1f	0.09	0.16	1.50	1.25	0.11	0.00
0.40 cfs	0.40 cfs	2004.81	0.30	0.555	1-S1f	0.12	0.23	1.50	1.25	0.23	0.00
0.60 cfs	0.60 cfs	2004.81	0.37	0.562	1-S1f	0.15	0.29	1.50	1.25	0.34	0.00
0.87 cfs	0.87 cfs	2004.83	0.45	0.577	1-S1f	0.18	0.35	1.50	1.25	0.49	0.00
1.00 cfs	1.00 cfs	2004.84	0.49	0.588	1-S1f	0.19	0.37	1.50	1.25	0.57	0.00
1.20 cfs	1.20 cfs	2004.87	0.54	0.619	1-S1f	0.21	0.41	1.50	1.25	0.68	0.00
1.40 cfs	1.40 cfs	2004.83	0.58	0.565	1-JS1f	0.23	0.44	1.50	1.25	0.79	0.00
1.60 cfs	1.60 cfs	2004.87	0.62	0.571	1-JS1f	0.24	0.47	1.50	1.25	0.91	0.00
1.80 cfs	1.80 cfs	2004.91	0.66	0.577	1-JS1f	0.26	0.50	1.50	1.25	1.02	0.00
2.00 cfs	2.00 cfs	2004.95	0.70	0.584	1-JS1f	0.27	0.53	1.50	1.25	1.13	0.00

Culvert Barrel Data

Culvert Barrel Type Straight Culvert

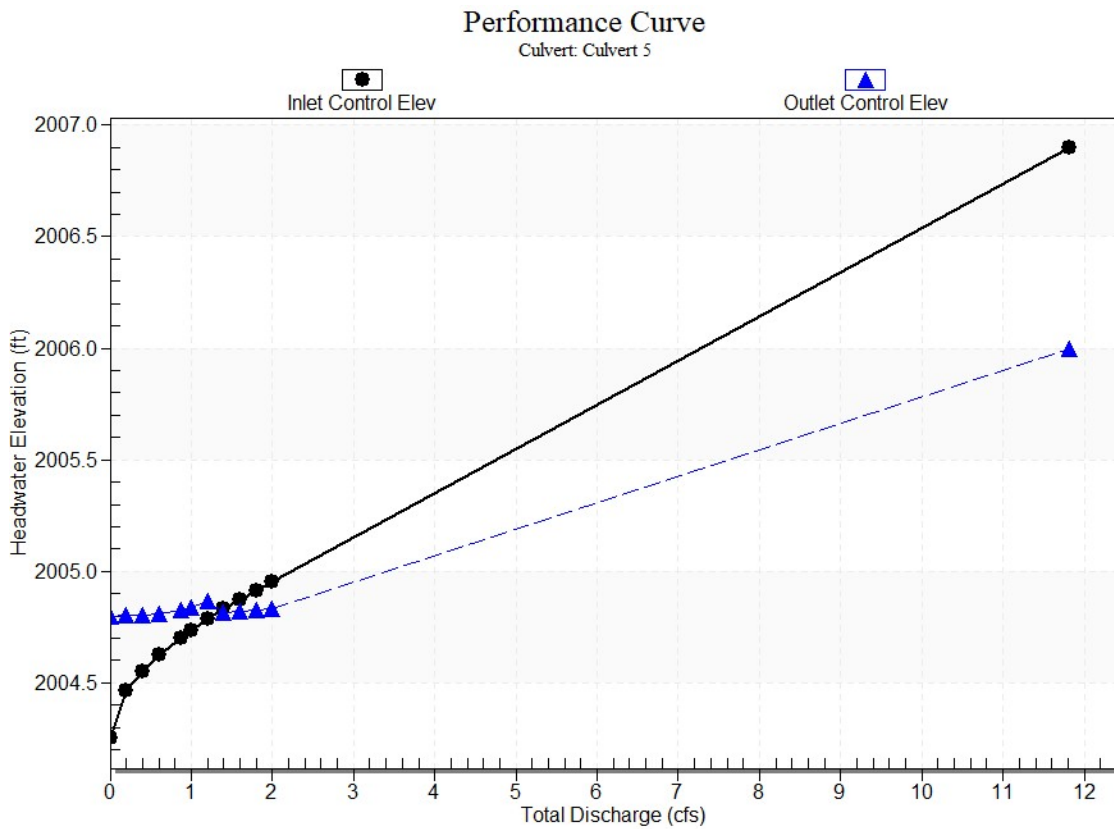
Inlet Elevation (invert): 2004.25 ft,

Outlet Elevation (invert): 2003.06 ft

Culvert Length: 19.42 ft,

Culvert Slope: 0.0614

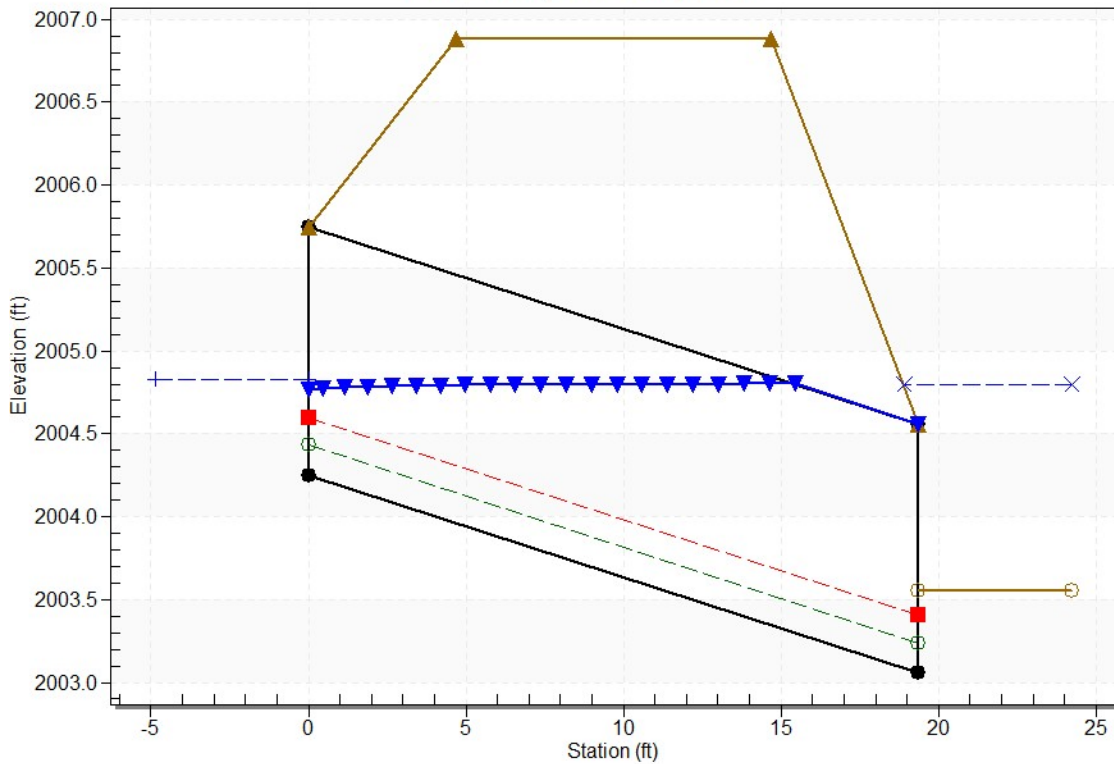
Culvert Performance Curve Plot: Culvert 5



Water Surface Profile Plot for Culvert: Culvert 5

Crossing - Culvert 5, Design Discharge - 0.9 cfs

Culvert - Culvert 5, Culvert Discharge - 0.9 cfs



Site Data - Culvert 5

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 2004.25 ft

Outlet Station: 19.38 ft

Outlet Elevation: 2003.06 ft

Number of Barrels: 1

Culvert Data Summary - Culvert 5

Barrel Shape: Circular

Barrel Diameter: 1.50 ft

Barrel Material: Concrete

Embedment: 0.00 in

Barrel Manning's n: 0.0120

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall

Inlet Depression: None

Tailwater Data for Crossing: Culvert 5

Table 2 - Downstream Channel Rating Curve (Crossing: Culvert 5)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)
0.00	2004.80	1.25
0.20	2004.80	1.25
0.40	2004.80	1.25
0.60	2004.80	1.25
0.87	2004.80	1.25
1.00	2004.80	1.25
1.20	2004.80	1.25
1.40	2004.80	1.25
1.60	2004.80	1.25
1.80	2004.80	1.25
2.00	2004.80	1.25

Tailwater Channel Data - Culvert 5

Tailwater Channel Option: Enter Constant Tailwater Elevation

Constant Tailwater Elevation: 2004.80 ft

Roadway Data for Crossing: Culvert 5

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 30.00 ft

Crest Elevation: 2006.88 ft

Roadway Surface: Gravel

Roadway Top Width: 10.00 ft

STANTEC
PROJECT: OCONALUFTEE
STANTEC JOB #: 234364224

CULVERT 6		BY	DATE
	COMPUTED	SMH	8/18/2025
	CHECKED	MIA	8/19/2025

SOIL TYPE	% SLOPE	LANDUSE	AREA (SF)	2, 10-YR STORM	25-YR STORM	
				C	CA	CA
---	---	IMPERVIOUS	19627.00	0.90	17664.30	17664.30
B	---	WOODED AREAS	1126066.00	0.15	168909.90	168909.90
TOTALS			1145693.00		186574.20	186574.20

COMPOSITE C FACTOR (2, 10-YR): 0.16
COMPOSITE C FACTOR (25-YR): 0.16

TIME OF CONCENTRATION

Tc = 22.3 MIN

STORM EVENT (YR)	RAINFALL INTENSITY	DISCHARGE (CFS)
2	2.90	12.43
10	4.01	17.18
25	4.64	19.86

Project: Oconaluftee	Project #: 234264224
Subwatershed: Culvert 1	County: Swain
Calculations By: Susan Handley	8/18/2025
Checked By: Matthew Armstrong	

TOTAL TRAVEL TIME (HRS) = 0.37
TOTAL TRAVEL TIME (MIN) = 22.27

SHEET FLOW ROUGHNESS EQUATIONS			Grasses	
Manning's roughness coefficients for sheet flow (flow depth generally <0.1 ft)			Short-grass prairie.....	0.15
Surface Description			Dense grasses =	0.24
Smooth surface (concrete, asphalt, gravel, or bare soil)			Bermudagrass.....	0.41
Fallow (no residue)			Range (natural).....	0.13
Cultivated Soils with residue cover < 20%			Woody =	0.40
Cultivated Soils with residue cover > 20%			Light underbrush.....	0.80
Short-Grass Prairie			Dense underbrush.....	0.80
Dense Grasses			1 The Manning's n values are a composite of information compiled by Engman (1986).	
Bermudagrass			2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.	
Range (natural)			3 When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.	
Woods with light underbrush				
Woods with dense underbrush				

Manning's equation is:		Table B.2. Manning's Roughness Coefficients for Various Boundaries.	
$V = \frac{1.49 R^{2/3} S^{1/2}}{n}$ (eq. 15-10)			
where:			
V = average velocity, ft/s			
r = hydraulic radius, ft			
= $\frac{a}{P_w}$			
a = cross-sectional flow area, ft ²			
P _w = wetted perimeter, ft			
s = slope of the hydraulic grade line (channel slope), ft/ft			
n = Manning's n value for open channel flow			
is assumed to occur. Open channels are assumed to begin where surveyed cross-sectional information has been obtained, where channels are visible on aerial photographs, or where bluelines (indicating streams) appear on U.S. Geological Survey (USGS) quadrangle sheets.			
may have a large variation. In practice, calculations are typically based on the 2-year frequency discharge event since it is normally assumed that the time of concentration computed using these characteristics is representative of travel time conditions for a wide			

HY-8 Culvert 6- Analysis Report

Crossing Discharge Data

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 0.00 cfs

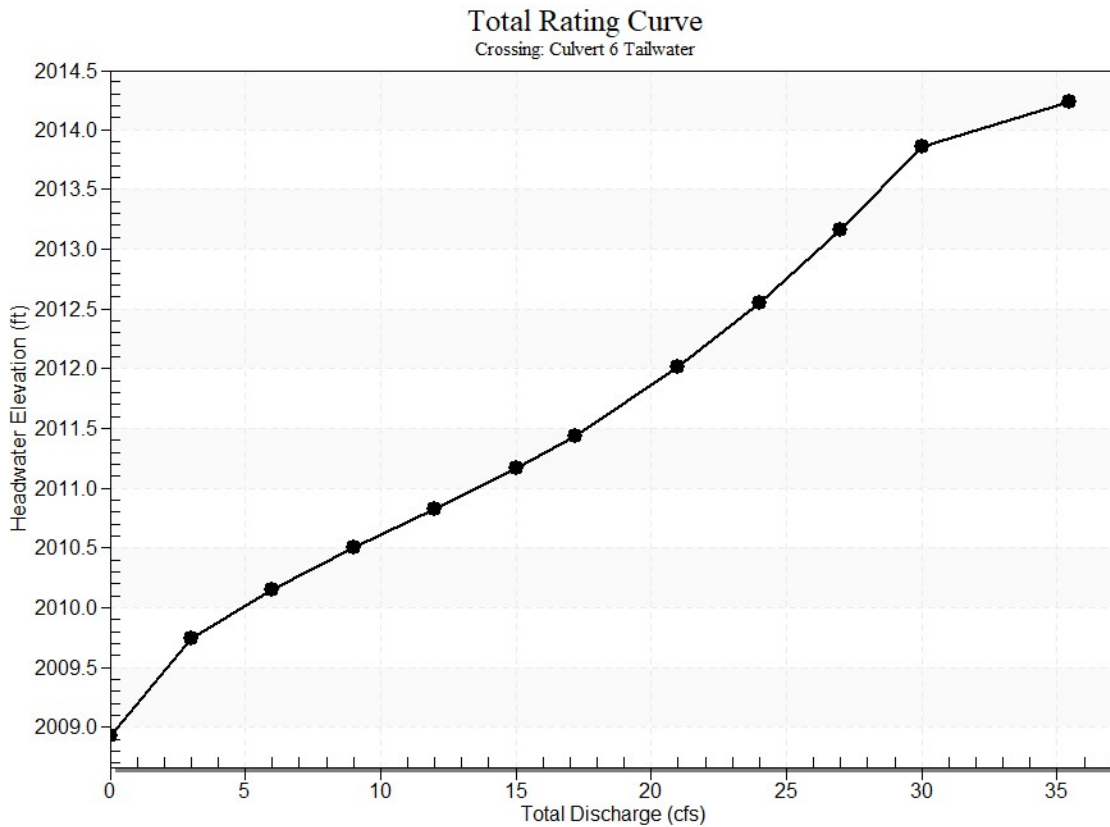
Design Flow: 17.18 cfs

Maximum Flow: 30.00 cfs

Table 1 - Summary of Culvert Flows at Crossing: Culvert 6 Tailwater

Headwater Elevation (ft)	Total Discharge (cfs)	Culvert 6 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
2008.93	0.00	0.00	0.00	1
2009.74	3.00	3.00	0.00	1
2010.15	6.00	6.00	0.00	1
2010.50	9.00	9.00	0.00	1
2010.82	12.00	12.00	0.00	1
2011.16	15.00	15.00	0.00	1
2011.44	17.18	17.18	0.00	1
2012.01	21.00	21.00	0.00	1
2012.54	24.00	24.00	0.00	1
2013.16	27.00	27.00	0.00	1
2013.86	30.00	30.00	0.00	1
2015.00	30.58	30.58	0.00	Overtopping

Rating Curve Plot for Crossing: Culvert 6 Tailwater



Culvert Data: Culvert 6

Table 1 - Culvert Summary Table: Culvert 6

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
0.00 cfs	0.00 cfs	2008.93	0.00	0.000	0-NF	0.00	0.00	1.07	1.07	0.00	0.00
3.00 cfs	3.00 cfs	2009.74	0.81	0.0*	1-S2n	0.00	0.60	0.36	1.07	7.74	0.00
6.00 cfs	6.00 cfs	2010.15	1.22	0.0*	1-S2n	0.00	0.60	0.51	1.07	9.39	0.00
9.00 cfs	9.00 cfs	2010.50	1.57	0.0*	1-S2n	0.00	0.60	0.63	1.07	10.50	0.00
12.00 cfs	12.00 cfs	2010.82	1.89	0.0*	1-S2n	0.00	0.60	0.75	1.07	11.18	0.00
15.00 cfs	15.00 cfs	2011.16	2.23	0.0*	5-S2n	0.00	0.60	0.85	1.07	11.82	0.00
17.18 cfs	17.18 cfs	2011.44	2.51	0.0*	5-S2n	0.00	0.60	0.90	1.07	12.44	0.00
21.00 cfs	21.00 cfs	2012.01	3.08	0.0*	5-S2n	0.00	0.60	1.03	1.07	12.84	0.00
24.00 cfs	24.00 cfs	2012.54	3.61	0.0*	5-S2n	0.00	0.60	1.12	1.07	13.23	0.00
27.00 cfs	27.00 cfs	2013.16	4.23	0.299	5-S2n	0.00	0.60	1.22	1.07	13.49	0.00
30.00 cfs	30.00 cfs	2013.86	4.93	1.127	5-S2n	0.00	0.60	1.30	1.07	13.82	0.00

* Full Flow Headwater elevation is below inlet invert.

Culvert Barrel Data

Culvert Barrel Type Single Broken-back Culvert

Inlet Elevation (invert): 2008.93 ft,

Break Elevation (invert): 2004.96 ft,

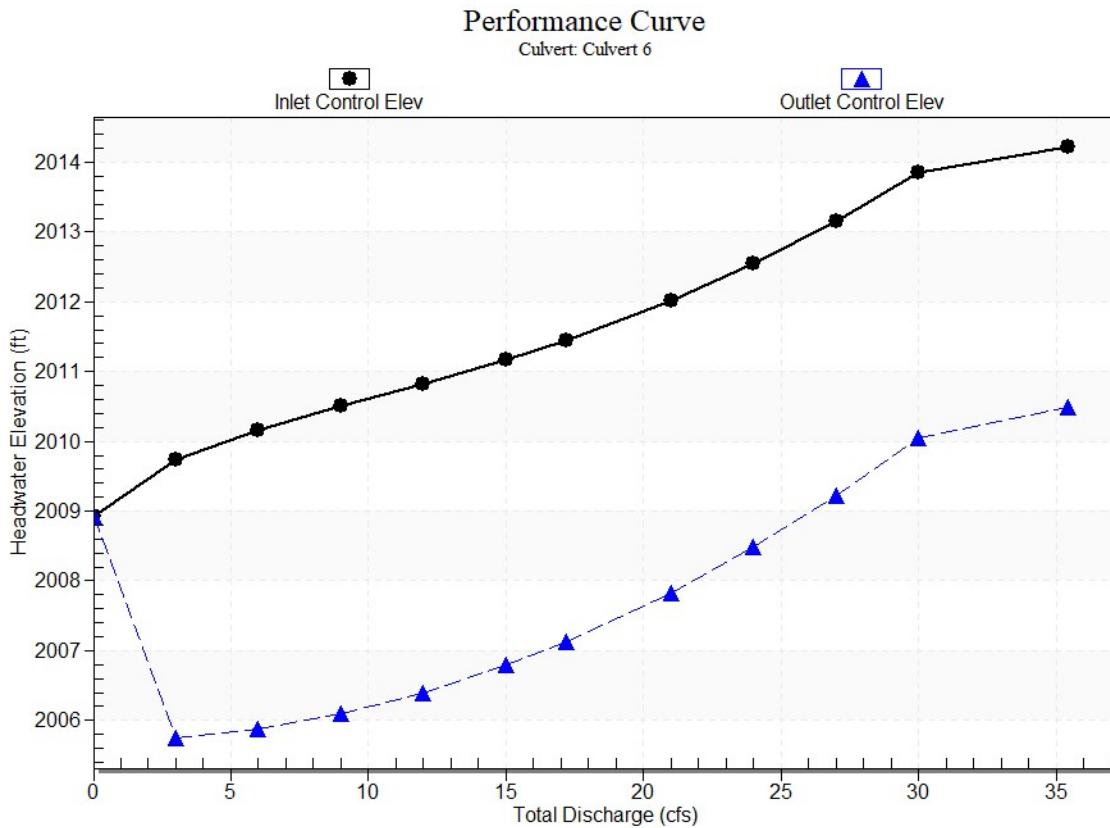
Outlet Elevation (invert): 2004.43 ft

Culvert Length: 167.06 ft,

Upper Culvert Section Slope: 0.0265

Steep Culvert Section Slope: 0.0312

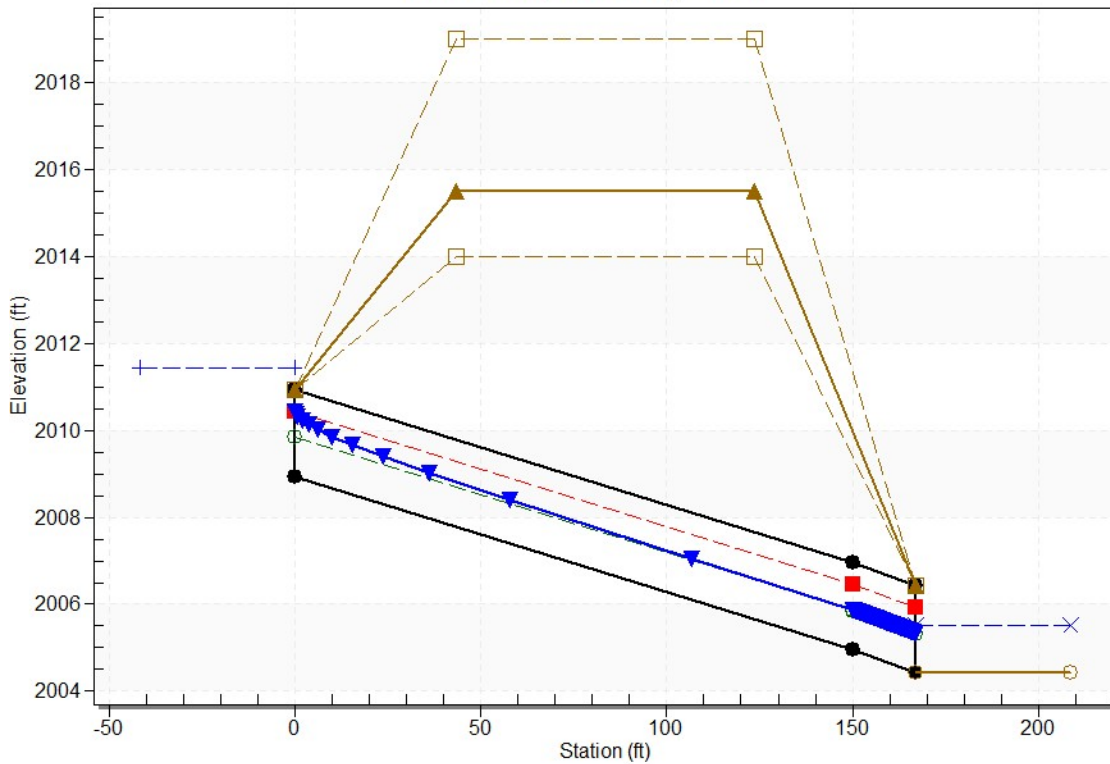
Culvert Performance Curve Plot: Culvert 6



Water Surface Profile Plot for Culvert: Culvert 6

Crossing - Culvert 6 Tailwater, Design Discharge - 17.2 cfs

Culvert - Culvert 6, Culvert Discharge - 17.2 cfs



Site Data - Culvert 6

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 2008.93 ft

Break Station: 150.00 ft

Break Elevation: 2004.96 ft

Outlet Station: 167.00 ft

Outlet Elevation: 2004.43 ft

Number of Barrels: 1

Culvert Data Summary - Culvert 6

Barrel Shape: Circular

Barrel Diameter: 2.00 ft

Upper Section Material: Smooth HDPE

Lower Section Material: Concrete

Embedment: 0.00 in

Upper Section Manning's n: 0.0120

Lower Section Manning's n: 0.0120

Culvert Type: Single Broken-back

Inlet Configuration: Square Edge with Headwall

Inlet Depression: None

Tailwater Data for Crossing: Culvert 6 Tailwater

Table 2 - Downstream Channel Rating Curve (Crossing: Culvert 6 Tailwater)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)
0.00	2005.50	1.07
3.00	2005.50	1.07
6.00	2005.50	1.07
9.00	2005.50	1.07
12.00	2005.50	1.07
15.00	2005.50	1.07
17.18	2005.50	1.07
21.00	2005.50	1.07
24.00	2005.50	1.07
27.00	2005.50	1.07
30.00	2005.50	1.07

Tailwater Channel Data - Culvert 6 Tailwater

Tailwater Channel Option: Enter Constant Tailwater Elevation

Constant Tailwater Elevation: 2005.50 ft

Roadway Data for Crossing: Culvert 6 Tailwater

Roadway Profile Shape: Irregular Roadway Shape (coordinates)

Irregular Roadway Cross-Section

Coord No.	Station (ft)	Elevation (ft)
0	0.00	2014.00
1	150.00	2015.00
2	260.00	2015.60
3	351.00	2016.00
4	446.00	2017.00
5	530.00	2018.00
6	580.00	2019.00

Roadway Surface: Paved

Roadway Top Width: 80.00 ft

STANTEC
PROJECT: OCONALUFTEE
STANTEC JOB #: 234364224

CULVERT 7		BY	DATE
		COMPUTED	SMH 1/21/2026
		CHECKED	MIA 1/22/2026

SOIL TYPE	% SLOPE	LANDUSE	AREA (SF)	2, 10-YR STORM	CA	25-YR STORM	
				C		C	CA
B	---	LAWNS, HEAVY SOIL, AVG (2-5%)	62973.00	0.20	12594.60	0.20	12594.60
---	---	IMPERVIOUS	6192.00	0.90	5572.80	0.90	5572.80
TOTALS			69165.00		18167.40		18167.40

COMPOSITE C FACTOR (2, 10-YR): 0.26
COMPOSITE C FACTOR (25-YR): 0.26

TIME OF CONCENTRATION

Tc = 14.5 MIN

STORM EVENT (YR)	RAINFALL INTENSITY	DISCHARGE (CFS)
2	3.52	1.47
10	4.77	1.99
25	5.47	2.28

Project: Oconaluftee	Project #: 234264224
Subwatershed: Culvert 7	County: Swain
Calculations By: Susan Handley	1/21/2026
Checked By: Matthew Armstrong	1/22/2026

Shallow Concentrated Flow	Segment 3	Flow Type: Forest with heavy ground litter and hay meadows
		Shallow Concentrated Flow Length (ft): 53
		Slope of Land Surface (ft/ft): 0.039
		Average Velocity (ft/s): 0.50
		Travel Time (hrs): 0.03

TOTAL TRAVEL TIME (HRS) = 0.24
TOTAL TRAVEL TIME (MIN) = 14.50

[illegible]

SHEET FLOW ROUGHNESS EQUATIONS		
Manning's roughness coefficients for sheet flow (flow depth generally <0.1 ft)		
Surface Description	n	
Smooth surface (concrete, asphalt, gravel, or bare soil)	0.011	
Fallow (no residue)	0.05	
Cultivated Soils with residue cover < 20%	0.06	
Cultivated Soils with residue cover > 20%	0.17	
Short-Grass Prairie	0.15	
Dense Grasses	0.24	
Bermudagrass	0.41	
Range (natural)	0.13	
Woods with light underbrush	0.40	
Woods with dense underbrush	0.80	

[illegible]

HY-8 Culvert 7- Analysis Report

Crossing Discharge Data

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 0.00 cfs

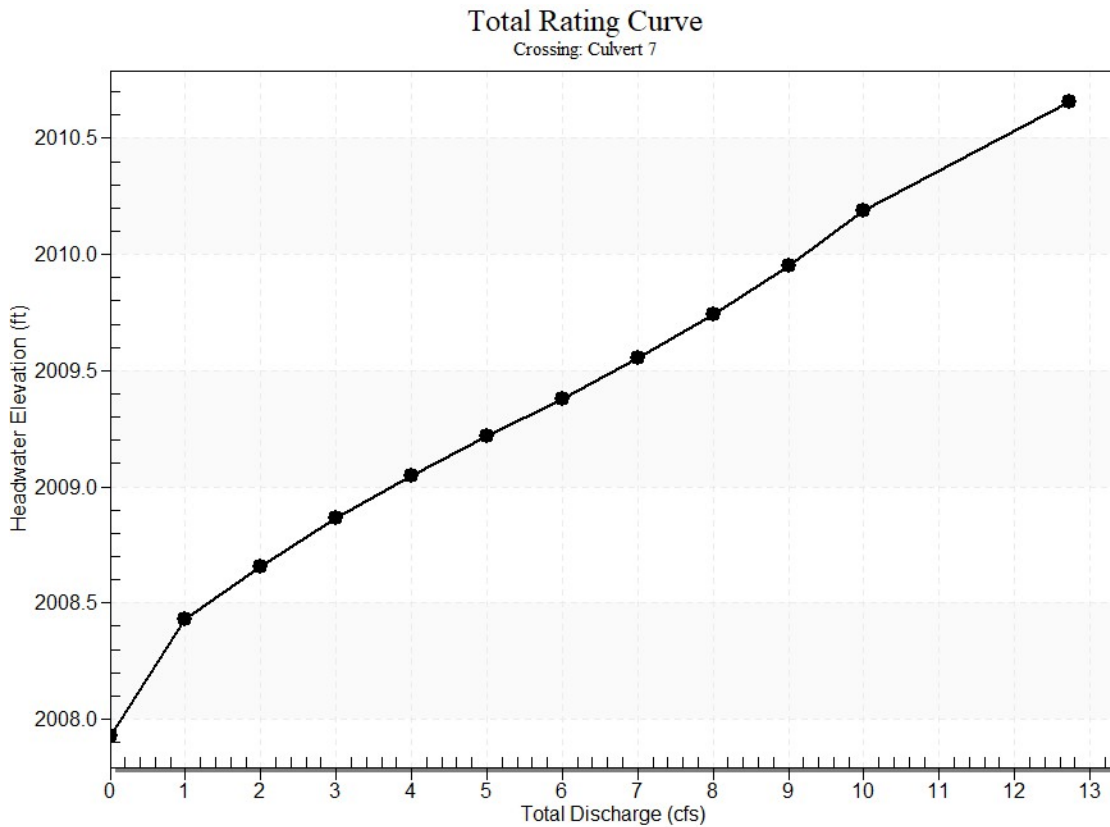
Design Flow: 1.99 cfs

Maximum Flow: 10.00 cfs

Table 1 - Summary of Culvert Flows at Crossing: Culvert 7

Headwater Elevation (ft)	Total Discharge (cfs)	Culvert 7 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
2007.93	0.00	0.00	0.00	1
2008.43	1.00	1.00	0.00	1
2008.65	1.99	1.99	0.00	1
2008.87	3.00	3.00	0.00	1
2009.05	4.00	4.00	0.00	1
2009.22	5.00	5.00	0.00	1
2009.38	6.00	6.00	0.00	1
2009.55	7.00	7.00	0.00	1
2009.74	8.00	8.00	0.00	1
2009.95	9.00	9.00	0.00	1
2010.19	10.00	10.00	0.00	1
2010.60	11.53	11.53	0.00	Overtopping

Rating Curve Plot for Crossing: Culvert 7



Culvert Data: Culvert 7

Table 1 - Culvert Summary Table: Culvert 7

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
0.00 cfs	0.00 cfs	2007.93	0.00	0.000	0-NF	0.00	0.00	0.00	0.00	0.00	0.00
1.00 cfs	1.00 cfs	2008.43	0.50	0.141	1-S2n	0.25	0.37	0.27	0.00	4.63	0.00
1.99 cfs	1.99 cfs	2008.65	0.72	0.325	1-S2n	0.36	0.53	0.39	0.00	5.39	0.00
3.00 cfs	3.00 cfs	2008.87	0.94	0.494	1-S2n	0.44	0.66	0.50	0.00	5.89	0.00
4.00 cfs	4.00 cfs	2009.05	1.12	0.659	1-S2n	0.51	0.77	0.58	0.00	6.27	0.00
5.00 cfs	5.00 cfs	2009.22	1.29	0.830	1-S2n	0.57	0.86	0.67	0.00	6.60	0.00
6.00 cfs	6.00 cfs	2009.38	1.45	1.008	1-S2n	0.63	0.95	0.74	0.00	6.89	0.00
7.00 cfs	7.00 cfs	2009.55	1.62	1.195	5-S2n	0.69	1.02	0.81	0.00	7.17	0.00
8.00 cfs	8.00 cfs	2009.74	1.81	1.392	5-S2n	0.75	1.10	0.88	0.00	7.43	0.00
9.00 cfs	9.00 cfs	2009.95	2.02	1.769	5-S2n	0.80	1.16	0.94	0.00	7.69	0.00
10.00 cfs	10.00 cfs	2010.19	2.26	1.957	5-S2n	0.85	1.22	1.00	0.00	7.95	0.00

Culvert Barrel Data

Culvert Barrel Type Straight Culvert

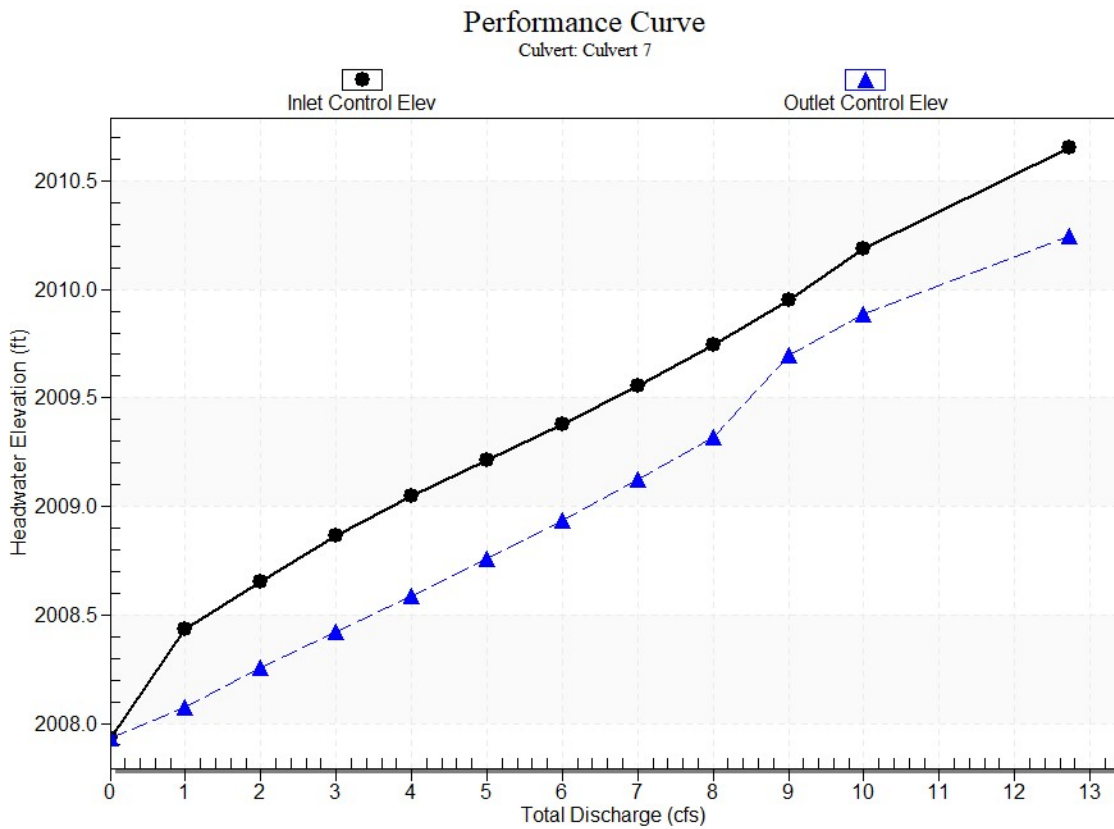
Inlet Elevation (invert): 2007.93 ft,

Outlet Elevation (invert): 2007.69 ft

Culvert Length: 12.00 ft,

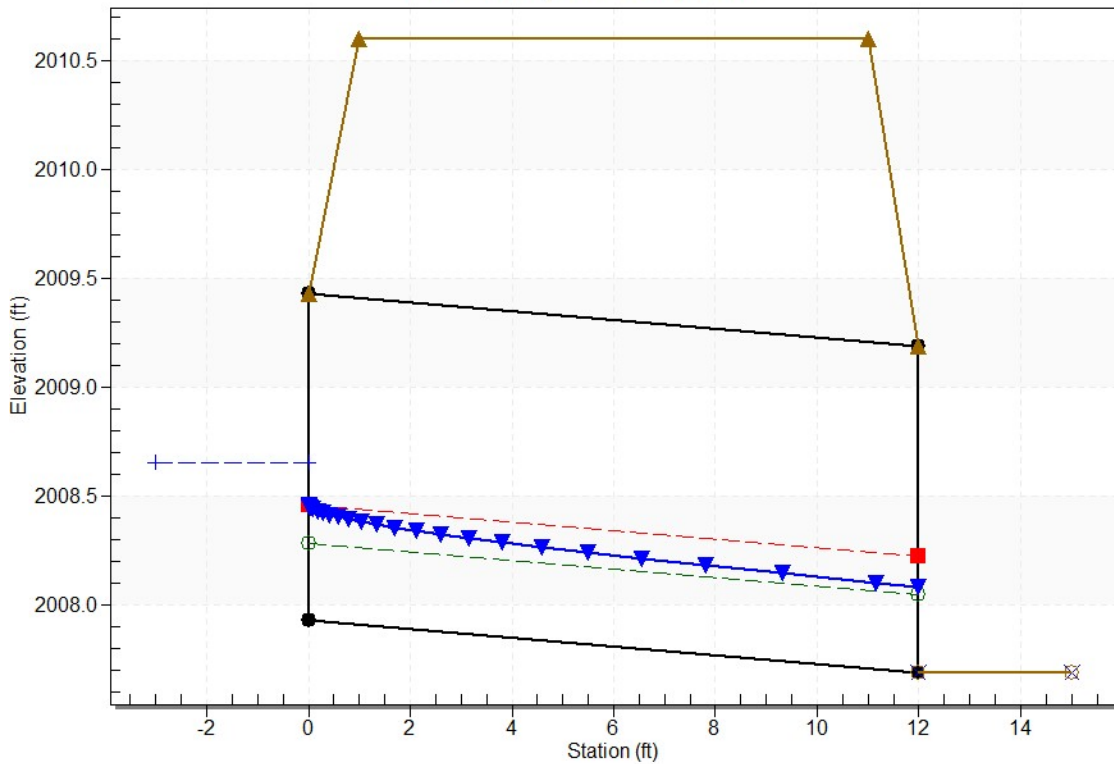
Culvert Slope: 0.0200

Culvert Performance Curve Plot: Culvert 7



Water Surface Profile Plot for Culvert: Culvert 7

Crossing - Culvert 7, Design Discharge - 2.0 cfs
Culvert - Culvert 7, Culvert Discharge - 2.0 cfs



Site Data - Culvert 7

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 2007.93 ft

Outlet Station: 12.00 ft

Outlet Elevation: 2007.69 ft

Number of Barrels: 1

Culvert Data Summary - Culvert 7

Barrel Shape: Circular

Barrel Diameter: 1.50 ft

Barrel Material: Concrete

Embedment: 0.00 in

Barrel Manning's n: 0.0120

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall

Inlet Depression: None

Tailwater Data for Crossing: Culvert 7

Table 2 - Downstream Channel Rating Curve (Crossing: Culvert 7)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)
0.00	2007.69	0.00
1.00	2007.69	0.00
1.99	2007.69	0.00
3.00	2007.69	0.00
4.00	2007.69	0.00
5.00	2007.69	0.00
6.00	2007.69	0.00
7.00	2007.69	0.00
8.00	2007.69	0.00
9.00	2007.69	0.00
10.00	2007.69	0.00

Tailwater Channel Data - Culvert 7

Tailwater Channel Option: Enter Constant Tailwater Elevation

Constant Tailwater Elevation: 2007.69 ft

Roadway Data for Crossing: Culvert 7

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 30.00 ft

Crest Elevation: 2010.60 ft

Roadway Surface: Gravel

Roadway Top Width: 10.00 ft

STANTEC
PROJECT: OCONALUFTEE
STANTEC JOB #: 234364224

CULVERT 8		BY	DATE
	COMPUTED	SMH	1/21/2026
	CHECKED	MIA	1/22/2026

SOIL TYPE	% SLOPE	LANDUSE	AREA (SF)	2, 10-YR STORM	25-YR STORM		
				C	CA	C	CA
---	---	IMPERVIOUS	1408.00	0.90	1267.20	0.90	1267.20
B	---	WOODED AREAS	1675.00	0.15	251.25	0.15	251.25
TOTALS			3083.00		1518.45		1518.45

COMPOSITE C FACTOR (2, 10-YR): 0.49
COMPOSITE C FACTOR (25-YR): 0.49

TIME OF CONCENTRATION

Tc = 6.0 MIN

STORM EVENT (YR)	RAINFALL INTENSITY	DISCHARGE (CFS)
2	4.86	0.17
10	6.55	0.23
25	7.52	0.26

HY-8 Culvert 8- Analysis Report

Crossing Discharge Data

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 0.00 cfs

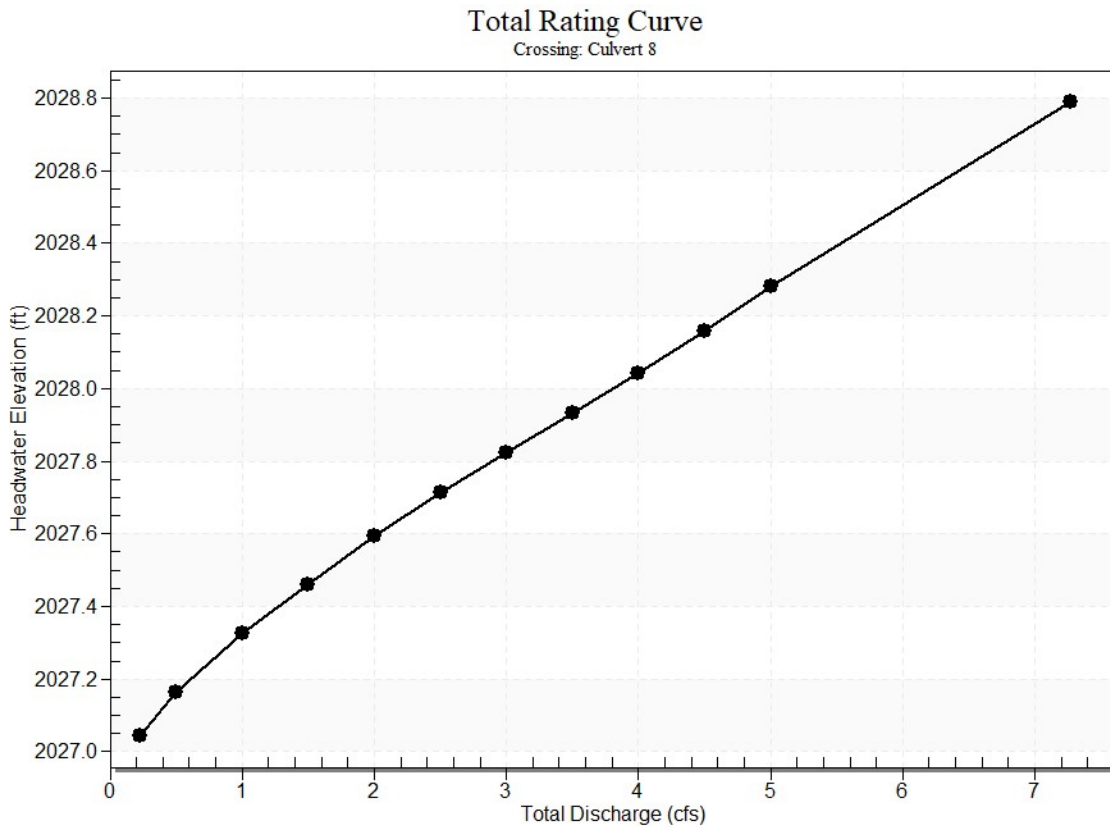
Design Flow: 0.23 cfs

Maximum Flow: 5.00 cfs

Table 1 - Summary of Culvert Flows at Crossing: Culvert 8

Headwater Elevation (ft)	Total Discharge (cfs)	Culvert 8 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
2027.04	0.23	0.23	0.00	1
2027.17	0.50	0.50	0.00	1
2027.33	1.00	1.00	0.00	1
2027.46	1.50	1.50	0.00	1
2027.59	2.00	2.00	0.00	1
2027.71	2.50	2.50	0.00	1
2027.82	3.00	3.00	0.00	1
2027.93	3.50	3.50	0.00	1
2028.04	4.00	4.00	0.00	1
2028.16	4.50	4.50	0.00	1
2028.28	5.00	5.00	0.00	1
2028.75	6.58	6.58	0.00	Overtopping

Rating Curve Plot for Crossing: Culvert 8



Culvert Data: Culvert 8

Table 1 - Culvert Summary Table: Culvert 8

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
0.23 cfs	0.23 cfs	2027.04	0.24	0.0*	1-S2n	0.11	0.19	0.11	0.00	4.17	0.00
0.50 cfs	0.50 cfs	2027.17	0.37	0.0*	1-S2n	0.16	0.28	0.17	0.00	5.06	0.00
1.00 cfs	1.00 cfs	2027.33	0.53	0.0*	1-S2n	0.23	0.39	0.24	0.00	5.98	0.00
1.50 cfs	1.50 cfs	2027.46	0.66	0.0*	1-S2n	0.28	0.48	0.30	0.00	6.53	0.00
2.00 cfs	2.00 cfs	2027.59	0.79	0.0*	1-S2n	0.33	0.56	0.36	0.00	6.93	0.00
2.50 cfs	2.50 cfs	2027.71	0.91	0.112	1-S2n	0.37	0.63	0.41	0.00	7.24	0.00
3.00 cfs	3.00 cfs	2027.82	1.02	0.228	1-S2n	0.40	0.70	0.45	0.00	7.51	0.00
3.50 cfs	3.50 cfs	2027.93	1.13	0.348	1-S2n	0.44	0.75	0.49	0.00	7.74	0.00
4.00 cfs	4.00 cfs	2028.04	1.24	0.473	1-S2n	0.47	0.81	0.54	0.00	7.96	0.00
4.50 cfs	4.50 cfs	2028.16	1.36	0.605	5-S2n	0.50	0.86	0.58	0.00	8.15	0.00
5.00 cfs	5.00 cfs	2028.28	1.48	0.742	5-S2n	0.53	0.91	0.61	0.00	8.34	0.00

* Full Flow Headwater elevation is below inlet invert.

Culvert Barrel Data

Culvert Barrel Type Straight Culvert

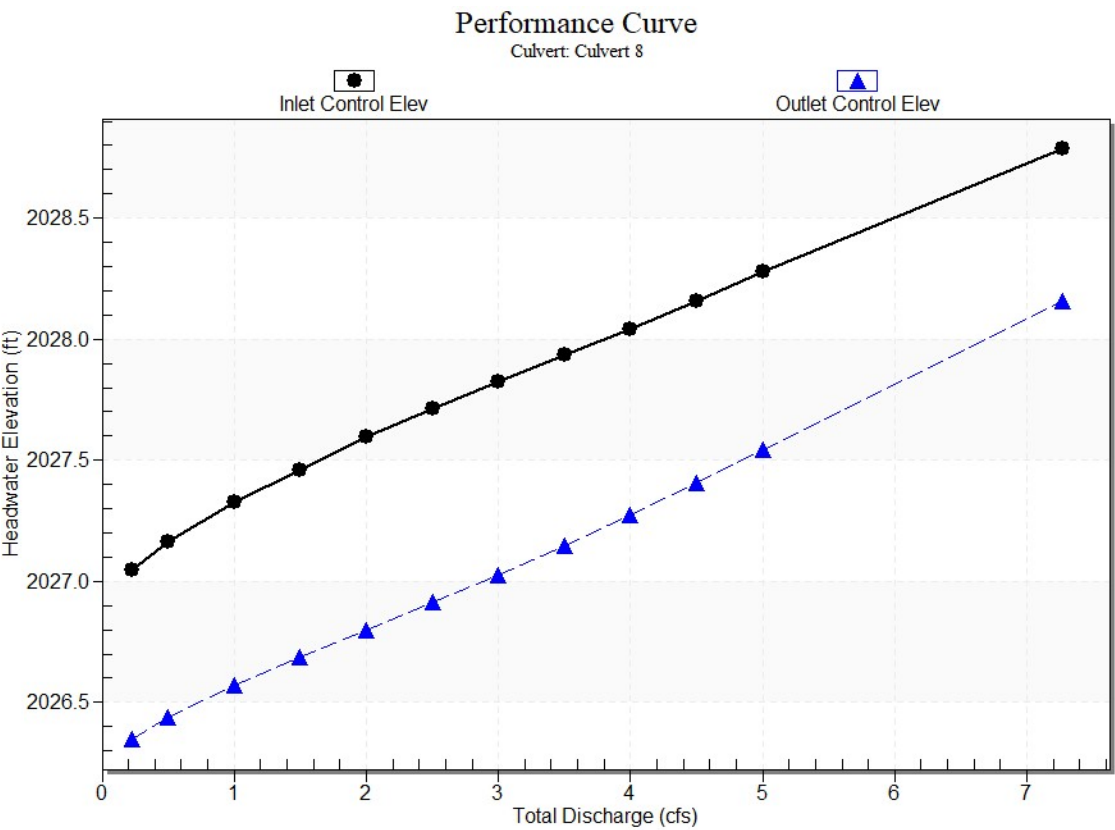
Inlet Elevation (invert): 2026.80 ft,

Outlet Elevation (invert): 2026.16 ft

Culvert Length: 17.51 ft,

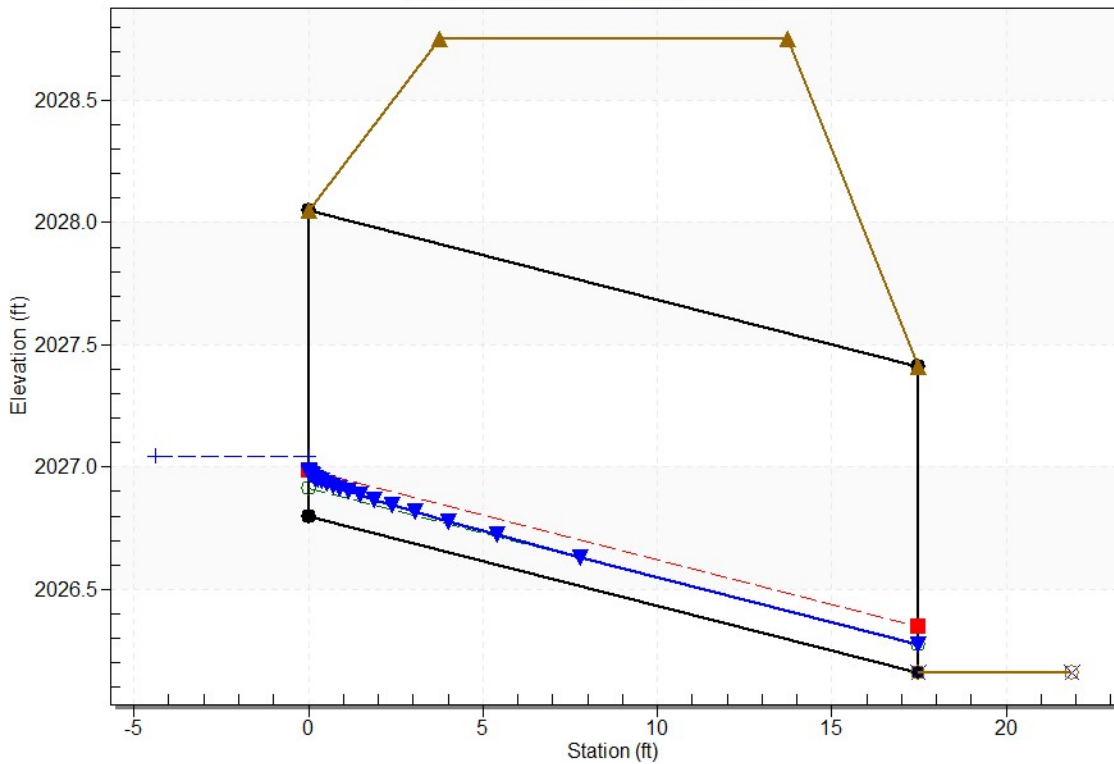
Culvert Slope: 0.0366

Culvert Performance Curve Plot: Culvert 8



Water Surface Profile Plot for Culvert: Culvert 8

Crossing - Culvert 8, Design Discharge - 0.2 cfs
Culvert - Culvert 8, Culvert Discharge - 0.2 cfs



Site Data - Culvert 8

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 2026.80 ft

Outlet Station: 17.50 ft

Outlet Elevation: 2026.16 ft

Number of Barrels: 1

Culvert Data Summary - Culvert 8

Barrel Shape: Circular

Barrel Diameter: 1.25 ft

Barrel Material: Concrete

Embedment: 0.00 in

Barrel Manning's n: 0.0120

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall

Inlet Depression: None

Tailwater Data for Crossing: Culvert 8

Table 2 - Downstream Channel Rating Curve (Crossing: Culvert 8)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)
0.23	2026.16	0.00
0.50	2026.16	0.00
1.00	2026.16	0.00
1.50	2026.16	0.00
2.00	2026.16	0.00
2.50	2026.16	0.00
3.00	2026.16	0.00
3.50	2026.16	0.00
4.00	2026.16	0.00
4.50	2026.16	0.00
5.00	2026.16	0.00

Tailwater Channel Data - Culvert 8

Tailwater Channel Option: Enter Constant Tailwater Elevation

Constant Tailwater Elevation: 2026.16 ft

Roadway Data for Crossing: Culvert 8

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 30.00 ft

Crest Elevation: 2028.75 ft

Roadway Surface: Gravel

Roadway Top Width: 10.00 ft

APPENDIX D

BUOYANCY COMPUTATIONS

Displaced Water Weight

$W_w = \frac{\pi}{4} (B_c^2) 62.4$

where

W_w = weight of displaced water per linear foot, pounds,
 B_c = outside pipe diameter, feet.

$B_c = 18" + 2.5" + 2.5" = 23" \quad 1.917 \text{ ft}$
 $Ww = (3.14/4) * (1.917^2) * 62.4 \quad \text{lbs/lf}$
 180.04 lbs/lf

Length= 16 lf

Weight Displaced per Pipe

2880.63 lbs

Pipe Weight

$W_p = \frac{\pi}{4} (B_c^2 - D^2) 150$

where

W_p = weight of pipe in pounds per linear foot.
 B_c = outside pipe diameter, feet.
 D = inside pipe diameter, feet

$D = 18" \quad 1.5 \text{ ft}$
 $Wp = (3.14/4) * (1.917^2 - 1.5^2) * 150$
 167.72 lbs/lf

Length= 16 lf

Weight per Pipe

2683.44 lbs

Upward Forces

- 2880.63 lbs

Downward Forces

+ 2683.44 lbs
+ 690.6375

Net

Sum 2880.63 3374.08 493.45 lbs

Downward forces are greater than upward forces.
Pipe should not float.

Backfill Weight

$w_1 = w - \left[\frac{w}{(SG \times 62.4)} \times 62.4 \right]$

where;

w_1 = average unit weight of inundated backfill, pounds per cubic foot.
 w = average unit weight of surface dry backfill, pounds per cubic foot.
 SG = specific gravity of backfill.

$w = 90 \text{ lbs/cf}$ Visitor Center Geotech Report
 $SG = 2.65$ US National Cooperative Soil Survey

$w_1 = 90 - [90 / (2.65 * 62.4) * 62.4]$
 56.03774 lbs/cf

$W_1 = w_1 (0.1073 B_c^2 + H_i B_c) \quad (5)$

where;

W_1 = weight of inundated backfill directly over the pipe, pounds per linear foot.
 H_i = depth of inundated backfill above top of pipe, feet.

$H_1 = 1 \text{ ft}$ Conservative cover

$W_1 = 129.4945 \text{ lbs/lf}$

Length= 8 lf Conservatively using the length only under the trail

Weight Inundated Backfill Over Pipe=

1035.956 lbs

Weight Dry Backfill Over Pipe=

$W_D = w (H - H_i) B_c \quad (6)$

where;

W_D = weight of dry backfill directly over the pipe, pounds per linear foot.
 H = depth from top of pipe to surface of backfill, feet.

$H = H_1$

$WD = 0 \text{ lbs}$

$Wb = W_1 + WD$

$Wb = 1035.956 \text{ lbs}$

Factor of Safety (FS) 1 if Weight of Pipe is greater than Displaced Water Weight
1-1.5 if dependent on backfill forces

Used FS= 1.5 Most Conservative

$Wb/FS = 690.6375 \text{ lbs}$

Flotation of Circular Concrete Pipe

There are several installation conditions where there is the possibility that concrete pipe may float even though the density of concrete is approximately 2.4 times that of water. Some of these conditions are: the use of flooding to consolidate backfill; pipelines in areas which will be inundated, such as, a flood plain or under a future man-made lake; subaqueous pipelines; flowable fill installations; and pipelines in areas with a high groundwater table. When such conditions exist, flotation probability should be checked.

FLOTATION FACTORS

The buoyancy of concrete pipe depends upon the weight of the pipe, the weight of the volume of water displaced by the pipe, the weight of the liquid load carried by the pipe and the weight of the backfill. As a conservative practice in analysis, the line should be considered empty so the weight of any future liquid load is then an additional safety factor.

Pipe Weights

The average density of concrete is 150 pounds per cubic foot and the approximate weight per linear foot of circular concrete pipe may be calculated by the following equation:

$$W_p = \frac{\pi}{4} (B_c^2 - D^2) 150 \quad (1)$$

where

W_p = weight of pipe in pounds per linear foot.

B_c = outside pipe diameter, feet.

D = inside pipe diameter, feet

Average weights in pounds per linear foot for ASTM C14 Nonreinforced Concrete Sewer, Storm Drain and Culvert Pipe and ASTM C76 Reinforced Concrete Culvert, Storm Drain and Sewer Pipe are given in Tables I and II. Most pipe manufacturers publish data that tabulates product dimensions and weight. The data from these publications should be used when available.

Water Density

The density of fresh water is 62.4 pounds per cubic foot for normal ranges of ambient temperature. The av-

erage density of seawater is 64.0 pounds per cubic foot. In this Design Data, only fresh water is considered, but local conditions should be investigated when seeking solutions for specific projects.

Displaced Water Weight

When water is displaced a buoyant or upward force exists, and, if the buoyant force is greater than the weight of the object displacing the water, flotation will occur. The weight of fresh water displaced per linear foot of circular pipe can be calculated by the following equation:

$$W_w = \frac{\pi}{4} (B_c^2) 62.4 \quad (2)$$

where

W_w = weight of displaced water per linear foot, pounds,

B_c = outside pipe diameter, feet.

The average weights of the volume of fresh water displaced per linear foot of C14 and C76 pipe are presented in Tables 3 and 4.

Backfill Weight

The weight of the backfill directly over the pipe assists in holding the pipe down. The unit weight of compacted backfill material varies with specific gravity, the grain size, and the degree of compaction. For preliminary computations, however, average values for surface dry density and specific gravity of backfill materials are of sufficient accuracy.

The unit weight of inundated backfill is equal to the surface dry density of the backfill minus the weight of water displaced by the solid particles and can be calculated as followed:

$$w_i = w - \left[\frac{w}{(SG \times 62.4)} \times 62.4 \right] \quad (3)$$

which reduces to:

$$w_i = w - \left[\frac{W}{SG} \right] \text{ or } W \left(1 - \frac{1}{SG} \right) \quad (4)$$

where;

w_I = average unit weight of inundated backfill,
pounds per cubic foot.

w = average unit weight of surface dry backfill,
pounds per cubic foot.

SG = specific gravity of backfill.

Figure 1 illustrates the backfill over the pipe and the different volumes to be considered. The volume of backfill over the haunches from the springline to the top of the pipe is equal to $0.1073 B_C^2$ cubic feet per linear foot of pipe. The volume of backfill from the top of the pipe to the level of inundation equals $H_I B_C$ cubic feet per linear foot of pipe. Therefore, the weight of inundated backfill per linear foot of pipe acting downward on the pipe can be calculated as follows:

$$W_I = w_I (0.1073 B_C^2 + H_I B_C) \quad (5)$$

where;

W_I = weight of inundated backfill directly over the pipe, pounds per linear foot.

H_I = depth of inundated backfill above top of pipe, feet.

The weight of dry backfill above the water level, if any, per linear foot of pipe acting downward on the pipe can be calculated as follows:

$$W_D = w (H - H_I) B_C \quad (6)$$

where;

W_D = weight of dry backfill directly over the pipe, pounds per linear foot.

H = depth from top of pipe to surface of backfill, feet.

Therefore, the total weight of backfill per linear foot of pipe acting downward on the pipe is the algebraic sum of Equations 5 and 6 as follows:

$$W_B = W_I + W_D \quad (7)$$

where;

W_B = total weight of backfill directly over the pipe, pounds per cubic ft.

FACTOR OF SAFETY

Construction soils are noted for lack of uniformity. Depending on the extent of information of the proposed backfill material and site condition, a factor of safety ranging between 1.0 and 1.5 should be applied. This factor of safety shall be applied to decrease the downward force of the backfill. Generally, if the weight of the structure

is the primary force resisting flotation than a safety factor of 1.0 is adequate. However, if friction or cohesion are the primary forces resisting flotation, then a higher safety factor would be more appropriate to account for the variability of the soil properties.

PREVENTIVE PROCEDURES

If the total weight of the pipe and backfill is not adequate to prevent flotation of the pipe, preventive nonflotation procedures, such as additional backfill, mechanical anchorage, heavier pipes, or combinations of these would be required. Some of the commonly used methods are:

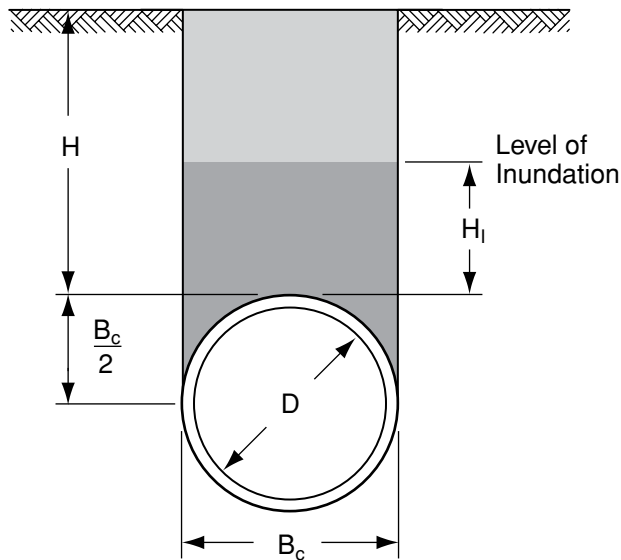
1. Increased wall thickness.
2. Precast or cast-in-place concrete collars.
3. Precast or cast-in-place concrete blocks, fastened by suitable means.
4. Pipe strapped to piles or concrete anchor slab.
5. Additional backfill.

When computing the volume of concrete required per linear foot for pipe anchorage, remember that concrete which weighs 150 pounds per cubic foot in air, weighs only 87.6 pounds per cubic foot under water.

DESIGN PROCEDURE

A suggested seven step logical procedure is presented for determining the degree of buoyancy of empty concrete pipeline and possible measures needed to prevent flotation. Downward forces are considered positive and upward forces are considered negative.

1. Determine the downward force of the pipe weight in pounds per linear foot.
2. Determine the buoyant upward force of the weight of the displaced water in pounds per linear foot of pipe.
3. Find the algebraic sum of the forces determined in Steps 1 and 2. If the resultant force is positive, the pipe will not float. If the resultant force is negative proceed with Step 4.
4. Determine the downward force of the total weight of backfill in pounds per linear foot of pipe.
5. Apply a factor of safety to determine the decreased total weight of backfill.
6. Find the algebraic sum of the downward force determined in Step 5 and the excess upward force determined in Step 3. If the resultant force is positive, the pipe will not float. If the resultant force is negative, proceed with Step 7.
7. Select and analyze the procedures to be used to prevent flotation.

Figure 1 Backfill Volumes Over Pipe**Table 1 Dimensions and Approximate Weights of Nonreinforced Concrete Pipe**

ASTM C 14 - Nonreinforced Sewer, and Culvert Pipe, Bell and Spigot Joint						
Internal Diameter, Inches	Class 1		Class 2		Class 3	
	Minimum Wall Thickness, Inches	Average Weight, Pounds Per Foot	Minimum Wall Thickness, Inches	Average Weight, Pounds Per Foot	Minimum Wall Thickness, Inches	Average Weight, Pounds Per Foot
4	5/8	9.5	3/4	13	3/4	13
6	5/8	17	3/4	20	7/8	21
8	3/4	27	7/8	31	1-1/8	36
10	7/8	37	1	42	1-1/4	50
12	1	50	1-3/8	68	1-3/4	90
15	1-1/4	78	1-5/8	100	1-7/8	120
18	1-1/2	105	2	155	2-1/4	165
21	1-3/4	159	2-1/4	205	2-3/4	260
24	2-1/8	200	3	315	3-3/4	350
27	3-1/4	390	4	450	3-7/8	450
30	3-1/2	450	4-1/4	54	4-1/4	540
33	3-3/4	520	4-1/2	620	4-1/2	620
36	4	580	4-3/4	700	4-3/4	700

These tables are based on concrete weighing 150 pounds per cubic foot and will vary with heavier or lighter weight concrete

Note: Pipe listed above the heavy black line will not float in sea water and need not be considered.

Example 1**Given:**

A 72-inch diameter, wall B, ASTM C76 reinforced concrete pipe is to be installed in a trench in a sandy coastal area with 8 feet of backfill over the

Table 2 Dimensions and Approximate Weights of Circular Concrete Pipe

ASTM C 76 - Reinforced Concrete Culvert, Storm Drain and Sewer Pipe						
Internal Diameter, Inches	Wall A		Wall B		Wall C	
	Minimum Wall Thickness, Inches	Average Weight, Pounds Per Foot	Minimum Wall Thickness, Inches	Average Weight, Pounds Per Foot	Minimum Wall Thickness, Inches	Average Weight, Pounds Per Foot
12	1-3/4	79	2	93	-	-
15	1-7/8	103	2-1/4	127	-	-
18	2	131	2-1/2	168	-	-
21	2-1/4	171	2-3/4	214	-	-
24	2-1/2	217	3	264	3-3/4	366
27	2-5/8	255	3-1/4	322	4	420
30	2-3/4	295	3-1/2	384	4-1/4	476
33	2-7/8	336	3-1/4	451	4-1/2	552
36	3	383	4	524	4-3/4	654
42	3-1/2	520	4-1/2	686	5-1/4	811
48	4	683	5	867	5-3/4	1011
54	4-1/2	864	5-1/2	1068	6-1/4	1208
60	5	1064	6	1295	6-3/4	1473
66	5-1/2	1287	6-1/2	1542	7-1/4	1735
72	6	1532	7	1811	7-3/4	2015
78	6-1/2	1797	7-1/2	2100	8-1/4	2410
84	7	2085	8	2409	8-3/4	2660
90	7-1/2	2395	8-1/2	2740	9-1/4	3020
96	8	2710	9	3090	9-3/4	3355
102	8-1/2	3078	9-1/2	3480	10-1/4	3760
108	9	3446	10	3865	10-3/4	4160
114	9-1/2	3840	10-1/2	4278	11-1/4	4611
120	10	4263	11	4716	11-3/4	5066
126	10-1/2	4690	11-1/2	5175	12-1/4	5542
132	11	5148	12	5655	12-3/4	6040
138	11-1/2	5627	12-1/2	6156	13-1/4	6558
144	12	6126	13	6679	13-3/4	7098
150	12-1/2	6647	13-1/2	7223	14-1/4	7659
156	13	7190	14	7789	14-3/4	8242
162	13-1/2	7754	14-1/2	8375	15-1/4	8846
168	14	8339	15	8983	15-3/4	9471
174	14-1/2	8945	15-1/2	9612	16-1/4	10,117
180	15	9572	16	10,263	16-3/4	10,785

These tables are based on concrete weighing 150 pounds per cubic foot and will vary with heavier or lighter weight concrete

Note: Pipe listed above the heavy black line will not float in sea water and need not be considered.

top of the pipe. Since the groundwater table is near the ground surface in this area and the natural soil is basically sand, flooding of the backfill for consolidation is permitted. The sandy soil is assumed to have a surface dry density of 110 pounds per cubic foot and a specific gravity of 2.65.

Table 3 Approximate Weight of Water Displaced by Circular Nonreinforced Concrete Pipe

ASTM C 14 - Nonreinforced Concrete Pipe, Bell and Spigot Joint			
Internal Diameter, Inches	Weight of Water Displaced, Pounds Per Linear Foot		
	Class 1	Class 2	Class 3
4	9.3	10.7	10.7
6	19.3	20.6	21.0
8	33	35	37
10	49	51	55
12	70	77	86
15	109	118	127
18	154	174	179
21	216	235	258
24	281	327	342
27	422	461	509
30	516	558	558
33	617	664	664
36	729	779	779

Note: Pipe listed above the heavy black line will not float in sea water.

Find:

If the pipe would float under conditions of complete backfill, determine the procedures necessary to prevent flotation and what height of backfill is necessary to prevent flotation.

Solution:

1. Weight of pipe

From Table 2, WP = + 1811 pounds per linear foot (downward force).

2. Weight of displaced water.

From Table 4, WW = - 2519 pounds per linear foot of pipe (upward force).

3. Algebraic sum of Steps 1 and 2.

$WP + WW = + 1811 + (-2519) = -708$ pounds per linear foot of pipe (upward force).

The resultant force is upward, therefore proceed to Step 4.

4. Total weight of backfill.

Weight of inundated backfill:

Given the compacted surface dry density of sand is 110 pounds per cubic foot with a specific gravity of 2.65.

From Equation 4, the unit weight of inundated back-

fill equals, $wl = 110 \left(1 - \frac{1}{2.65} \right) = 68$ pounds per cubic foot.

Table 4 Dimensions and Approximate Weight of Reinforced Circular Concrete Pipe

ASTM C 76 - Reinforced Concrete Pipe, Tongue and Groove Joint			
Internal Diameter, Inches	Weight of Water Displaced, Pounds Per Linear Foot		
	Wall A	Wall B	Wall C
12	82	87	-
15	119	130	-
18	164	181	-
21	222	239	-
24	287	306	339
27	355	381	418
30	429	465	505
33	511	560	600
36	600	660	704
42	816	885	940
48	1069	1143	1206
54	1351	1440	1504
60	1666	1764	1842
66	2020	2122	2207
72	2401	2519	2605
78	2786	2944	3043
84	3271	3401	3508
90	3752	3899	4005
96	4266	4423	4545
102	4823	4980	5109
108	5403	5580	5706
114	6017	6203	6341
120	6674	6863	7008
126	7354	7556	7709
132	8067	8282	8443
138	8826	9042	9210
144	9906	9836	10,010
150	10,418	10,662	10,844
156	11,278	11,523	11,711
162	12,157	12,416	12,612
168	13,069	13,343	13,546
174	14,031	14,303	14,513
180	15,009	15,296	15,513

Note: Pipe listed above the heavy black line will not float in sea water.

From Equation 5, the weight of inundated backfill equals, $WI = 68 [0.1073 (7.17)^2 + (8 \times 7.17)] = + 4276$ pounds per linear foot of pipe (downward force).

Weight of dry backfill:

Since the groundwater table was assumed to be at the ground surface, there would be no additional downward force.

Total weight of backfill:

From Equation 7, the total weight of backfill per linear foot of pipe equals, $WB = +4267 + 0 = + 4276$ pounds per linear foot of pipe (downward force)

5. Application of Factor of Safety.

Since no precise information is available on the density and the specific gravity of the sandy backfill, a Factor of Safety of 1.25 will be used to reduce the assumed total weight of the backfill.

$$\frac{W_B}{F.S.} = \frac{+ 4276}{1.25} = + 3421 \text{ pounds (downward force)}$$

6. Algebraic sum of Steps 3 and 5.

From Step 3, the resultant upward force is -708 and from Step 5, the downward force is $+ 3421$, which produces a resultant downward force of $+ 2713$ pounds per linear foot of pipe.

Answer:

Therefore, the pipe will not float when backfill is completed, additional procedures described in Step 7 are not required. However, to find the required depth of inundated backfill necessary to prevent flotation during construction use Equation 5. Solve for H_I by setting the algebraic sum of W_I , the weight of inundated backfill over the pipe, decreased by the factor of safety, and the resultant upward force determined in Step 2 equal to zero, as follows:

$$\frac{+68 [0.1073 (7.17)^2 + (H_I \times 7.17)]}{1.25} + (-708) = 0$$

$H_I = 1.05$ ft. above the top of the pipe

Therefore, a minimum depth of 1 foot 1-inch of inundated backfill above the top of the pipe is required to prevent flotation of the pipe.

Example 2

Given:

A 144-inch diameter ASTM C76 reinforced concrete pipe is to be installed as an outfall line for a wastewater treatment plant. The line is to be installed underneath the flood plain of the stream and will have only one foot of cover over the top of the pipe for a portion of its length. It will have a flap gate at the discharge end to prevent flood water and debris from entering the pipe. Soil tests have determined that the average surface dry density of the in-place clay backfill is 123 pounds per cubic foot with specific gravity of 2.66.

Find:

If the pipe will float and if required, the volume of concrete per linear foot of pipe expressed as ad-

ditional wall thickness necessary to prevent flotation.

Solution:

1. Weight of pipe.

From Table 2, $WP = + 6126$ pounds per linear foot (downward force).

2. Weight of displaced water.

From Table 4, $WW = -9606$ pounds per linear foot of pipe (upward force).

3. Algebraic sum of Steps 1 and 2.

$WP + WW = +6126 + (-9606) = - 3480$ pounds per linear foot of pipe (negative, upward force)

The resultant force is upward, therefore, proceed to Step 4.

4. Total weight of backfill.

Weight of inundated backfill:

Given, the average surface dry density of the clay backfill is 123 pounds per cubic foot with a specific gravity of 2.66

From Equation 4, the unit weight of inundated

backfill equals, $WI = 123 (1 - \frac{1}{2.66}) + 77$ pounds per cubic foot

From Equation 5, the weight of inundated backfill equals, $WI = 77 [0.1073 (14)^2 + (1 \times 14)] = +2697$ pounds per linear foot of pipe (downward force).

Weight of dry backfill:

Since the site is a floodplain, the backfill is considered completely inundated, therefore there is no additional downward force.

Total weight of backfill:

From Equation 7, the total weight of backfill per linear foot of pipe equals, $WB = +2697 + 0 = +2697$ pounds per linear foot of pipe (downward force).

5. Application of Factor of Safety

Since the soils information is based on tests, a Factor of Safety of 1.15 will be used to decrease the downward force of the inundated backfill.

$$\frac{W_B}{F.S.} = \frac{+ 2697}{1.15} = + 2345 \text{ pounds (downward force)}$$

6. Algebraic sum of Steps 3 and 5

From Step 3, the resultant upward force is -3480 pounds and from Step 5, the downward force is $+2345$ pounds, which produces a resultant upward

force of -1135 pounds per linear foot of pipe. The pipe will float, therefore proceed to Step 7.

7. Analysis of method to prevent flotation.

As given, the method will be to increase the wall thickness of the pipe. The algebraic sum of the unbalanced upward force of -1135 pounds per linear foot pipe as determined in Step 6 must equal the weight of the additional wall thickness (t_x) required, and may be expressed in the following quadratic equation:

$$\pi (B_c + t_x) t_x \gamma_c + F_B = 0, \text{ or solving for } t_x$$

$$t_x = \frac{-B_c \pm \sqrt{B_c^2 - \frac{4F_B}{\gamma_c \pi}}}{2}$$

where;

t_x = additional wall thickness in feet.

B_c = density of submerged concrete, +87.6 pounds per cubic foot.

F_B = upward force in pounds per linear foot of pipe.

Substitution appropriate values in the above equation:

$$t_x = \frac{-14 + \sqrt{(14)^2 - \frac{4(-1135)}{87.6 (3.14)}}}{2}$$

$$t_x = +0.29 \text{ feet}$$

Since negative values have no significance, use $t_x = 0.29$ feet or 3.5 inches.

Answer:

Therefore, 3.5 inches of additional wall thickness are required to prevent flotation of the pipe in this installation.

EXAMPLE 3

Given:

The 144-inch diameter pipe in Example 2 submerged in a fresh water lake with no backfill placed over it.

Find:

The dimensions per linear foot of a concrete anchor slab required to prevent flotation.

Solution:

1. Steps 1, 2, and 3 are the same as Example 2, leaving -3480 pounds per linear foot of pipe upward force.

Since the resultant force is upward, proceed to Step 4.

4. Total weight of backfill.

Since the pipe is submerged with no backfill placed over it, there is no additional downward force.

5. Application of Factor of Safety.

Since this pipe is submerged in water only, a Factor of Safety of 1.0 is used.

6. Algebraic sum of Steps 3 and 5.

From Step 3, the resultant upward force is -3480 pounds per linear foot of pipe. The pipe will float, therefore proceed to Step 7.

7. Analysis of method to prevent flotation.

As stated, determine the required dimensions of a concrete anchor slab linear foot of pipe.

To prevent flotation, the algebraic sum of the submerged weight of the anchor slab per linear foot and, the resultant upward force per linear foot must equal zero, and may be expressed in equation form as follows:

$$F_B = \gamma_c (bd \times 1)$$

where;

F_B = The total negative (buoyant) force in pounds.

b = Width of concrete slab, feet.

d = Depth of concrete slab, feet.

1 = One linear foot.

γ_c = Submerged weight of concrete per cubic foot.

Substituting appropriate values in the above equation:

$$87.6 (bd \times 1) = 3480$$

$$\text{and } b \times d \times 1 \text{ ft.} = 39.37 \text{ ft.}^3$$

Since the outside diameter of the pipe, BC , is approximately 14 ft. selecting this dimension for b , d will then be:

$$d = \frac{39.37}{14} = 2.84 \text{ ft.}$$

Answer:

Therefore, a concrete anchor slab, 14 feet wide and 2.84 feet deep will prevent flotation of the pipe, assuming proper anchorage of the pipe to the slab.