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NORMANDY RESERVOIR
OPTIMIZATION OF RESERVOIR RELEASES

DRAFT ENVIRONMENTAL ASSESSMENT

Bedford, Coffee, Marshall, and Maury Counties, Tennessee

Prepared by
TENNESSEE VALLEY AUTHORITY
Knoxville, Tennessee

In partnership with the
TENNESSEE DUCK RIVER DEVELOPMENT AGENCY

May 2024

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Symbols, Acronyms, and Abbreviations

ARPA	Archaeological Resource Protection Act
cfs	cubic feet per second
CCC	Criterion Continuous Concentration
CDC	Center for Disease Control
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CMC	Criterion Maximum Concentration
CRMRC	Cumberlandian Region Mollusk Restoration Committee
DMP	Drought Management Plan
DO	Dissolved oxygen
DRM	Duck River mile
DRUC	Duck River Utility Commission
EA	Environmental Assessment
EIS	Environmental Impact Statement
ESA	Endangered Species Act
FONSI	Finding of No Significant Impact
ft	feet
GHG	Greenhouse gas
IPaC	Information for Planning and Consultation
IPCC	Intergovernmental Panel on Climate Change
LAA	Likely to Adversely Affect
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NLAA	Not Likely to Adversely Affect
NRHP	National Register of Historic Places
NWI	National Wetland Inventory
ONRR	Optimization of Normandy Reservoir Releases
STP	Sewage treatment plant
TDEC	Tennessee Department of Environment and Conservation
TDRDA	Tennessee Duck River Development Agency
TNC	The Nature Conservancy
TVA	Tennessee Valley Authority
TWRA	Tennessee Wildlife Resources Agency
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WWTP	Wastewater treatment plant

CHAPTER 1 - PURPOSE AND NEED

1.1 Introduction

Normandy Reservoir was constructed in 1976 by the Tennessee Valley Authority (TVA) to provide recreation, water supply, water quality benefits and flood control to the watershed comprising Bedford, Coffee, Marshall, Maury, and southern Williamson counties, collectively referred to as "the region" (Figure 1). TVA also manages Normandy Reservoir and its associated dam to meet State designated beneficial uses of the downstream Duck River, including water supplies (industrial and domestic), supporting aquatic biota and wildlife, irrigation and livestock watering, and recreation.

Normandy Reservoir, and the Duck River which lies downstream of Normandy Dam, serve as critical sources of water for communities within southern Middle Tennessee. This reservoir is the primary source of water for the Duck River Utility Commission (DRUC), which serves the cities of Tullahoma and Manchester, and for five additional water districts located downstream of Normandy Reservoir (Shelbyville Power, Water, and Sewerage System; Bedford County Utility District; Lewisburg Water and Wastewater; Spring Hill Water System; Columbia Power and Water Systems). Importantly, the Duck River watershed is widely considered one of the most biologically rich watersheds in North America; therefore, any change in operational procedures for Normandy Reservoir must be considered with due cognizance of the various values sustained by the waters impounded by Normandy Reservoir.

According to the US Drought Monitor, the region experienced an exceptional drought in 2007 and 2008, necessitating altered management of flows released by TVA from Normandy Reservoir to maintain water capacity and limit detrimental effects of prolonged drought conditions in both Normandy Reservoir and the Duck River. As a direct result of the 2007/2008 drought, the Tennessee Duck River Development Agency (TDRDA), which represents seven water utilities that serve approximately 250,000 people and industries in the region, developed a report focused on the optimization of releases from Normandy Dam entitled *Optimization of Normandy Reservoir Releases* report (ONRR, OBG 2013a). This report identified the potential for improvement in the operational procedures of Normandy Dam to satisfy downstream flow targets more precisely at a river gage in Shelbyville, Tennessee, thereby preserving water in storage in Normandy Reservoir.

TVA is responding to the ONRR report by evaluating whether its existing operating procedures of Normandy Reservoir best serve the public's needs or whether changes to its operating procedures would provide TVA with greater flexibility to meet operational goals by ensuring water supply needs for stakeholders of Normandy Reservoir while protecting downstream water quality, aquatic habitat, and the needs of water users of the Duck River during drought conditions. TVA has prepared this EA to address its Proposed Action to modify how it releases water from Normandy Dam to meet flow targets 28 miles downriver at the Shelbyville, Tennessee gage.

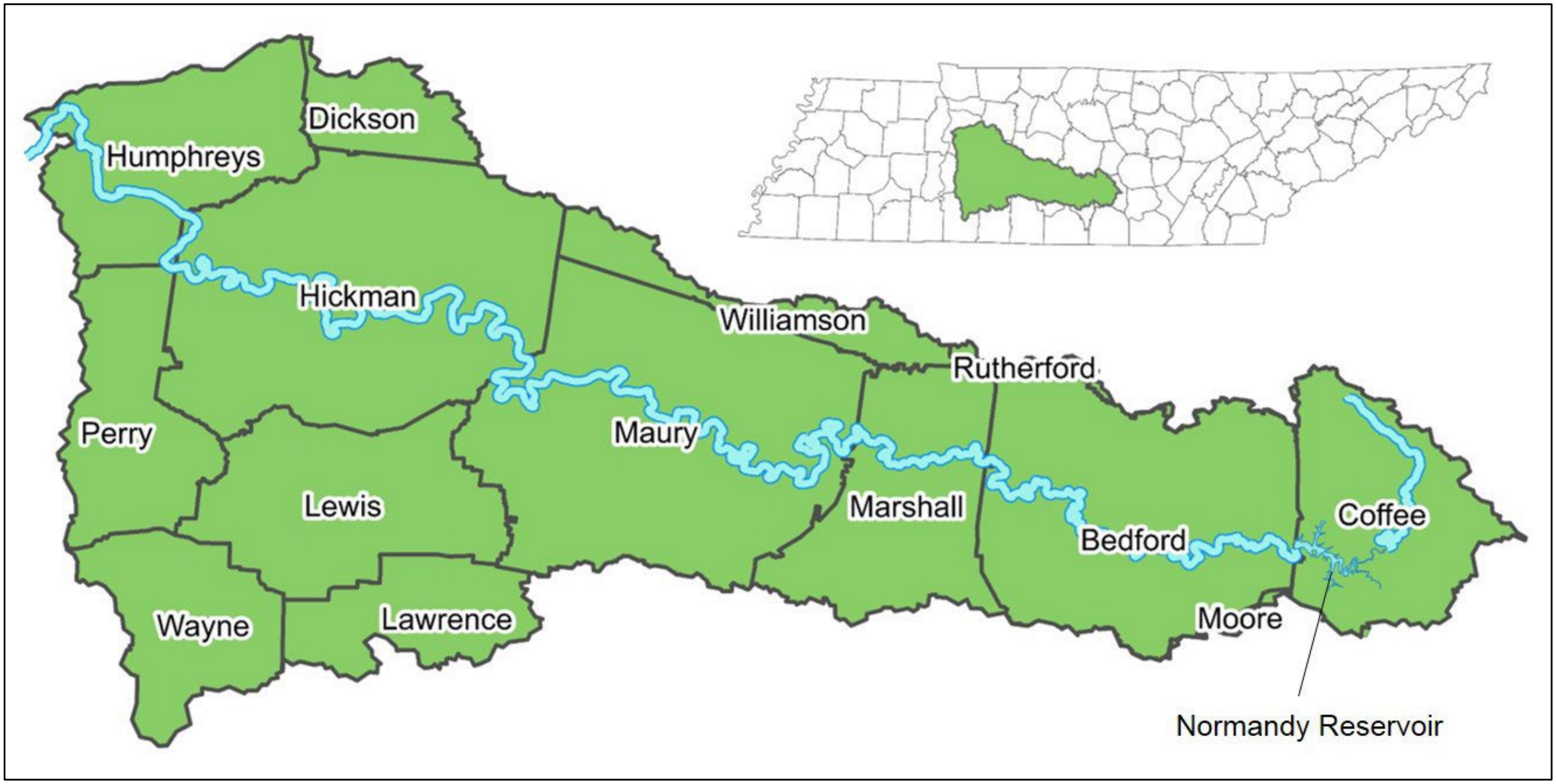

Figure 1 – Map of the Duck River Watershed, Tennessee

1.2 Purpose and Need

The purpose of the Proposed Action is to improve TVA's operation of Normandy Reservoir. TVA is seeking greater flexibility in its management of water releases from the reservoir into the Duck River while continuing to meet key operational goals related to water supply, water quality, and sensitive aquatic habitat. The proposal would also meet objectives of the TDRDA and the State of Tennessee to address regional development within the Duck River watershed as well as protect water resources. The proposal also has the potential to assist TVA and its partners in addressing drought conditions in the watershed that may affect water supply in the region.

The need for the action derives from TVA's obligations to operate its reservoirs while considering multiple social, economic, and environmental objectives, consistent with its Reservoir Operations Study. The action would also be consistent with previously established TVA flow targets on the Duck River.

1.3 Decision to be Made

This Environmental Assessment (EA) has been prepared to inform TVA decision makers and the public about the environmental consequences of the Proposed Action. TVA is considering whether to modify how it releases water from Normandy Dam to meet flow targets 28 miles downriver at the Shelbyville, Tennessee gage, or to take no action. TVA will use this EA to support the decision-making process and to determine whether an environmental impact statement (EIS) should be prepared or whether a Finding of No Significant Impact (FONSI) can be issued.

1.4 Scope of the Environmental Assessment

To ensure the potential effects of the proposal are properly analyzed, the EA will address resources potentially impacted by the proposal that are within the reach of the Duck River that are influenced by TVA water releases from the Normandy Dam. TVA prepared this EA to comply with the National Environmental Policy Act (NEPA), regulations of the Council on Environmental Quality (CEQ) at 40 CFR part 1500 (as amended), and TVA's procedures for implementing NEPA at 18 CFR part 1318. TVA and TDRDA reviewed the proposed action and identified the following issues to be evaluated in detail in the EA:

- Water Supply/Quantity
- Water Quality
- Aquatic Habitat
- Threatened and Endangered Species
- Wetlands
- Climate Change
- Cultural Resources
- Socioeconomics, Visual Resources, and Recreation

TVA and TDRDA determined that other issues do not require detailed analysis due to the nature of the proposal and/or there would be no potential for impacts to these resources or uses. These resource issues include botany, navigation, land use, solid and hazardous waste, and environmental justice. The proposed action alternative would not impact terrestrial vegetation; wetland vegetation is considered in section 3.5. Navigation during recreational activities (fishing boats, kayaking) is not likely to be impacted by either of the alternatives considered herein. There is no proposed change in land use, and there is no solid or hazardous waste associated with either of the alternatives. Environmental justice was not addressed in this environmental assessment as there are no adverse effects from the proposal to human health or the environment that would disproportionately affect any community. Floodplains were considered in accordance with Executive Order 11988; however, this resource was dismissed from further consideration because there would be no potential for impacts to floodplains of the Duck River as the proposed modifications would only occur within the river's stream channel, thus would not alter floodplains or materially affect flood storage of the Normandy Reservoir. There would be no meaningful change to reservoir flood risk.

1.5 Public and Agency Involvement

The scope of the EA was developed with input from TVA, TDRDA, and state and federal agencies. In May 2017, a workshop was held at Cumberland Mountain State Park (Crossville, TN) with the purpose of discussing and formalizing the EA scope. Attendees included representative experts from TVA, TDRDA (including environmental and engineering consultants), U.S. Fish and Wildlife Service (USFWS), Tennessee Department of Environment and Conservation (TDEC), Tennessee Wildlife Resources Agency (TWRA), and The Nature Conservancy (TNC). Attendees discussed the proposed optimization of flows as well as a proposed regional drought management plan that was prepared in 2013 in conjunction with the ONRR report. TVA and agencies developed a scoping document that addressed the drought management plan and the optimization recommendations in the ONRR report.

In July 2018, TVA and TDRDA initiated an environmental review process by holding a public scoping period to solicit input from the public on the proposed optimization of water releases and the drought management plan. During the public comment period, TVA received comments from four individuals and two organizations (Tennessee Wildlife Federation and The Nature Conservancy).

After the public scoping period, interagency discussions on the drought management plan have continued and are ongoing. While those discussions continue, TVA and TDRDA have modified the initial scope of the environmental review to address only the proposed optimization of water releases from Normandy Reservoir. Therefore, this EA excludes consideration of the drought management plan. The Proposed Action (optimizing releases) has utility and benefits to TVA that are independent of the drought management plan proposal that is separately under development. TVA will conduct a separate environmental review of the drought management plan once the plan is drafted.

The Endangered Species Act (ESA) directs federal agencies to conserve listed species, which includes evaluating effects of agency actions on threatened and endangered species and their critical habitat. Under Section 7 of the ESA, TVA must consult with the USFWS when actions may impact threatened or endangered species and/or their designated critical habitats. TVA is consulting with the USFWS on this proposal and has partnered extensively with USFWS to protect resources within the Duck River watershed. TVA has also consulted with the Tennessee Historical Commission and federally recognized Indian tribes, consistent with Section 106 of the National Historic Preservation Act.

1.6 Necessary Permits

There are no permits or licenses that TVA must obtain prior to modifying its operations at Normandy.

CHAPTER 2 - DESCRIPTION OF ALTERNATIVES

This chapter describes the two alternatives under consideration and discusses the methodology used for determining impacts. This chapter also provides a table that compares the environmental consequences associated with each alternative (Table 1).

2.1 Alternatives

2.1.1 Alternative A – No Action

Under Alternative A, TVA would continue to operate Normandy Reservoir/Dam according to the current operating rule curve[1] (Figure 2) and procedures. TVA currently releases water from the dam in order to meet the following *instantaneous flow targets*[2]:

- 155 cfs from June through November at Shelbyville;
- 120 cfs from December through May at Shelbyville; and
- The minimum flow from Normandy Dam would continue to be 40 cfs.

During low water conditions, TVA accounts for the 18-hour lag between the time water is released from the dam to the flow measurement at the Shelbyville U.S. Geological Survey (USGS) gage by releasing more than the required amount of water to ensure that the Shelbyville target is achieved. Under Alternative A, TVA would continue to provide this additional flow for water supply between the dam and Shelbyville to ensure that seasonal minimum *instantaneous flow targets* are met at the Shelbyville gage. This additional flow is designated as 10 cfs above the minimum instantaneous flow targets in the OASIS model (described in more detail in Section 3.1.1 and Appendix A).

2.1.2 Alternative B – Optimization of Releases

Under Alternative B, the Proposed Action, TVA would modify its operation of Normandy Reservoir/Dam by changing the typical flow releases of water from Normandy Dam. The current flow target at the Shelbyville gage would be revised from an instantaneous flow target to a weekly average flow target, coupled with a minimum instantaneous flow threshold. In other words, rather than operating to maintain its Shelbyville flow target instantaneously (i.e., measured during one instant in time), TVA proposes to operate flows to meet a target that is based on the average flows at Shelbyville over the course of a week (through 2400 hours on Sunday). Alternative B would also include a minimum instantaneous flow requirement to augment the weekly average flow target. TVA would be required to meet this minimum instantaneous flow requirement even if the average flow for any day or combination of days of the week was considerably higher than the weekly target.

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[1] Flood guide elevations are an important part of the operating rule curve as they indicate the amount of storage allocated in a reservoir for flood reduction. Normandy Reservoir's flood guide elevations are: 1) Summer/Fall (June-November) reservoir elevation of 875 feet, and 2) Winter/Spring (December-May) reservoir elevation of 864 feet. In general, if the Normandy Reservoir elevation is above the flood guide elevations, TVA could release more than the below-listed minimum instantaneous flows to get the reservoir back to or below the flood guide.

[2] In this case, an instantaneous flow is defined as the flow of water (in cubic feet per second [cfs]) in the Duck River measured at Shelbyville at any given moment.

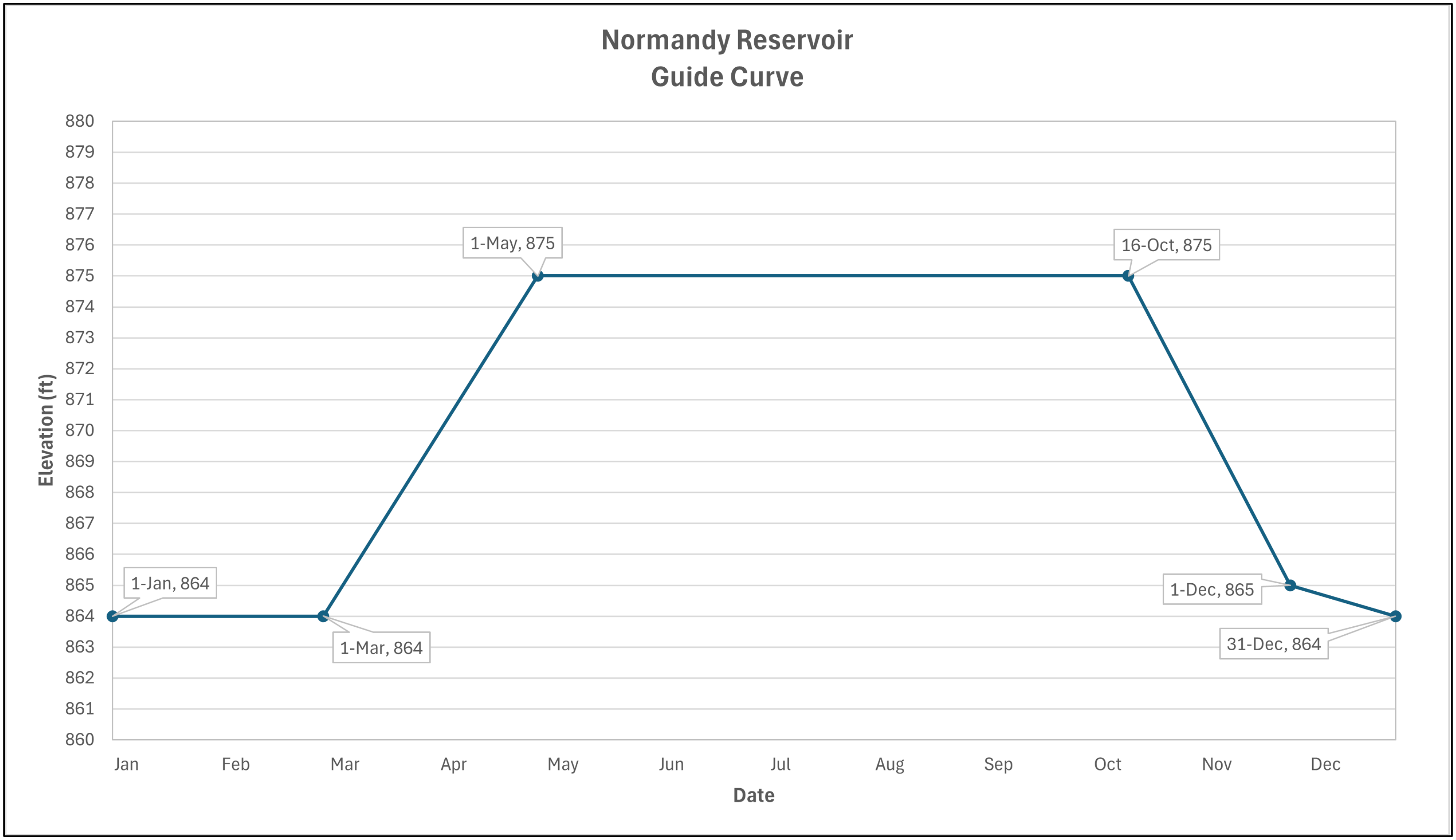

Figure 2 – Normandy Reservoir Operating Rule Curve

The proposal would not alter TVA's flood guide elevations for Normandy Reservoir or affect how TVA operates during flood operations. In addition, this alternative would be in effect regardless of drought triggers or hydrologic conditions. Under this alternative, TVA would not change the minimum flow from Normandy Dam.

Under this alternative, the revised flow target at Shelbyville would consist of the following:

- During June 1 through November 30 - Weekly average flow of 155 cfs, average to be calculated at the end of the week (2400 hours on Sunday). The minimum instantaneous flow at the Shelbyville gage would be 135 cfs during this period;
- During December 1 through May 31 - Weekly average flow of 120 cfs, average to be calculated at the end of the week (2400 hours on Sunday). The minimum instantaneous flow at the Shelbyville gage would be 100 cfs during this period;
- Any partial weeks resulting from the change in target average flows at 2400 (midnight) on June 1 and at midnight on December 1 shall be treated as full weeks with respect to compliance with the required weekly average flow targets; and
- A minimal flow of 40 cfs from Normandy Dam would continue to be maintained.

Implementing this alternative would allow TVA to satisfy the Shelbyville flow targets more accurately during times of drought and would eliminate the current practice of releasing "excess water" to account for the 18-hour water travel time between Normandy Dam and the Shelbyville USGS gage. The elimination of this practice would result in more water conserved in Normandy Reservoir, therefore increased reservoir elevations in Normandy Reservoir during periods of low water (e.g., reservoir elevation below the winter/summer flood guide target). Increased reservoir elevations during times of drought provide TVA with greater flexibility to meet operational goals related to adequate domestic water supply, sustaining adequate reservoir releases during exceptional drought periods, and protecting water quality. TVA uses forecast informed reservoir operations, such that forecasters are monitoring around the clock and have the ability to operate more conservatively or aggressively with strategies based on current conditions and predicted rain. This alternative is preferred by TVA.

Some examples of operational goals and benefits that could be facilitated by the greater flexibility afforded by Alternative B include:

- Alternative B would give TVA more flexibility during spring fill of the reservoir.
- Alternative B would give TVA more flexibility to release additional water to ameliorate downstream water quality issues, including algal blooms.
- The increased reservoir elevations resulting from implementation of Alternative B mean that more water is available to ensure minimum flows in the Duck River during prolonged exceptional drought conditions.
- Alternative B would also reduce the potential for impacts on DRUC operations that may result from a low reservoir elevation (e.g., increased water treatment and pumping costs as water must be withdrawn from deeper in the reservoir from a zone of poorer water quality).

2.2 Comparison of Alternatives

The potential environmental effects that could result from the two alternatives are evaluated in this EA. Impact analyses are based on current and potential future conditions at Normandy Reservoir, Duck River, and the surrounding area. Impact severity is dependent upon the relative magnitude and intensity of the impact as well as the sensitivity of the resource. In this document, four descriptors are used to characterize the level of impacts in a manner that is consistent with TVA's current practice. In order of degree of impact, the descriptors are as follows:

- **No Change** - Impact on the resource area is negligibly positive or negative but is barely perceptible or not measurable or confined to a small area; or the extent of the impact is limited to a very small portion of the resource.
- **Slightly Adverse/Beneficial** - Impact on the resource area is perceptible and measurable and is localized; or its intensity is minor but over a broader area and would not have an appreciable effect on the resource. This can also refer to non-reoccurring impacts with a short duration.
- **Moderately Adverse/Beneficial** - Impact is clearly detectable and could have an appreciable effect on the resource area. Moderate impacts can be caused by combinations of impacts, ranging from high-intensity impacts over a small area to small or moderate impacts over a large area. This also can occur with minor to moderate impacts that are recurring over a period of years.
- **Substantially Adverse/Beneficial** - Impact would result in a major, highly noticeable influence on the resource area— generally over a broader geographic extent and/or recurring for many years.

A comparison of the environmental consequences associated with each alternative is presented in Table 1.

Table 1. Summary and comparison of alternatives by resource area

Resource Area	Impacts from Alternative A (No Action)	Impacts from Alternative B (Optimization of Releases)
Water Supply / Quantity	No change in water supply or quantity, but less reservoir water for release to Duck River under severe drought conditions	Slightly beneficial impact as conserved reservoir water is available for release to the Duck River, especially during drought conditions
Water Quality	No change in water quality, but during drought conditions, lower reservoir elevations would continue to cause raw water treatment issues and less water for release to augment Duck River water quality	Slightly beneficial impact; increased reservoir water improves raw water quality; no impacts from ammonia toxicity; small impact to Dissolved Oxygen, but quick recovery; during critical drought conditions, additional water is available to augment Duck River water quality
Aquatic Habitat and Species	No change to aquatic habitat or species, but during severe drought conditions, less reservoir water would be available for release to augment Duck River water quality	Slightly beneficial impacts to reservoir and river; conserved reservoir water would improve water quality/aquatic habitat; minor reduction in Duck River wetted perimeter, but additional reservoir water is available for release to increase wetted perimeter during critical drought conditions

Resource Area	Impacts from Alternative A (No Action)	Impacts from Alternative B (Optimization of Releases)
Threatened and Endangered Species	No change to threatened and endangered species, but during severe drought conditions, less reservoir water would be available for release to augment Duck River water quality	Slightly beneficial impacts to listed species; more reservoir water during drought conditions would improve water quality and aquatic habitat; most mussels occupy unaffected middle of the stream; decreases in wetted perimeter would be small and temporary; additional reservoir water would be available for release to Duck River during critical drought conditions
Wetlands	No change in wetland type, condition, or function	Slightly beneficial impact; additional water would have a positive impact on reservoir wetlands; wetlands adjacent to Duck River would benefit from additional releases during dryer periods
Climate Change	No change; alternative does not produce greenhouse gases (GHG); however, less reservoir water would be available to ameliorate droughts, which are predicted to increase in frequency and duration as climate change progresses	No change; alternative does not produce GHG; however, more reservoir water would be available to ameliorate droughts, which are predicted to increase in frequency and duration as climate change progresses
Cultural Resources	No change	No change
Socioeconomics	No change in socioeconomic factors, but cost of treating raw water during severe drought conditions would not be ameliorated	Slightly beneficial impacts; minor positive impacts to recreation could lead to increase revenue and employment in this sector; lower potable water costs due to higher quality reservoir water
Visual Resources	No change in the aesthetic qualities of Normandy Reservoir and Duck River	Slightly beneficial impacts; higher reservoir elevation increases aesthetic appeal; lower wetted perimeter in river is less noticeable due to typical variation in flow
Recreation	No change, recreational impacts from low reservoir elevations during drought conditions would continue at existing rates (e.g., problematic for bank fishing, boat access, small craft navigation)	Slightly beneficial impacts; increased reservoir surface area for boat launch access/boating/reservoir fishing/bank fishing; more high quality water available for release to the Duck River during low flow conditions would augment boating and fishing

2.3 Summary of Proposed Mitigation Measures

Based on the lack of appreciable adverse impacts to the examined environmental resource categories in the EA, no mitigation measures are proposed.

CHAPTER 3 - AFFECTED ENVIRONMENT AND IMPACT ANALYSIS

This chapter describes the affected environment (existing conditions) for environmental resource categories that have the potential to be affected by the alternatives under consideration associated with the Normandy Reservoir and sections of the Duck River (see Section 1.4 for a discussion of project scoping activities). The potential affected environment from alterations of the operation of Normandy Dam includes Normandy Reservoir and stretches of the Duck River.

This chapter also describes the anticipated impacts (environmental consequences) of the alternatives on the following resources: (1) water supply/quantity, (2) water quality, (3) aquatic habitat, (4) threatened and endangered species, (5) wetlands (6) climate change, (7) cultural resources, and (8) socioeconomics/visual resources/recreation.

3.1 Water Supply/Quantity

3.1.1 Affected Environment

Normandy Reservoir and the Duck River provide vitally important public water supplies, in addition to supporting recreation, industry, and other water-dependent businesses (OBG 2013b). Releases from Normandy Reservoir are the primary source of water for the Duck River upstream of the city of Columbia, Tennessee, with a volume of water in reservoir storage of approximately 36 billion gallons from June-November at a reservoir elevation of 875 ft, and 25 billion gallons from December-May at a reservoir elevation of 864 ft. In the Duck River, water quantities are also affected by supply withdrawals that occur between Shelbyville and Columbia, in addition to point source discharges from public utilities and industry.

Due to historic and anticipated population growth, water utilities that withdraw water from the Duck River are at various stages of proposed or potential water infrastructure expansion (Table 2). The potential infrastructure demands and expansions listed in Table 2 are not the subject of this EA. However, the EA evaluates both the actual 2015 water withdrawal and an estimate of 2040 average daily water withdrawal demand projections. The estimated demand projections used growth projections on the higher side of reasonable, so the results are conservative with regard to the possible expansion of infrastructure and water withdrawals from the Duck River. The 2040 demands account for demand growth in the region of approximately 48%, while the proposed infrastructure expansion, as is recently known or estimated, accounts for growth of up to 37%. TDEC is conducting a basin-wide water withdrawal permitting pilot program, which would encompass all future water withdrawal requests described above. The intent of TDEC's holistic permitting process would be to establish a cooperative, comprehensive regional approach to equitable permitting of public water withdrawals.

Table 2. Water Utilities that withdraw from Duck River, listed from upstream to downstream.

Water Utility	Existing Design Capacity (MGD)	Proposed 2040 Design Capacity (MGD)
Duck River Utilities Commission	12.00	12.00
Shelbyville Power & Water	10.30	10.30
Bedford County Utility District	4.25	8.00
Lewisburg Water and Wastewater	4.00	5.00
Marshall County Board of Public Utilities-New	--	3.00
Spring Hill Water Department	4.30	6.00
Maury County Water System - New	--	3.00
Columbia Power and Water Systems	20.00	20.00
Columbia Power and Water Systems - New	--	12.00
Town of Centerville (Big Swan Creek)	2.30	4.00
TOTAL	**57.15**	**83.30**

Notes: Data taken from a 2021 TDEC presentation “Update of Pilot Water Withdrawal Permitting in the Duck River Watershed.”

The alternatives evaluated in this EA have the potential to impact the quantity of water in Normandy Reservoir and Duck River. Water quantity modeling was conducted for this EA using the OASIS model which incorporates hydrology, point source discharges, and recent and future water demands to estimate Normandy Reservoir elevations and Duck River flow. Refer to Appendix A for a detailed discussion of the OASIS model.

Only one hydrologic inflow scenario was used in this EA – historic inflows from 1921 to 2016. Historic flow records (hourly flow in cubic feet per second [cfs]) were obtained from this time frame from seven United States Geological Survey (USGS) gage locations within the Duck River watershed (Figure 3). The utilization of a synthetic 1000-year inflow dataset was considered to document drought conditions that might be worse than the historic record, however, a recent unpublished review of the precipitation dataset indicates that the 2007 drought is the drought of record for the Duck River Basin. The drought of record is defined as the period of time when natural hydrological conditions provided the least amount of water supply. Since the historic inflows dataset (1921 to 2016) includes the 2007 drought of record, the results of the synthetic 1000-year inflow OASIS model are not evaluated herein.

Two average day water demand scenarios are used in this assessment: recent (2015) and projected (2040) (Table 3). It is important to note that these two water demand scenarios are conservative, as water systems would likely not be drawing water at maximum existing withdrawal rates during severe droughts due to the application of water conservation measures by water users throughout the Duck River Basin.

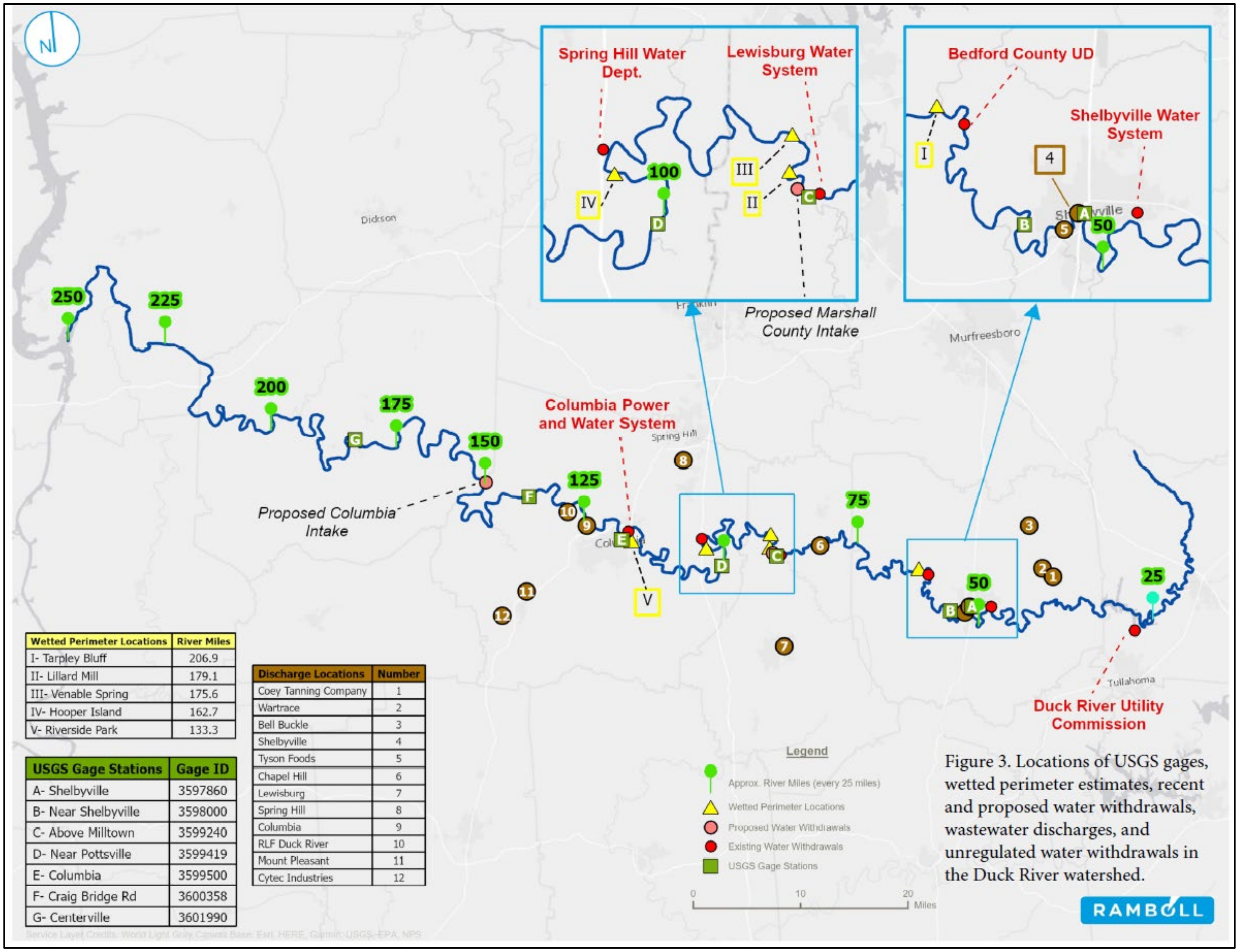

Figure 3 – Locations of USGS gages, wetted perimeter estimates, recent and proposed waster withdrawals, wastewater discharges and unregulated water withdrawals in the Duck River watershed

Table 3. Estimated recent and projected water demands and maximum existing withdrawal limits associated with utilities in the Duck River basin.

Utility	Recent Demands (MGD) 2015	Projected Demands (MGD) 2040	Recent Max. Existing Withdrawal Allowed (MGD)
Tullahoma Utilities Board	3.7	4.4	12[a]
Manchester Water and Sewer Dept.	2.7	3.3	
Shelbyville Power, Water, and Sewerage System	4.6	7.4	10.3
Bedford County Utility District	2.2	3.4	4.7
Lewisburg Water and Wastewater	3.2	4.4	4
Spring Hill Water System	2.9	4.2	6
Columbia Power and Water Systems	9.6	15.6	20
TOTAL BASIN DEMAND	**26.2**	**42.7**	**57**

Notes: The 2015 and 2040 estimated demand values were developed in 2013 using population projections from the University of Alabama, Center for Business and Economic Research (CBER) to extrapolate from actual 2010 withdrawal data.

Agricultural withdrawals are present in the Duck River basin, and an assessment conducted as part of the DMP development estimated that water withdrawals from agriculture are minimal across the full extent of the watershed (estimated to be 0.18 MGD in 2020 using irrigation data from USGS report [2015]). The projected (2040) water demand does not include an increase in agriculture withdrawal as this demand is expected to stay relatively unchanged through 2040. Historical agricultural withdrawals from the Duck River are reflected in the USGS stream gage data and thus are captured in the OASIS model results.

Verification of OASIS model output was conducted by comparing modeled Normandy Reservoir elevations and Duck River flows to actual values during the 2007-2008 drought (Appendix A, Figures 2 through 7). In general, the OASIS model is representative of historical flows and reservoir elevations. Discrepancies between computed and historic results, where they exist, can largely be attributed to the fact that the model follows the current operations guide precisely, whereas actual river flows and reservoir elevations varied in response to real time water management decisions made under very challenging drought conditions. For example, releases from Normandy Dam were reduced in the fall to conserve water in the reservoir for release at a later time.

The OASIS model inputs were subjected to independent peer review and were found to be reasonable and consistent with standard engineering practices. The peer review suggested that the project team conduct a sensitivity analysis to understand the uncertainty associated with predicting future water demands. A sensitivity analysis was conducted by altering annual average daily demands in the OASIS model for the 2040 scenario. This analysis demonstrated that OASIS-generated flow estimates are relatively insensitive to changes in 2040 water demands. For example, a 10% decrease in water demand yielded percent flow increases that were similar for both alternatives and ranged from 0.40% in the summer to 0.46% in the winter. Likewise, a 10% increase in water demand yielded percent flow decreases that ranged from -

0.79% in the summer to -0.96% in the winter. Based on the results of the sensitivity analysis, minor deviations in actual versus projected 2040 demands are unlikely to alter the inferences made for this evaluation using the OASIS model.

3.1.2 Environmental Effects of Alternative A

With Alternative A, the selected recommendation in the ONRR would not be implemented and TVA would continue to operate releases from the dam at Normandy Reservoir according to the current release schedule. TVA would continue to release water to meet a minimum instantaneous flow targets at the Shelbyville gage, with a minimum flow from Normandy Dam of 40 cfs. As indicated in Table 4, continued operation of releases would result in marginally lower elevations in the reservoir, when compared to the Proposed Action.

3.1.3 Environmental Effects of Alternative B

Under Alternative B, TVA would modify the operation of Normandy Dam to a weekly average flow target at Shelbyville, with a minimum instantaneous flow as described in Section 2.1.2.

Table 4. Normandy Reservoir elevations (ft.) for Alternative A and Alternative B based on 2015 and 2040 water demands.

Historic inflow	2015 Demands	2040 Demands
Alternative A - No Action		
Lowest elevation (ft.)	851	849
Alternative B – Optimization of Releases		
Lowest elevation (ft.)	+2 (0.2%)	+2 (0.2%)

Notes: Values for Alternative B represent absolute and percentage change from Alternative A; a 1 ft increase in elevation of Normandy Reservoir at 850 ft equates to approximately 0.7 billion gallons of reservoir water storage.

During the winter season, the predicted 50th percentile flow values (representing normal, non-drought conditions) under Alternative B are slightly higher than those predicted for Alternative A (Table 5). This is because TVA would be releasing a surplus of water from the reservoir beyond the Shelbyville flow target in the winter. Therefore, the net savings in reservoir storage are manifesting as slightly more flow downstream due to higher levels at the reservoir compared to Alternative A. It should be noted that the reductions in summer river flows brought about by the implementation of Alternative B (Tables 5 and 6) are expected to occur gradually and be of a temporary duration (i.e., a flow reduction or wetted perimeter reduction lasting between 0 and 24 hours under non-drought conditions and between 24 and 48 hours under drought conditions).

Table 5 identifies the predicted 50th percentile simulated flow values at seven Duck River gages comparing 2015 and 2040 water demands. The 50th percentile simulated flows represent flows occurring during normal, non-drought conditions. Table 6 identifies the lowest simulated river flows, comparing the 2015 and 2040 water demands; the flows in Table 6 represent critical drought conditions.

Table 5. 50th percentile simulated river flows (cfs) for Alternatives A and B with 2015 and 2040 water demands at seven USGS gage locations during summer and winter periods.

Demand	Season	Alternative	USGS Gage Locations						
			Shelbyville	Near Shelbyville	Above Milltown	Mile 156 - Pottsville	Columbia	Craig Bridge Road	Highway 100 at Centerville
2015	Summer	A	170	192	256	307	386	515	835
		B	160	182	247	299	379	508	829
		Change	-5.9%	-5.1%	-3.4%	-2.6%	-1.9%	-1.4%	-0.8%
	Winter	A	581	665	1395	1547	1811	2146	3054
		B	585	668	1400	1551	1813	2148	3054
		Change	0.6%	0.4%	0.4%	0.3%	0.1%	0.1%	0.0%
2040	Summer	A	170	196	256	305	374	508	828
		B	160	186	248	297	368	501	821
		Change	-5.9%	-5.0%	-3.4%	-2.6%	-1.8%	-1.3%	-0.8%
	Winter	A	574	661	1392	1542	1795	2139	3045
		B	577	666	1394	1544	1797	2141	3049
		Change	0.5%	0.7%	0.2%	0.1%	0.1%	0.1%	0.1%

Notes: Percentage values are percent change in flow from Alternative A to Alternative B; all other values represent lowest simulated flow (cfs) in Duck River.

What follows is a summary of the modeled Duck River flow for each gage comparing Alternative B to Alternative A during normal and drought conditions:

Shelbyville, TN (USGS gage 03597860) – Relative to Alternative A, a change in flow at Shelbyville is predicted to occur approximately 36% and 37% of the time under Alternative B, based on 2015 and 2040 demands, respectively (Appendix B, Figures B-1c and B-8c). Under normal, non-drought conditions, the lowest modeled 50th percentile flow estimate for Alternative B is 160 cfs during the summer (Table 5). The estimated lowest flow reductions under Alternative B are projected to be approximately 10 cfs during the summer months and 5 cfs during the winter months under both water demand scenarios (Table 6). The estimated lowest Duck River flow at Shelbyville is 125 cfs and would occur under critical drought conditions (Table 6, Appendix B, Figures B-1a and B-8a).

Near Shelbyville, TN (USGS gage 03598000) – Relative to Alternative A, a change in flow at this gage is predicted to occur approximately 36% and 37% of the time under Alternative B, based on 2015 and 2040 demands, respectively (Appendix B, Figures B-2c and F-9c). Under normal, non-drought conditions, the lowest modeled 50th percentile flow estimate for Alternative B is 182 cfs during the summer (Table 5). The estimated lowest flow reductions under Alternative B are projected to be approximately 10 cfs during the summer months and 5 cfs during the winter months under both water demand scenarios (Table 6). The estimated lowest Duck River flow at this gage is 131 cfs and would occur under critical drought conditions (Table 6, Appendix B, Figures B-2a and F-9a).

Table 6. Lowest simulated river flows (cfs) for Alternatives A and B with 2015 and 2040 water demands at seven USGS gage locations during summer and winter periods.

Demand	Season	Alternative	USGS Gage Locations						
			Shelbyville	Near Shelbyville	Above Milltown	Mile 156 - Pottsville	Columbia	Craig Bridge Road	Highway 100 at Centerville
2015	Summer	A	170	176	161	153	118	143	180
		B	160	166	154	143	108	133	170
		Change	-5.9%	-5.7%	-4.3%	-6.5%	-8.5%	-7.0%	-5.6%
	Winter	A	130	136	134	137	136	190	214
		B	125	131	129	132	130.7	186.4	216.6
		Change	-3.8%	-3.7%	-3.7%	-3.6%	-3.9%	-1.9%	+1.2%
2040	Summer	A	170	179	161	152	107	138	173
		B	160	169	154	142	97	128	163
		Change	-5.9%	-5.7%	-4.3%	-6.5%	-9.4%	-7.3%	-5.8%
	Winter	A	130	140	135	136	125	187	212
		B	125	135	130	131	120	177	202.1
		Change	-3.8%	-3.6%	-3.7%	-3.7%	-4.0%	-5.4%	-4.7%

Notes: Percentage values are percent change in flow from Alternative A to Alternative B; all other values represent lowest simulated flow (cfs) in Duck River.

Above Milltown, TN (USGS gage 03599240) – Relative to Alternative A, a change in flow at this gage is predicted to occur approximately 30% of the time with the implementation of Alternative B, based on both recent and future water demands (Appendix B, Figure B-3c and B-10c). Under normal, non-drought conditions, the lowest modeled 50th percentile flow estimate for Alternative B is 247 cfs during the summer (Table 5). The estimated lowest flow reductions under Alternative B are projected to be approximately 7 cfs during the summer months and 5 cfs during the winter months under both water demand scenarios (Table 6). The estimated lowest Duck River flow at this gage is 129 cfs and would occur under critical drought conditions (Table 6, Appendix B, Figure B-3a and B-10a).

Mile 156 near Pottsville, TN (USGS gage 03599419) – Relative to Alternative A, a change in flow at this gage is predicted to occur approximately 28% of the time with the implementation of Alternative B, based on both recent and future water demands (Appendix B, Figures B-4c and B-11c). Under normal, non-drought conditions, the lowest modeled 50th percentile flow estimate for Alternative B is 297 cfs during the summer (Table 5). The estimated lowest flow reductions under Alternative B are projected to be approximately 10 cfs during the summer months and 5 cfs during the winter months under both water demand scenarios (Table 6). The estimated lowest Duck River flow at this gage is 131 cfs and would occur under critical drought conditions (Table 6, Appendix B, Figure B-4a and B-11a).

Columbia, TN (USGS gage 03599500) – Relative to Alternative A, the implementation of Alternative B is expected to yield an overall decrease in flow at Columbia approximately 25% of the time under the recent water demand scenario and 24% under future water demands (Appendix B, Figures B-5c and B-12c). Under normal, non-drought conditions, the lowest modeled 50^{th} percentile flow estimate for Alternative B is 366 cfs during the summer under the projected water demand scenario (Table 5). The estimated lowest flow reductions under Alternative B are projected to be approximately 10 cfs during the summer months and 5 cfs during the winter months under both water demand scenarios (Table 6). The estimated lowest Duck River flow at this gage is 97 cfs and would occur under critical drought conditions (Table 6, Appendix B, Figure B-5a and B-12a).

Craig Bridge Road, Williamsport, TN (USGS gage 03600358) – Relative to Alternative A, the implementation of Alternative B under recent water demands is not expected to frequently yield an overall decrease in flow at this location (Appendix B, Figure B-6c). However, under projected water demands, an overall decrease in flow is predicted to occur approximately 23% of the time (Appendix B, Figure B-13c). Under normal, non-drought conditions, the lowest modeled 50^{th} percentile flow estimate for Alternative B is 501 cfs during the summer under the projected water demand scenario (Table 5).The estimated lowest flow reductions under Alternative B are projected to be approximately 3.6 cfs during the summer/recent demand scenario and 10 cfs for the other three scenarios (i.e., winter/recent demands; summer/future demands; winter/future demands; Table 6). The estimated lowest Duck River flow at this gage is 128 cfs and would occur in critical drought conditions (Table 6, Appendix B, Figure B-6a and B-13a).

Highway 100 at Centerville, TN (USGS gage 03601990) – Relative to Alternative A, the estimated lowest flow reductions under Alternative B are projected to be approximately 10 cfs for three of the four season/demand scenarios (Table 6). Under normal, non-drought conditions, the lowest modeled 50^{th} percentile flow estimate for Alternative B is 821 cfs for the summer/future demand scenario (Table 5). Under the winter months/recent demands scenario, flow is projected to increase by a maximum of 2.6 cfs compared to Alternative A (Table 6). The estimated lowest Duck River flow at this gage is 163 cfs for the summer/future demand scenario, during critical drought conditions (Table 6, Appendix B, Figure B-7a and B-14a).

Modeled Normandy Reservoir elevations under Alternatives A and B are generally consistent (Figure 4). However, during low water periods (e.g., reservoir elevation below the winter/summer flood guide target), the implementation of Alternative B is predicted to conserve water in Normandy, resulting in increased reservoir elevations in Normandy Reservoir (Table 4). Under both recent and predicted water demands, the implementation of Alternative B yields lowest modeled Normandy Reservoir elevations that are a maximum of 2 ft greater than the modeled elevations for Alternative A (Figure 5). This 2-foot difference represents approximately 1.4 billion gallons of stored water available under Alternative B that would not be available under Alternative A during low water periods. For example, when the reservoir is below the winter flood guide target (864 feet), Alternative B is predicted to yield an increase in reservoir elevations approximately 25% of the time under recent water demands compared to reservoir elevations under Alternative A (Figure 5).

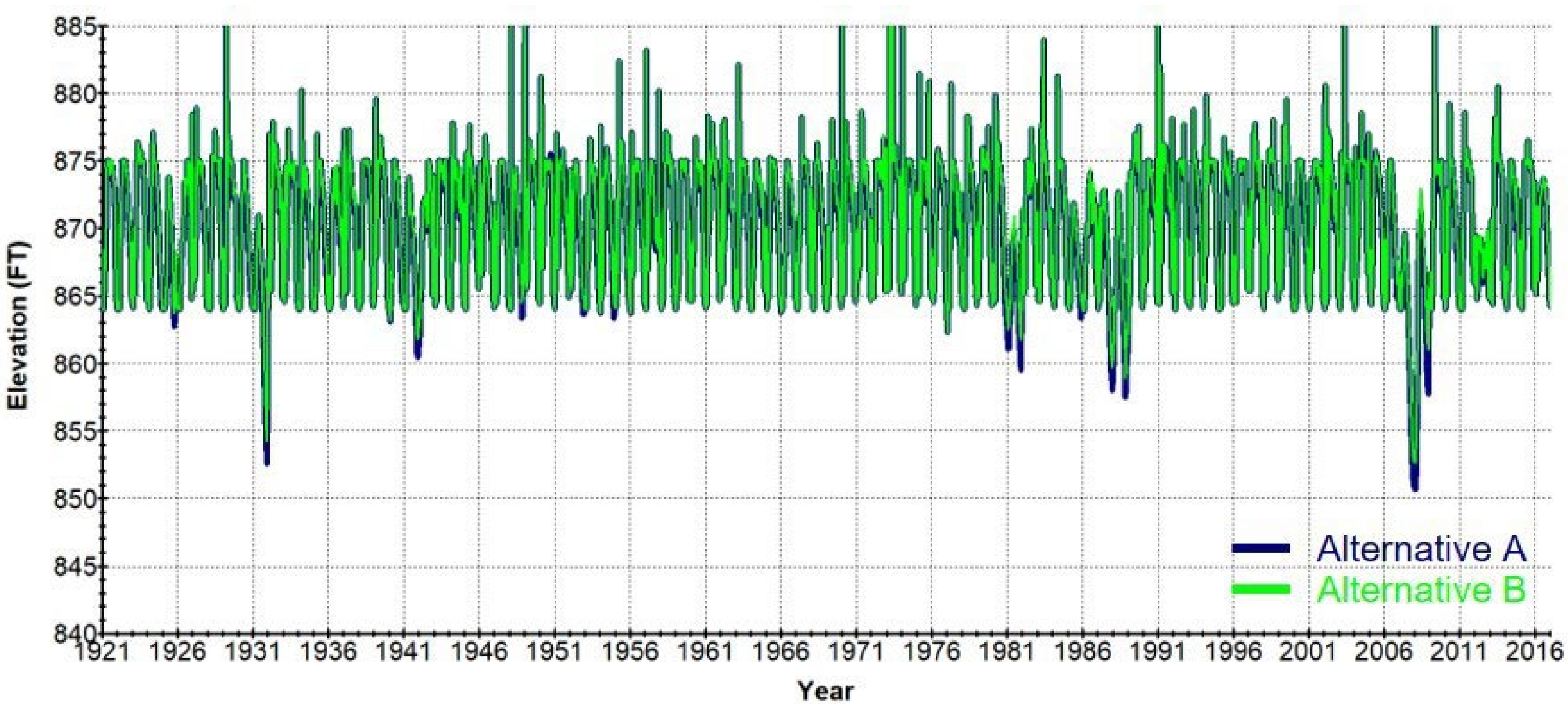

Figure 4 – Simulated Normandy Reservoir Elevations for Alternative A and Alternative B with Recent Water Demands

Under Alternative B, Duck River flow with recent and projected water demands would generally be lower than the flow modeled for Alternative A (Tables 5 and 6). Figures E-1 to E-7 in Appendix B depict modeled flows for the Duck River under Alternative B at the seven USGS gage locations with recent water demands. Note that the modeled flows at the “near Shelbyville” gage for both the summer and winter periods are greater for the 2040 demands scenario than for the 2015 demands scenario under both alternatives (Tables 5 and 6). The increase in flow between the Shelbyville and near Shelbyville USGS gages, under both demand scenarios, may be attributed to the wastewater discharges located between these two gages. The modeled flow at the near Shelbyville gage is greater under the 2040 demand scenario due to the fact that when withdrawals are increased under this scenario there is a corresponding increase in wastewater discharges which manifests as increase flow at the Shelbyville gage. The fact that the modeled flows at the above Milltown gage are the same under both demand scenarios can be attributed to the relatively small withdrawals between the Near Shelbyville and above Milltown gages and to the Lewisburg wastewater discharges into this reach which decreases their "net withdrawal" even further. The modeled flows under the 2040 demand scenario are lower than the 2015 demand scenario at the last three USGS gages as would be expected.

In conclusion, the OASIS model indicates that the implementation of Alternative B would generally yield a 10 cfs (summer) to 5 cfs (winter) reduction in Duck River flow under both water demand scenarios. These flow reductions are projected to occur between 0% to 37% of the year depending on the USGS gage and modeling scenario. In addition, during periods of low water (e.g., reservoir elevations below the winter/summer flood guide target), Alternative B is predicted to conserve water in Normandy, resulting in an increase in reservoir elevation approximately 25% of the time compared to Alternative A (Figure 5). This difference in reservoir elevation may reach as much as 2 ft under Alternative B (Figure 5).

Under normal, non-drought conditions, changes in flows and reservoir elevations brought about by the implementation of Alternative B would have a negligible impact relative to Alternative A as flows and reservoir elevations are generally higher during non-drought periods and fluctuations in these parameters are typical. During critical drought conditions, however, the higher reservoir elevations associated with Alternative B would equate to more water available for release to augment Duck River flow for any purpose deemed necessary by TVA and other Duck River stakeholders (e.g., water supply, aquatic habitat augmentation, water quality improvement, reducing harmful algal blooms). Therefore, the implementation of Alternative B would have a slightly beneficial impact on water quantity of the Normandy Reservoir and Duck River.

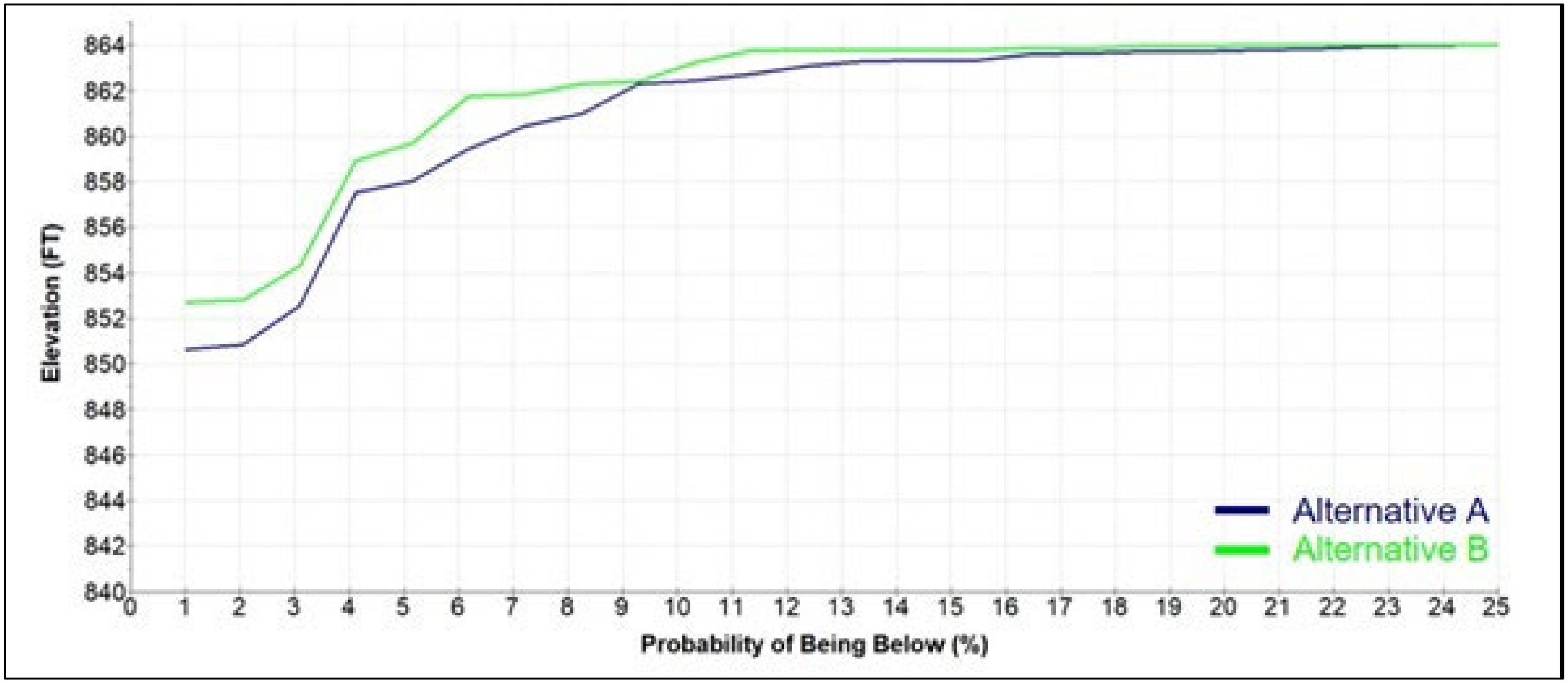

Figure 5 - Probabilities of water level elevations in Normandy Reservoir for Alternative A and Alternative B with recent water demands

3.2 Water Quality

3.2.1 Affected Environment

Water quality of the Duck River is an important consideration when assessing the proposed changes to releases from Normandy Reservoir. Water suppliers utilize both Normandy Reservoir and the Duck River to supply water to numerous municipalities in the basin, providing potable water to residents of multiple counties. In addition, several facilities have permitted discharges into the Duck River, particularly at or downstream of Shelbyville. These include the Shelbyville sewage treatment plant (STP), Tysons Farms Shelbyville processing plant, and the Chapel Hill wastewater treatment plant (WWTP). These discharges are located between River Mile 221 downstream to River Mile 185.5. Potential changes to water quality resulting from either of the alternatives evaluated herein are described in this section, with special reference to potential impacts to freshwater mussel species and permitted discharge limits for point source discharges.

Based on the State of Tennessee's 2022 303(d) list of impaired waterways, there are eight segments of the Duck River identified as water quality limited, which includes four each in the Upper Duck River and Lower Duck River sub-basins (TDEC 2022). These impaired segments include:

Upper Duck River

- TN06040002020_1000, Bedford County. Impairment – *Eschericha coli*
- TN06040002027_1000, Bedford County. Impairments – sedimentation/siltation
- TN06040002030_1000, Bedford County. Impairments – temperature alterations, flow regime modification, manganese

Lower Duck River

- TN06040003001_2000, Humphreys County. Impairments – *E. coli*, mercury, nutrients
- TN06040003005_1000, Humphreys County and Hickman County. Impairment – mercury
- TN06040003009_1000, Hickman County. Impairment – *E. coli*
- TN06040003024_1000, Maury County. Impairments – *E. coli*, nutrients
- TN06040003026_1000, Maury County. Impairments – dissolved oxygen, *E. coli*, nutrients

Water quality modeling was conducted in both Normandy Reservoir and the Duck River by TVA and TDEC, respectively. Water quality models for Normandy Reservoir included wet (2018) and dry years (2016, 2007). The TDEC Duck River water quality model evaluated ammonia toxicity and dissolved oxygen (DO) assimilative capacity from the Normandy Reservoir outflow (Segment 1 in Figure 6), and a critical segment between Shelbyville (to include point source discharges) to River Mile 207 (Segment 3 in Figure 6). Segment 3 includes the Tarpley Bluff mussel bed sampling location, and the modeling framework assumed that if water quality in this segment showed no impacts or recovery, a similar condition would be expected below River Mile 207 due to no significant point source inputs downstream.

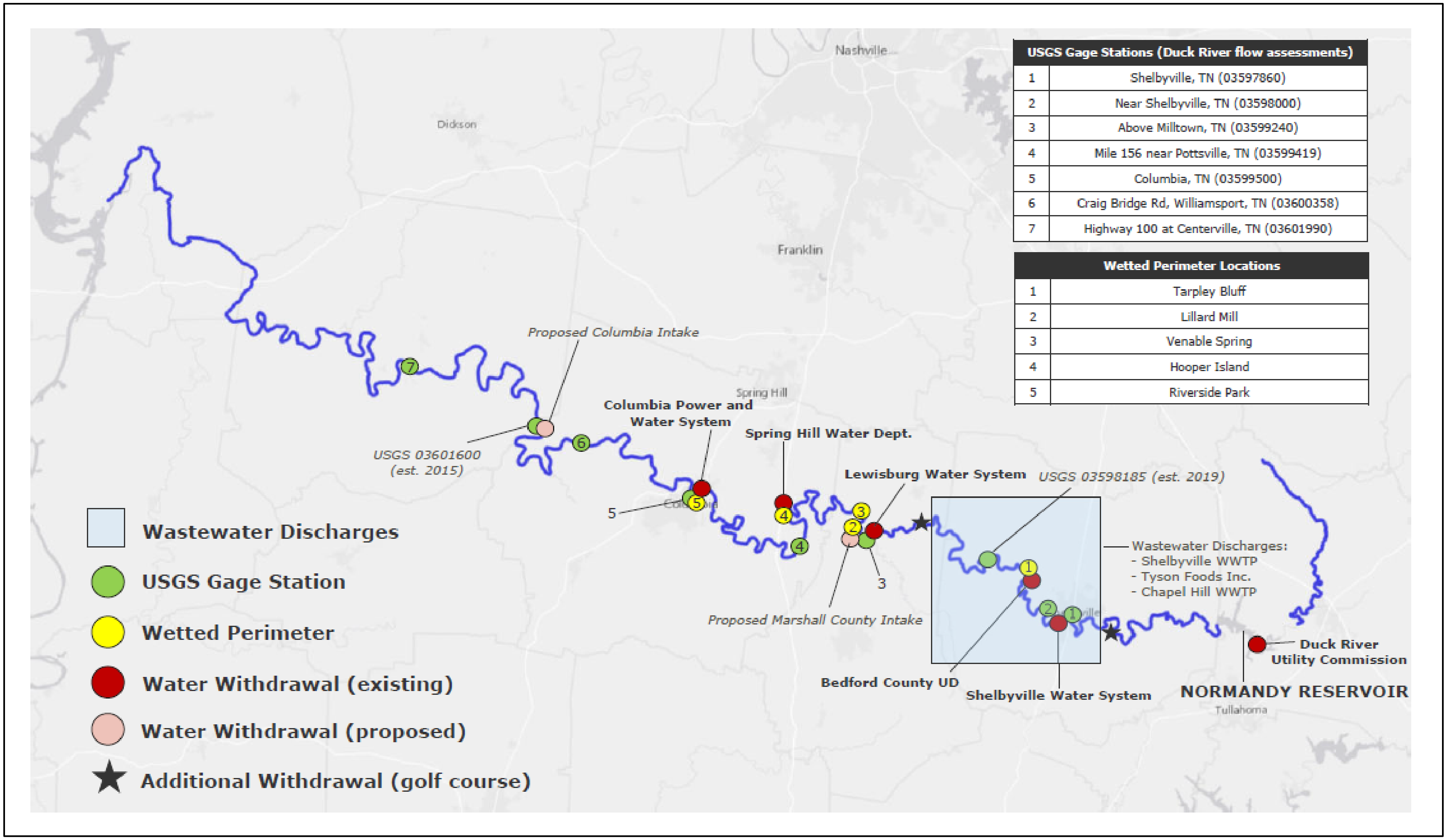

Figure 6 – Schematic of the approach for modeling Duck River water quality (ammonia toxicity and dissolved oxygen (DO) assimilative capacity)

The TDEC steady-state water quality model assumed that point source discharges in the Shelbyville segment operated at full permitted capacity (see Appendix C for additional details on the TDEC water quality modeling). Model simulations were evaluated at the lowest minimum flows for Alternative A (155 cfs), Alternative B (135 cfs), and the $1Q_{10}$ flow (139 cfs), which serves as the basis for waste load permit allocation limits. The $1Q_{10}$ flow is the lowest one-day average flow that occurs (on average) once every 10 years.

Ammonia toxicity criteria were evaluated based on the protection of aquatic life acute (CMC) and chronic (CCC) effects, including the revised ammonia criteria established with the USEPA. Temperature and pH output from the calibrated model were used to calculate stream-specific CMC and CCC toxicity criteria, which were compared with modeled ammonia concentrations to assess if toxicity exceedances would occur. In addition, assimilative capacity, or the ability of a water body to receive organic wastes without decreasing stream DO concentrations below the State minimum criterion of 5.0 mg L^{-1}, was evaluated for each alternative. The critical period for the Duck River water quality modeling assessment was during the summer (June-November) when river water temperatures would be most likely to contribute to ammonia toxicity.

3.2.2 Environmental Effects of Alternative A

Under the No Action Alternative, the selected recommendation in the ONRR would not be implemented, and TVA would continue to operate releases from the dam at Normandy Reservoir according to the current release schedule. Modeling indicates that under non-drought conditions, Alternative A would not cause ammonia toxicity or DO concentrations below 5.0 mg L^{-1} at the five locations evaluated in the TDEC (2020) report.

As discussed in Section 3.1, during low water periods Alternative A is expected to yield lower reservoir elevations approximately 25% of the time compared to Alternative B (Figure 5, Table 4). Under drought conditions, lower water levels can impact the water quality of the reservoir and river. For example, during the drought of 2007/2008 the DRUC reported that lower reservoir elevation increased water temperature and caused taste and odor issues. Lower reservoir elevations can also reduce withdrawal depth flexibility, causing water to be drawn from deeper in the reservoir where higher concentrations of manganese and iron and lower dissolved oxygen levels exist.

3.2.3 Environmental Effects of Alternative B

Under Alternative B, TVA would modify its operation of Normandy Reservoir and typical flow releases from Normandy Dam would change to a weekly average flow target, coupled with a minimum instantaneous flow. The calibrated TDEC QUAL2k steady state model indicates that no conditions of ammonia toxicity would be expected at any of the modeled locations under this alternative (Appendix C).

Under the lowest boundary condition (6.0 mg L^{-1}), modeled dissolved oxygen concentrations for the Alternative B scenario are slightly below the 5.0 mg L^{-1} criterion. A DO concentration of 4.9 mg L^{-1} was modeled between Duck River Mile (DRM) 216-217. Note that DO recovers above 5.0 mg L^{-1} by river mile 215 and remains above criteria for the duration of the Shelbyville segment. It is important to remember that the Duck River water quality modeling includes the assumption that permitted discharges in the Shelbyville segment discharge at full capacity. During a drought condition, full permitted discharge may be unlikely with reduced water usage in the basin. The water quality assessment thus represents the worst-case water quality conditions for each alternative (lowest minimum instantaneous flows and full permitted discharges) in the Shelbyville segment. DO concentrations were not below the 5.0 mg L^{-1} criteria at any location when the field measured DO boundary condition of 7.13 mg L^{-1} was used at 135 cfs.

During periods of low water (e.g., reservoir elevation below the winter/summer flood guide target), Alternative B is predicted to yield an increase in reservoir elevation approximately 25% of the time compared to Alternative A (Figure 5). This difference in reservoir elevation may reach as much as 2 ft under Alternative B (Figure 5). This additional water would be available to TVA to release during drought conditions to ameliorate drought-related water quality and quantity impacts. Therefore, the implementation of Alternative B would have a slightly beneficial impact on the water quality of the Duck River, especially under critical drought conditions.

3.3 Aquatic Habitat and Species

3.3.1 Affected Environment

High quality aquatic habitat is available in Normandy Reservoir and the Duck River. While the reservoir provides habitat to support birds (e.g., American white pelican, pied-billed grebe, ring-billed gull, American coot, Canada goose), semi-aquatic mammals (e.g., mink, raccoon, muskrat, river otters, beavers), and numerous warm water fish species (e.g., largemouth bass, smallmouth bass, spotted bass, channel catfish, flathead catfish, black crappie, white crappie, walleye, bluegill, redear sunfish, rock bass, warmouth, and white bass), the most recent assessment (2016) of ecological health by TVA ranked the reservoir as “poor” for dissolved oxygen, chlorophyll, and bottom life; “fair” for sediment; and “good” for fish.

The Duck River downstream of Normandy Dam is one of the most biologically diverse rivers in the State, and perhaps eastern North America, with populations of aquatic species that are not found anywhere else (Palmer 2005). There have been 151 species of fish, 69 species of mussels, and 22 species of aquatic snails documented in the Duck River (TVA 2015). Aquatic insects and other invertebrates are similarly diverse in the Duck River. Benthic Index of Biotic Integrity scores have demonstrated the healthy condition of the Duck River.

Modeled changes in the wetted perimeter of Duck River were used herein to evaluate the potential impacts to aquatic habitat of TVA’s Proposed Action. The wetted perimeter of a river is defined as that part of the channel that is in contact with water. There is a positive relationship between river flow and wetted perimeter (i.e., the greater the flow the greater the wetted perimeter). Wetted perimeter estimates were derived using three sources of information: 1) flow data from the OASIS model, 2) surveyed channel cross sections (Trutta Environmental Solutions 2018), and 3) standard engineering calculations.

Two wetted perimeter values are presented in this EA for each alternative/water demand/season combination. The 50th percentile wetted perimeter values represent normal, non-drought conditions, and the lower wetted perimeter values represent severe drought conditions. These two wetted perimeter values were modeled for each alternative at five locations (Figure 3):

- Tarpley Bluff (DRM 206.9) – total channel width 110 ft
- Lillard Mill (DRM 179.1) – total channel width 170 ft
- Venable Spring (DRM 175.6) – total channel width 140 ft
- Hooper Island (DRM 162.7) – total channel width 136 ft
- Riverside Park (Columbia, DRM 133.3) – total channel width 133 ft

These five Duck River locations correspond to freshwater mussel sampling transects, conducted by the TWRA (TWRA 2010, 2015). In 2015, river flow and wetted perimeter data were collected at each location (BDY Environmental 2015), and the relationship between flow and wetted perimeter informed the OASIS modeling for each alternative. Results of the wetted perimeter modeling are used in this section to evaluate the extent to which Duck River aquatic habitat may be exposed, resulting in a decrease in available aquatic habitat.

A temporary reduction in river flow could also affect the aquatic organisms and habitat of the Duck River by reducing dissolved oxygen levels, increasing in-stream temperatures, and reducing the amount of water available to assimilate wastewater discharges. Impacts to water quality are discussed in Section 3.2.

3.3.2 Environmental Effects of Alternative A

With Alternative A, the selected recommendation in the ONRR would not be implemented and TVA would continue to operate releases from the dam at Normandy Reservoir according to the current release schedule.

3.3.3 Environmental Effects of Alternative B

Under Alternative B, TVA would modify the operation of Normandy Dam by implementing a weekly average flow target at Shelbyville, with a minimum instantaneous flow as described in Section 2.1.2.

Under normal, non-drought conditions, Alternative B is comparable to Alternative A and would have no discernible impacts on aquatic habitat or species. Regarding the 50th percentile wetted perimeter estimates (representing normal, non-drought conditions; Table 7), relative to Alternative A, the implementation of Alternative B under both demand scenarios would reduce the 50th percentile wetted perimeter by a small amount at all of the five modeled locations. The average 50th percentile wetted perimeter reduction at all locations is 0.6 ft (about 7 inches); the average channel width at these locations is about 138 ft.

The maximum reductions in 50th percentile wetted perimeter values under Alternative B are for the Tarpley Bluff location (0.9 ft reduction for recent water demands and 0.9 ft reduction for projected water demands; Table 7). Note that there is no difference between the alternatives for the winter 50th percentile wetted perimeter estimates (Table 7) because TVA would be releasing a surplus from the reservoir relative to the Shelbyville flow target in the winter. Therefore, the net savings in reservoir storage are manifesting as slightly more flow downstream due to higher reservoir elevations compared to Alternative A. This nearly identical flow equates to the same wetted perimeter estimates for the two alternatives during the winter period.

However, during periods of low water, Alternative B is predicted to conserve water in Normandy, resulting in an increase in reservoir elevation approximately 25% of the time compared to Alternative A (Figure 5). This difference in reservoir elevation during low water conditions may reach as much as 2 ft under Alternative B (Figure 5). This increase is anticipated to have a slightly beneficial impact to the aquatic habitat and species in the reservoir as more habitat would be available, and lower reservoir elevations can lead to increased water temperatures and chlorophyll concentrations, and consequent decreases in DO concentrations.

Table 7. Modeled 50th percentile wetted perimeter (ft) for Alternatives A and B with 2015 and 2040 water demands at five surveyed Duck River locations during summer and winter periods.

Demand	Season	Alternative	Surveyed River Locations				
			Tarpley Bluff	Lillard Mill	Venable Spring	Hooper Island	Riverside Park
Recent - 2015	Summer	A	127.6	160.6	165.9	132.0	70.7
		B	126.7	159.9	165.2	131.6	70.6
		Change	-0.7%	-0.4%	-0.4%	-0.3%	-0.1%
	Winter	A	140.2	169.7	174.9	158.4	70.9
		B	140.2	169.7	174.9	158.5	70.9
		Change	0.0%	0.0%	0.0%	-0.1%	0.0%
Projected - 2040	Summer	A	127.6	160.6	165.9	131.9	70.5
		B	126.7	159.9	165.2	131.4	70.4
		Change	-0.7%	-0.4%	-0.4%	-0.4%	-0.1%
	Winter	A	140.2	169.7	174.9	158.4	70.9
		B	140.2	169.7	174.9	158.4	70.9
		Change	0.0%	0.0%	0.0%	0.0%	0.0%

Notes: Percentage values are percent change in wetted perimeter from Alternative A to Alternative B; all other values represent 50th percentile wetted perimeter (ft) in Duck River.

The lowest modeled wetted perimeter values (representing drought conditions) under Alternative B would be reduced relative to Alternative A during both seasons and water demand scenarios (Table 8; Appendix D). Similar to the 50th percentile estimates, the implementation of Alternative B would temporarily reduce the lowest wetted perimeter values by a small amount at all locations. The average lowest percentile wetted perimeter reduction at all locations is 0.9 ft in the summer for both demand scenarios and 0.4 ft in the winter for both demand scenarios. The maximum reductions in the lowest wetted perimeter values under Alternative B are for the Tarpley Bluff location (1.5 ft reduction in the summer for both demand scenarios and 0.9 ft reduction in the winter for both demand scenarios; Table 8).

Table 8. Modeled lowest wetted perimeter (ft) for Alternatives A and B with 2015 and 2040 water demands at five surveyed Duck River locations during summer and winter periods.

Demand	Season	Alternative	Surveyed River Locations				
			Tarpley Bluff	Lillard Mill	Venable Spring	Hooper Island	Riverside Park
Recent - 2015	Summer	A	119.5	151.1	153.8	118.9	62.6
		B	118.1	150.2	152.5	118.2	62.0
		Change	-1.2%	-0.6%	-0.8%	-0.6%	-1.0%
	Winter	A	114.7	147.4	149.7	117.8	63.6
		B	113.8	146.6	148.9	117.5	63.3
		Change	-0.8%	-0.5%	-0.5%	-0.3%	-0.5%
Projected - 2040	Summer	A	119.6	151.1	153.8	118.8	61.9
		B	118.1	150.2	152.8	118.2	61.3
		Change	-1.3%	-0.6%	-0.7%	-0.5%	-1.0%
	Winter	A	114.6	147.5	149.9	117.7	63.0
		B	113.8	146.8	149.0	117.4	62.7
		Change	-0.7%	-0.5%	-0.6%	-0.3%	-0.5%

Notes: Percentage values are percent change in wetted perimeter from Alternative A to Alternative B; all other values represent lowest wetted perimeter (ft) in Duck River.

Under recent water demands, any deviation in the lowest wetted perimeter with Alternative B, relative to Alternative A, is predicted to occur >50% of the time. During the winter months, deviations in wetted perimeter from Alternative A are predicted to occur <1% to 9% of the time across the five sites. Under projected water demands, any deviation in wetted perimeter with Alternative B, relative to Alternative A, is predicted to occur >50% of the time during summer and approximately 4% in the winter.

A temporary decrease in the wetted perimeter of the Duck River during some of the year under Alternative B is not likely to impact birds, fish, or semi-aquatic mammals (e.g., mink, raccoon, muskrat, river otters, beavers) as these species are mobile and could easily acclimate to these changes. However, a temporary reduction in wetted perimeter may impact species that are generally non-motile (e.g., freshwater mussels and other sessile invertebrates, aquatic plants). While the minor reductions in wetted perimeter associated with the implementation of optimization generally correlates with a reduction in available freshwater mussel habitat, it is important to note that these drought-influenced decreases would be rare. When severe droughts do occur, the reduction of mussel habitat would be minimal, gradual, and temporary. Furthermore, most mussel species and individuals occupy habitat towards the middle of the channel which would remain unaffected.

Reductions in flow and wetted perimeter can be especially acute for juvenile mussels. Ahlstedt et al. (2017) designed a study to examine juvenile mussel distribution across the Duck River channel at Hooper Island in August of 2003 when the base flow at this location was approximately 300 cfs. Ten transects were set 10 meters apart and mussel samples were collected at 1-, 4-, and 7-meter distances from the channel margin. Results of this study indicated that, while there was no difference in overall mussel density (all life stages) at the 1-, 4-, and 7-meter distances from the channel margin, the density of juvenile mussels was significantly higher at the channel margin (i.e., the 1 m distance).

Non-juvenile mussels can use behavioral measures to avoid desiccation (Gagnon et al. 2004; e.g., movement towards water, burrowing into sediment). Therefore, if temporary, short-term reductions in flow and wetted perimeter occur gradually, as they would under normal (i.e., non-drought) conditions, it is unlikely that substantial population-level impacts to mussel species would occur.

In contrast, reductions in flow and wetted perimeter brought about by prolonged drought conditions could have moderate to substantially adverse impacts on the aquatic habitat and non-motile species of Normandy Reservoir and Duck River. Under these conditions, the implementation of Alternative B may ameliorate some of these impacts. As discussed in Section 3.1, under low water conditions the implementation of Alternative B would increase reservoir elevations approximately 25% of the time (relative to Alternative A). Under drought conditions, more water would be available for release to the Duck River to increase flow, wetted perimeter, DO, and wastewater assimilative capacity – all of which would have a positive impact on aquatic habitat and species. The release of additional water to Duck River could be particularly important to mussel species as severe drought conditions have been shown to cause punctuated mass mortality events in some waterbodies (Vaughn et al. 2015), and these die-off events can have cascading, long-term impacts on aquatic ecosystems (DuBose et al. 2019). The implementation of Alternative B provides TVA with additional flexibility to manage water quantity or quality issues in the Duck River and is therefore considered to have slightly beneficial impacts on aquatic habitat and species, especially during drought conditions.

3.4 Threatened and Endangered Species

The Endangered Species Act (ESA) mandates that federal agencies conserve listed species, which includes evaluating effects of agency actions on threatened and endangered species and their critical habitat. Threatened species include those that have been determined to likely become endangered in the near future; endangered species are those that have been documented to be in danger of extinction within all or a substantial extent of their range. Under Section 7 of the ESA, federal agencies are required to consult with the USFWS when actions may impact threatened or endangered species and/or their designated critical habitats. State-listed species are also considered in this EA.

3.4.1 Affected Environment

The Duck River contains Federally and State-listed species, including freshwater mussels at relatively high density and diversity in contrast to other rivers in the Tennessee River watershed (Ahlstedt 1991), thus the Duck River serves as a notable refugia for species in need of conservation (Cumberlandian Region Mollusk Restoration Committee [CRMRC] 2010).

The USFWS Information for Planning and Consultation (IPaC) system was consulted to identify federally-listed species that could be impacted by the alternatives considered herein (Appendix E). The location used for the IPaC inquiry included the Upper and Lower Duck River watersheds (i.e., from Normandy Dam to the Tennessee River) and Normandy Reservoir. The IPaC query indicated that listed species potentially within the project area include three bats, two fish, 18 mollusk species, and four vascular plants (Table 9). Proposed endangered or threatened species within the project area include one bat, one turtle, and four mollusk species (Table 9). A query of the TVA Natural Heritage Database identified additional listed mollusks as potentially occurring within the project area (Table 9). Regarding bats, there are two caves along the shoreline of Normandy Reservoir that are known habitat for bat species. The tricolored bat has been observed in these caves during the winter hibernation period, and the gray bat uses these caves for hibernation as well as a maternity roost during the summer. Additional caves occur along the Duck River with records of tricolored bat.

The IPaC system also indicated that the Upper and Lower Duck River watersheds serve as designated critical habitat for six species: Cumberlandian combshell, fluted kidneyshell, oyster mussel, rabbitsfoot, round hickorynut, and slabside pearlymussel. In August 2023, the USFWS proposed designated critical habitat for the Tennessee pigtoe, Tennessee clubshell, and cumberland moccasinshell throughout their entire ranges.

Table 9. Species Reported from the Duck River (DRM 249-DRM 70) by the USFWS IPaC System and TVA's Natural Heritage Database.

Common Name	Scientific Name	Federal Status	State Status
Bats			
Gray Bat	*Myotis grisescens*	E	E-S2
Indiana Bat	*Myotis sodalis*	E	E-S1
Northern Long-eared Bat	*Myotis septentrionalis*	E	E-S1S2
Tricolored Bat	*Perimyotis subflavus*	PE	T-S2S3
Reptiles			
Alligator Snapping Turtle	*Macrochelys temminckii*	PT	T-S2S3
Fishes			
Ashy Darter	*Etheostoma cinereum*	None	T-S2S3
Barrens Topminnow	*Fundulus julisia*	E	NOST
Bedrock Shiner	*Notropis rupestris*	None	NMGT-S2
Blotchside Logperch	*Percina burtoni*	None	NMGT-S2
Blue Sucker	*Cycleptus elongatus*	None	T-S2
Coppercheek Darter	*Etheostoma aquali*	None	T-S2S3
Egg-mimic Darter	*Etheostoma pseudovulatum*	None	E-S1
Flame Chub	*Hemitremia flammea*	None	NMGT-S3
Golden Darter	*Etheostoma denoncourti*	None	NMGT-S2
Highfin Carpsucker	*Carpiodes velifer*	None	NMGT-S2S3
Pygmy Madtom	*Noturus stanauli*	E	E-S1
Redband Darter	*Etheostoma luteovinctum*	None	NMGT-S4
Saddled Madtom	*Noturus fasciatus*	None	T-S2
Slenderhead Darter	*Percina phoxocephala*	None	NMGT-S3
Southern Brook Lamprey	*Ichthyomyzon gagei*	None	NMGT-S1
Striated Darter	*Etheostoma striatulum*	None	T-S1
Plants			
Leafy Prairie-clover	*Dalea foliosa*	E	E-S2S3
Price's Potato-bean	*Apios priceana*	T	E-S3
Short's Bladderpod	*Physaria globosa*	E	E-S2
Tennessee Yellow-eyed Grass	*Xyris tennesseensis*	E	E-S1
Mollusks			
Birdwing Pearlymussel	*Lemiox rimosus*	E	E-S1
Cincinnati Riffleshell	*Epioblasma phillipsi*	None	NOST
Clubshell	*Pleurobema clava*	E	E-SH
Cracking Pearlymussel	*Hemistena lata*	E	E-S1
Cumberland Moccasinshell	*Medionidus conradicus*	PE	NOST
Cumberland Monkeyface	*Theliderma intermedia*	E	E-S1
Cumberlandian Combshell	*Epioblasma brevidens*	E	E-S1
Fanshell	*Cyprogenia stegaria*	E	E-S1
Fluted Kidneyshell	*Ptychobranchus subtentus*	E	E-S2
Littlewing Pearlymussel	*Pegias fabula*	E	E-S2
Longsolid	*Fusconaia subrotunda*	T	NOST
Orangefoot Pimpleback	*Plethobasus cooperianus*	E	E-S1
Oyster Mussel	*Epioblasma capsaeformis*	E	E-S1

Common Name	Scientific Name	Federal Status	State Status
Pale Lilliput	*Toxolasma cylindrellus*	E	E-S1
Pink Mucket	*Lampsilis abrupta*	E	E-S2
Purple Cat's Paw	*Epioblasma obliquata*	E	E-S1
Rabbitsfoot	*Theliderma cylindrica cylindrica*	T	NOST-S3
Rayed Bean	*Villosa fabalis*	E	NOST-S1
Ring Pink	*Obovaria retusa*	E	E-S1
Round Hickorynut	*Obovaria subrotunda*	T	T-S2S3
Salamander Mussel	*Simpsonaias ambigua*	PE	NOST-S1
Scaleshell Mussel	*Leptodea leptodon*	E	NOST
Sheepnose Mussel	*Plethobasus cyphyus*	E	E-S2S3
Slabside Pearlymussel	*Pleuronaia dolabelloides*	E	E-S2
Snuffbox Mussel	*Epioblasma triquetra*	E	E-S3
Spectaclecase	*Cumberlandia monodonta*	E	E-S2S3
Tennessee Clubshell	*Pleurobema oviforme*	PE	NOST-S2S3
Tennessee Pigtoe	*Pleuronaia barnesiana*	PE	NOST
Tubercled Blossom	*Epioblasma torulosa torulosa*	E	EX-SX
Turgid Blossom	*Epioblasma turgidula*	E	EX-SX
Winged Mapleleaf	*Quadrula fragosa*	E	S1-E

Notes: E-endangered; T-threatened; PE-proposed endangered; PT-proposed threatened; NOST-no official state status; S1-critically impaired; S2-very rare/state imperiled; S3-rare and uncommon in state. Table does not include candidate species or species with experimental populations within the project area.

TVA's Natural Heritage Database was consulted to identify the state-listed species that could be impacted by the proposed action. This database records species that have been encountered in the 201-county area included in TVA's power service area. The species lists provided herein (Table 9) include those state-listed or state special concern species that have been reported from Duck River mile 249 (Lyndell Bell Road crossing of Normandy Reservoir) to Duck River mile 70 (Minnow Branch Road near Centerville, TN).

Taken together, these two sources (i.e., IPaC and TVA Natural Heritage Database) identify that four bat species, one turtle, 16 fish species, 31 mollusk species, and four vascular plants have the potential to be within the project area. In addition to these species, migratory birds are considered herein to address the Responsibilities of Federal Agencies to Protect Migratory Birds Executive Order for Migratory Birds (EO 13186). Refer to Appendix F for a detailed discussion of the ecology of some of the mollusk species listed in Tables 9.

3.4.2 Environmental Effects of Alternative A

With Alternative A (no action), the selected recommendation in the ONRR would not be implemented and TVA would continue to operate releases from the dam at Normandy Reservoir according to the current release schedule. Environmental conditions influencing threatened and endangered species would remain unchanged.

3.4.3 Environmental Effects of Alternative B

Under Alternative B, TVA would modify the operation of Normandy Dam by implementing a weekly average flow target at Shelbyville, with a minimum instantaneous flow as described in Section 2.1.2.

Under normal, non-drought conditions, Alternative B is comparable to Alternative A in terms of reservoir elevations, Duck River flows (Table 5), and wetted perimeter estimates (Table 7) and would have no discernible impacts on listed species or their habitats. However, a reduction in wetted perimeter may temporarily impact species that are generally non-motile (e.g., freshwater mussels and other sessile invertebrates, aquatic plants).

During periods of low water (e.g., reservoir elevations below the winter/summer flood guide target), Alternative B is predicted to yield an increase in reservoir elevation approximately 25% of the time compared to Alternative A (Figure 5). This difference in reservoir elevation may reach as much as 2 ft (Figure 5). This increase is anticipated to have a slightly beneficial impact to aquatic species in Duck River as higher reservoir elevations would lead to lower water temperatures and chlorophyll concentrations, and consequent increases in DO concentrations.

Regarding the Duck River, the lowest wetted perimeter values (representing drought conditions) under Alternative B are predicted to decrease (relative to Alternative A) by an average of 0.9 ft in the summer and 0.4 ft in the winter (Table 8). During the summer period, deviations in wetted perimeter (relative to Alternative A) are predicted to occur >50% of the time across the five locations and winter deviations are predicted to occur between 1% to 9% of the time.

Impacts to Listed Mollusks – As noted above, the IPaC query and TVA's Natural Heritage Database identified 31 species of mollusks as potentially occurring within the project area (Table 9). TVA has initiated consultation with USFWS under Section 7 of the ESA regarding potential impacts to the following freshwater mussel species: Birdwing Pearlymussel, Cracking Pearlymussel, Cumberland Moccasinshell (proposed), Cumberland Monkeyface, Cumberlandian Combshell, Fanshell, Fluted Kidneyshell, Littlewing Pearlymussel, Longsolid, Oyster Mussel, Pale Lilliput, Pink Mucket, Purple Cat's Paw, Rabbitsfoot, Rayed Bean, Ring Pink, Round Hickorynut, Salamander Mussel (proposed), Scaleshell Mussel, Sheepnose Mussel, Slabside Pearlymussel, Snuffbox Mussel, Spectaclecase, Tennessee Clubshell (proposed), Tennessee pigtoe (proposed), and Winged Mapleleaf. These 26 mussels may potentially be affected by implementation of Alternative B, although such effects would be minor. As discussed below, Alternative B is expected to have no effect on five of the 31 mussel species.

There would be no effects on five of the species listed on Table 9 because it is unlikely that they occur in the Duck River. Three mussels (Cincinnati Riffleshell, Orangefoot Pimpleback, and Tubercled Blossom), are questionable as to their occurrence in the Duck River despite published records (Parmalee and Bogan, 1998; Isom and Yokley, 1968). A single 1885 record of Cincinnati Riffleshell is considered doubtful (Ahlstedt, pers. comm. 2020), as is a single record of Tubercled Blossom (considered to be an Ohio River basin endemic) found by Herb Athearn (Ahlstedt, pers. comm. 2020). Both Cincinnati Riffleshell and Tubercled Blossom are considered extinct, with Cincinnati Riffleshell last being seen alive at various locations in the late

1800s and Tubercled Blossom last being seen alive in the Kanawha River, West Virginia, in 1969. The Orangefoot Pimpleback specimen found below Columbia Dam in 1968 was likely a misidentification (Ahlstedt, pers. comm. 2020). Turgid Blossom is also now considered extinct, with the last specimen observed alive in 1972 in the area that is now impounded by the Normandy Dam. Clubshell was dismissed because, though certain Tennessee clubshell (i.e., egg-shaped) specimens can have a superficial resemblance to Clubshell specimens, they are widely regarded as being unknown from the Duck River.

Four of the 26 freshwater mussels (Littlewing Pearlymussel, Ring Pink, Scaleshell Mussel, and Sheepnose Musselare) are unlikely to be affected by Alternative B because records indicate that these species have been extirpated or have extremely low population numbers in the Duck River.

For the remaining 22 species of freshwater mussels, Alternative B is not likely to have negative impacts on these species. Designated Critical Habitat Units for the following six species are present in the Duck River: Cumberlandian Combshell, Fluted Kidneyshell, Oyster Mussel, Rabbitsfoot, Round Hickorynut, and Slabside Pearlymussel. In August 2023, the USFWS proposed Designated Critical Habitat for the Tennessee Pigtoe, Tennessee Clubshell, and Cumberland Moccasinshell. There would be no destruction or adverse modifications to proposed critical habitat for these species due to the drought-influenced short-term decreases in wetted perimeter associated with the implementation of Alternative B.

While the minor reductions in wetted perimeter associated with the implementation of Alternative B generally correlate with a reduction in available freshwater mussel habitat, it is important to note that these decreases, including drought-influenced decreases, would be rare. When decreases in wetted perimeter do occur, the reduction of mussel habitat would be gradual and temporary. Furthermore, most mussel species and individuals occupy habitat towards the middle of the channel which will remain unaffected. Only a few federally-listed species are known to inhabit the stream margins nearest the bank (namely Cumberland Monkeyface and Rabbitsfoot). Neither of these species were found at high densities during the 2015 TWRA survey of Duck River segments at Tarpley Bluff, Lillard Mill, Venable Spring, Hooper Island, and Riverside Park. The most common federally-listed species surveyed at Lillard Mill and Hooper Island was Birdwing Pearlymussel. While a small portion of the marginal habitat for this species may be temporarily reduced under Alternative B, desiccation stress could be avoided via vertical (i.e., burrowing deeper into sediments) and/or horizontal movement in a distinct path towards the flowing water. According to Amyot and Downing (1997), the horizontal movement of freshwater mussels can be on the order of a few meters – enough to avoid stress from the gradual and temporary reductions in wetted perimeter expected during a drought from the implementation of Alternative B.

The implementation of Alternative B is predicted to increase Normandy Reservoir elevations approximately 25% of the time during low water conditions (relative to Alternative A). The availability of this additional water may have a positive effect on freshwater mussel species under severe drought conditions as more water could be released by TVA to the Duck River to increase flow, wetted perimeter, DO, and wastewater assimilative capacity – all of which would have a positive impact on aquatic habitat and species. The release of additional water to Duck

River could be particularly important to mussel species as severe drought conditions have been shown to cause punctuated mass mortality events in some waterbodies (Vaughn et al. 2015). The implementation of Alternative B provides TVA with additional flexibility to manage water quantity or quality issues in the Duck River and is therefore considered to have beneficial impacts to rare, threatened, and endangered species, especially during critical drought conditions.

TVA has no documented records of Alligator Snapping Turtle in any of the counties potentially impacted by the proposed action. As mentioned above, TVA's proposal may have a positive effect on aquatic species under severe drought conditions as more water could be released by TVA to the Duck River to increase flow, wetted perimeter, DO, and wastewater assimilative capacity – all of which would have a positive impact on aquatic habitat and species, including the alligator snapping turtle. During low water conditions, an increase in the wetted perimeter may reduce available nesting habitat; however, no records of this species, or their nests, have been documented from Normandy Reservoir or the Duck River.

Impacts to Listed Fish – The small, temporary reductions in flow associated with Alternative B would have no effect on the Duck River fish assemblage – including the rare, threatened, and endangered species listed in Table 9. Duck River water quality modeling (described in Section 3.3) indicated that Alternative B is not expected to cause ammonia toxicity at any of the modeled locations and, under the most realistic boundary condition (7.13 mg L^{-1} measured in the Duck River for this modeling effort), DO concentrations were not below the 5.0 mg L^{-1} criteria at any location. Moreover, should Duck River water issues arise for any reason (e.g., severe drought, algal blooms, etc.), the additional water stored in Normandy Reservoir as a result of Alternative B can be released to ameliorate these impacts. Because fish are likely to move towards more favorable conditions associated with water quantity and water quality, no impacts to fish are expected.

Impacts to Listed Bats – The implementation of Alternative B would have no effect on the bat species listed on Table 9. As mentioned above, there are two caves along the shoreline of the reservoir that provide habitat for bats (tri colored bat in the winter and the gray bat in the summer and winter). Bat movements to and from these caves would not be affected by the implementation of Alternative B as the maximum reservoir elevation is dictated by the flood guide not by the implementation of this alternative (i.e., if the reservoir elevation were above the flood guide target, TVA would release water until the reservoir elevation is at or near this target). Moreover, the implementation of this alternative would not impact other bat roosting or maternity habitats (trees, caves, crevices in rock formations, etc.), and the predicted increase in the area of the reservoir elevation during low water conditions (relative to Alternative A) is likely to increase the number of available food items (i.e., adult aquatic insects) for bats. The reductions in Duck River flow associated with Alternative B are also unlikely to significantly impact listed bat species as these reductions would be small and temporary and these wide-ranging species have plenty of foraging options. All caves with documented bat use occur at elevations well above the water line (high on bluffs), or far enough away from the river's edge such that they would not be impacted by any changes in wetted perimeters.

Impacts to Listed Plants – The implementation of Alternative B would have no effect on the vascular plants listed on Table 9. Three of the four plant species listed on Table 9 are plants that typically do not inhabit the margins of streams and therefore would not be affected by decreases in wetted perimeter. The leafy prairie-clover (*Dalea foliosa*) is typically found in open habitats with thin, calcareous soils. Price's Potato-bean (*Apios priceana*) thrives in open, wooded areas, often in forest gaps or along forest edges. Short's Bladderpod (*Physaria globosa*) is found in dry limestone cliffs, barrens, cedar glades, steep wooded slopes, and talus areas. The Tennessee yellow-eyed grass (*Xyris tennesseensis*) does grow in open areas in wet habitat types such as streambanks, seeps, fens, and wet meadows, but the projected temporary, minor changes to the wetted perimeter are not likely to impact this species.

Impacts to Migratory Bird Species - The implementation of Alternative B would not affect migratory bird species as the reductions in Duck River flow associated with Alternative B would be small and temporary, and would not noticeably impact the availability of stopover migration habitat along the Duck River. The predicted increase in the area of the reservoir elevation during low water conditions (relative to Alternative A) would likely increase the number of available food items (i.e., adult aquatic insects) for migratory birds that forage over open water. This would be a minor beneficial effect to birds.

3.5 Wetlands

3.5.1 Affected Environment

Wetlands are areas inundated by surface or groundwater often enough to support vegetation or aquatic life that requires saturated or seasonally saturated soil conditions for growth and reproduction. Wetlands generally include swamps, marshes, bogs, and similar areas such as sloughs, potholes, wet meadows, mud flats, and natural ponds. Executive Order 11990 requires all Federal agencies to minimize the destruction, loss, or degradation of wetlands and to preserve and enhance the natural and beneficial values of wetlands in carrying out the agency's responsibilities.

This EA uses the National Wetland Inventory (NWI) to identify the occurrence of potential wetland areas. The NWI is a planning and assessment tool that uses trained image analysts and high-altitude aerial imagery to indicate the potential presence of wetlands using the USFWS definition of wetlands (Cowardin et al. 1979).

The NWI maps depict a total of 201 acres of potential wetland area from Normandy Dam to Shelbyville, within 0.25-miles of Duck River (Figure 7). NWI identifies these wetlands as Freshwater Emergent Wetlands, Freshwater Forested/Shrub Wetlands and Freshwater Ponds. There is a relatively even distribution of these wetlands from Normandy Dam to Shelbyville, in general, mostly clustered around areas where tributaries enter Duck River. The NWI maps depict a total of 250 acres of wetlands surrounding Normandy Lake, within a 0.25-mile radius (Figure 8). NWI identified wetlands in the upper eastern boundary of the Lake, at the confluence of Hale Branch. NWI identifies these wetlands as Freshwater Forested/Shrub Wetlands, with less than 10 total acres being identified as Freshwater Emergent Wetlands and Freshwater Ponds.

3.5.2 Environmental Effects of Alternative A

With Alternative A (no action), the selected recommendation in the ONRR would not be implemented and TVA would continue to operate releases from the dam at Normandy Reservoir according to the current release schedule. Environmental conditions influencing wetlands would remain unchanged.

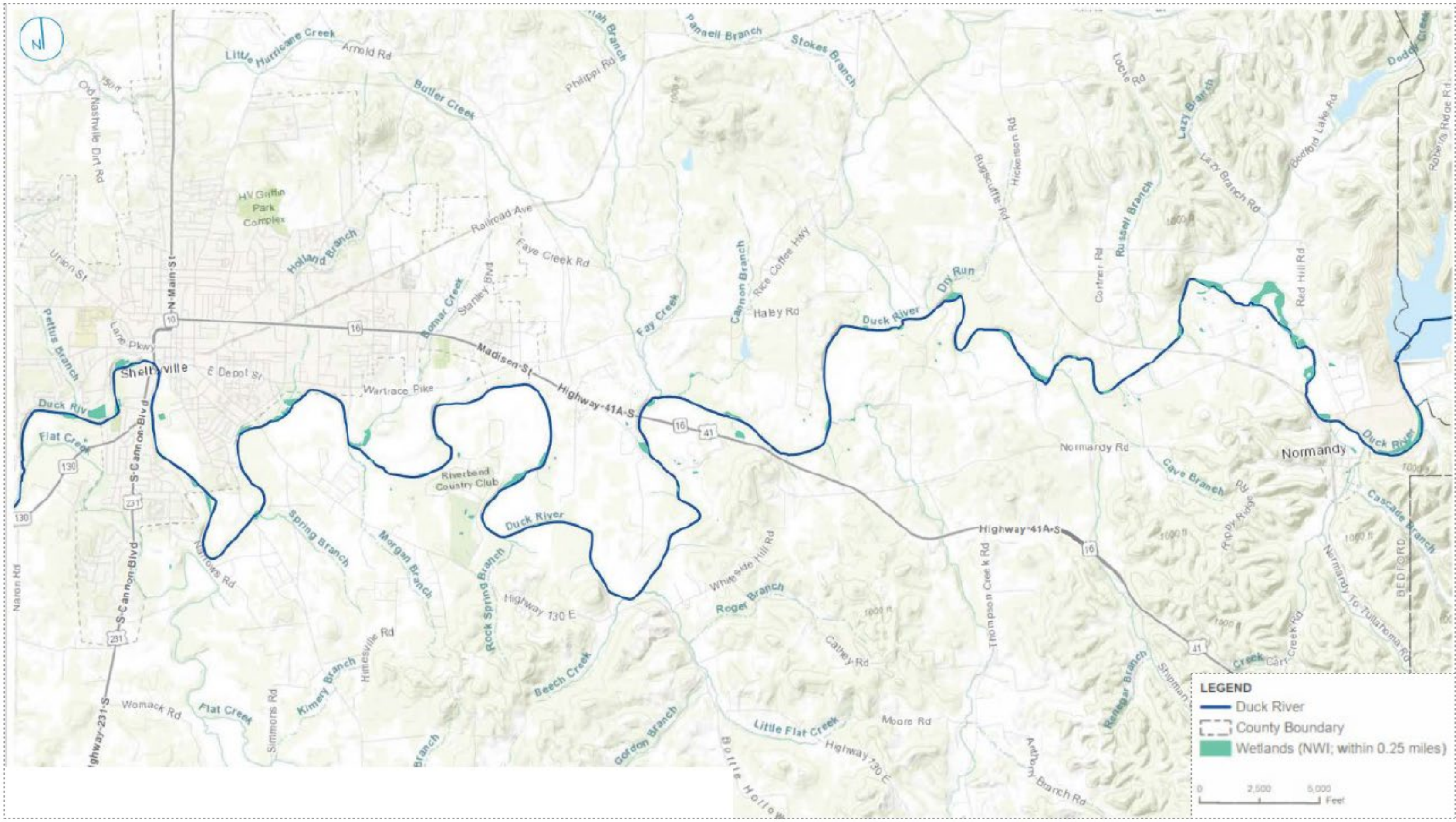

Figure 7 – National Wetland Inventory Map – Duck River

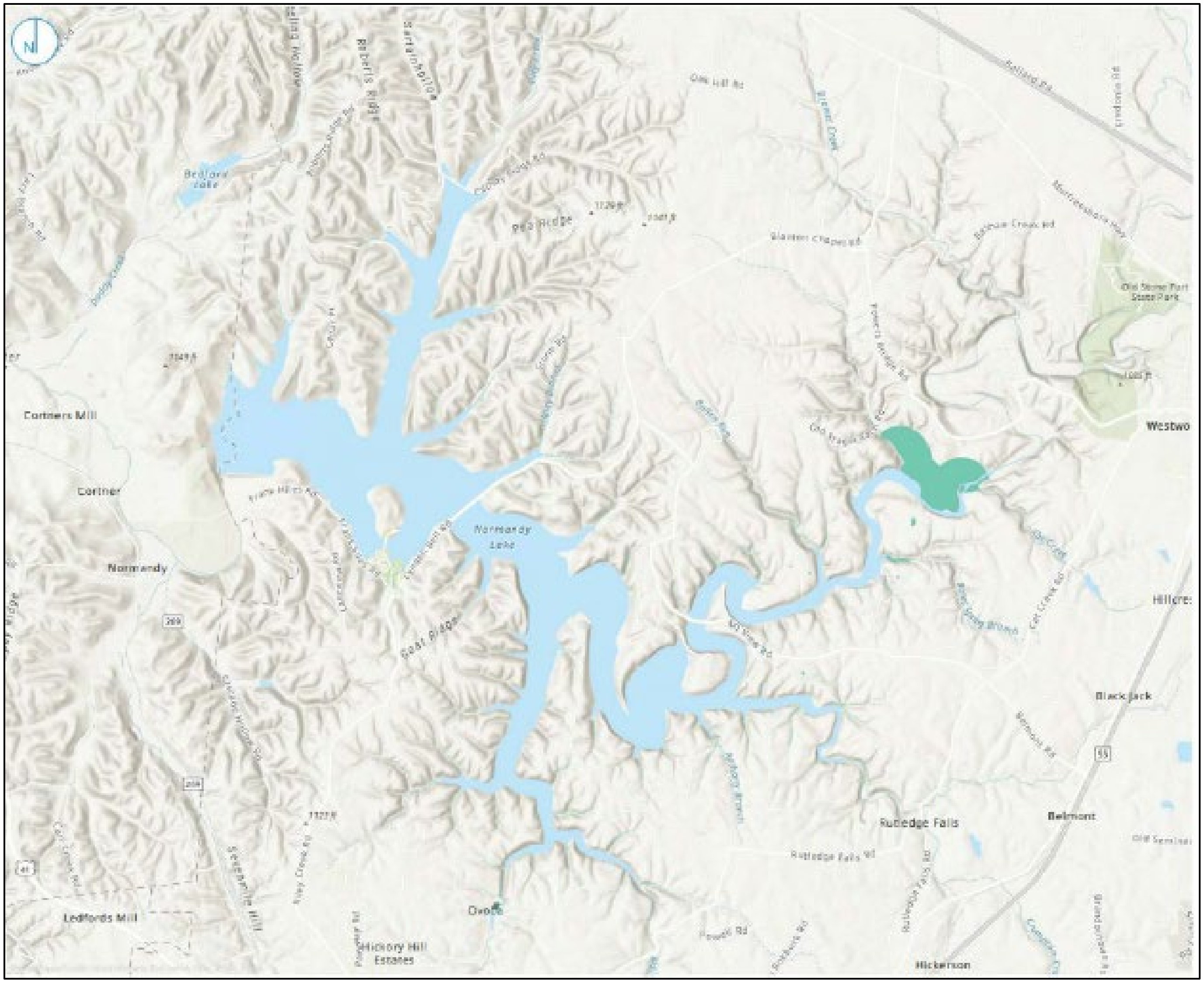

Figure 8 – National Wetland Inventory Map – Normandy Reservoir

3.5.3 Environmental Effects of Alternative B

Under Alternative B, TVA would modify the operational releases from Normandy Dam to a weekly average flow target at Shelbyville, with a minimum instantaneous flow as described in Section 2.1.2. The primary mechanism whereby the implementation of Alternative B could impact wetlands is by changing the near-shore hydrology through a temporary and minor decrease in the wetted perimeter of the Duck River and Normandy Reservoir.

As discussed in Section 3.1, during periods of low water (e.g., reservoir elevation below the winter/summer flood guide target), the implementation of Alternative B is predicted to conserve water in Normandy, resulting in an increase in reservoir elevation approximately 25% of the time compared to Alternative A (Figure 5). This difference in reservoir elevation may reach as much as 2 ft under Alternative B (Figure 5). Wetlands typically require saturation only two weeks out of the year during the growing season to exhibit defining characteristics. Normandy Reservoir elevations, as predicted by the OASIS model, have varied considerably during the modeling period (1921-2016). Typical reservoir elevations fluctuate between 865 ft and 875 ft, but extremes of greater than 880 ft and less than 860 ft have been reached on several occasions. As this historical variation in reservoir elevation is likely to capture the above-referenced changes associated with the implementation of Alternative B, it is unlikely that this action will have an impact on the wetland surrounding Normandy Reservoir.

Wetlands that are connected or adjacent to the Duck River can be divided into two groups: 1) wetlands that are clustered around a Duck River/tributary confluence, and 2) wetlands adjacent to the Duck River that are not near a confluence. These groups are discussed below.

The hydrology of wetlands that are clustered around the confluence of the Duck River with one of its tributaries are at least partially controlled by tributary flow. Since the implementation of Alternative B will not affect tributary flow, the proposed action is not expected to have negative effects on these wetlands.

For wetlands that receive the majority of their hydrology from the Duck River, it is possible that a temporary decrease in the wetted perimeter brought about by Alternative B could have negative impacts. These impacts are less likely during normal (non-drought) conditions, when flows and wetted perimeters are higher relative to drought conditions. While the implementation of Alternative B is expected to temporarily decrease Duck River flow and wetted perimeters, predicted values under normal (non-drought) conditions would still be high enough to support adjacent wetlands. Therefore, the implementation of Alternative B is unlikely to result in adverse impacts to wetlands adjacent to the Duck River under normal conditions.

Under Alternative B, the lowest wetted perimeter values (representing drought conditions) are predicted to decrease (relative to Alternative A) by an average of 0.9 ft in the summer and 0.4 ft in the winter (Table 8). It is unlikely that these small, temporary reductions in lowest wetted perimeter would have negative impacts on wetlands adjacent to the Duck River. In addition, much of the wetland acreage within 0.25 miles of the river is characterized as Freshwater Forested/Scrub-Shrub Wetlands. The riparian trees and shrubs that comprise this wetland type typically have deep root systems so it is likely that adequate water could be accessed in spite of a 1.0 ft decrease in the wetted perimeter.

The degree of wetland impacts from Alternative B would be related to the extent and duration of drought conditions. The highest potential for negative impacts would be during periods of prolonged drought. TVA indicates that a typical drought duration for the Duck River watershed is 3 - 6 months. However, longer duration droughts have been observed (e.g., the 1988 drought duration was 9 - 12 months and the 2007-2008 drought duration was 13 months).

Drought frequency and duration have the potential to increase in the future. According to Rungee and Kim (2017), the southeastern United States is likely to experience more severe droughts in the future due to the periodicity between rainfalls, elevated temperatures, and increased evaporation and evapotranspiration rates brought about by global climate change. Severe drought conditions can impact riparian forests by reducing biomass, decreasing seedling survival, and changing species composition and richness (Garssen et al. 2014). However, it is possible that the implementation of Alternative B would have a positive impact on the Duck River wetlands during severe drought conditions when compared to Alternative A. The increase in reservoir elevation predicted under this alternative would be available for release during drought conditions to help meet the basin's water quantity/quality needs. This water would also be available to adjacent wetland vegetation during this critical period. Therefore, it is concluded that the implementation of Alternative B is likely to have a slightly beneficial impact on the resilience of wetlands adjacent to the Duck River during drought conditions.

3.6 Climate Change

3.6.1 Affected Environment

This section addresses the regional climate of the Normandy Reservoir and Duck River study area and whether implementation of the proposed alternative could affect climate trends. This section also evaluates whether climate trends would affect the implementation of the proposed alternative.

Climate is the long-term regional average of temperature, precipitation, and humidity. Climate change is defined as a change in these conditions over a long period of time on a regional or global scale. The Sixth Intergovernmental Panel on Climate Change (IPCC) Assessment Report (2022) reported that climate change is occurring at an accelerated rate - exceeding any pace of change in the Earth's climate over the last 10,000 years. The observable impacts from climate change include increased droughts and floods, shifts in seasonal temperature ranges, accelerated sea level rise, adverse health effects, and other manifestations (IPCC 2022).

The Fourth National Climate Assessment (2018) details the impacts, risks, and adaptations to climate change for ten U.S. regions including the southeast. The report identifies recent (e.g., extreme precipitation) and future (e.g., high temperatures and humidity) risks for the southeast region and flags the potential for disproportionate effects for rural and disadvantaged communities (USGCRP 2018). Heat waves are expected to become more frequent and longer in duration, as are the duration and intensity of droughts (USGCRP 2018). Other climate-related trends observed or predicted for the southeast region of the United States include a higher prevalence of vector-borne disease and wildfires, impacts to infrastructure, transportation, and power, shifts in species and ecotypes and elevated risk to agricultural productivity (USGCRP 2018).

3.6.1.1 Climate Change in Tennessee

The effects of a changing climate may have profound local impacts in the Tennessee Valley region. For example, changes in temperature and precipitation can contribute to more frequent and severe flooding and drought conditions, reductions in ecosystem and human health, and detract from economic vitality (USEPA 2016). Although Tennessee is among States that have seen the least warming due to natural cycles and sulfates in the atmosphere, changes to emissions and weather patterns suggest this circumstance is likely to end, with temperatures in Tennessee expected to increase over time (USEPA 2016).

Tennessee has also witnessed increases in average annual rainfall since the first half of the 20th century (USEPA 2016). In the southeastern United States, fall precipitation has increased 30 percent in the last 120 years and spring rainfall is also likely to continue to rise over the next half century leading to the potential for increased flooding (USEPA 2016; Rungee and Kim 2017). Despite the observed and expected trends in precipitation, the southeastern United States is also likely to experience more severe droughts due to the periodicity between rainfalls, elevated temperatures, and increased evaporation and evapotranspiration (USEPA 2016, Rungee and Kim 2017). Importantly, these conditions are likely to influence the operational needs and approaches to the management of TVA's reservoir network system, including modifications to procedures necessary to maintain downstream water quality, quantity, and safety.

In acknowledgement of the need to incorporate climate resilience into regional planning efforts and in response to Executive Order 13834, TVA has developed a Climate Change Adaptation and Resiliency Plan which incorporates the latest information, science, and technology to guide strategy and decision-making (TVA 2020). Plan implementation includes addressing data gaps and improving understanding of climate change-related impacts to specific elements of TVA's operational footprint.

Further, TVA is currently in the final year of a multi-year project in support of determining climate change impacts on the river systems managed in the Tennessee Valley. This climate change study will be developed utilizing the results of various global climate models run by the Oak Ridge National Laboratory and downscaled to the region. The precipitation and temperature data from those models will then be utilized within TVA's operational framework to determine the extent to which climate changes could impact key benefit areas such as changes to water supply, flood prevention, navigation, recreation, water quality, and power production.

3.6.2 Environmental Effects

Under the Council on Environmental Quality's (CEQ) *draft National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions and Climate Change* (CEQ 2023), agencies are encouraged to consider the potential effects of a proposed action on climate change and the effects of climate change on a proposed action.

Incremental increases in greenhouse gas (GHG) emissions are recommended as a proxy for evaluating the effect of an alternative on climate change, since fundamentally global warming is a result of added greenhouse gases to the earth's atmosphere. The implementation of the alternatives described herein would not result in GHG emissions, therefore, it is anticipated that the proposed action will not impact climate change. The remainder of this section focuses on the degree to which ongoing climate change would affect the implementation of the alternatives.

Of the many anticipated local impacts of a changing climate, alterations to the hydrologic regime are among the most observable, measured, and germane to the evaluation of alternatives in this EA. Future climate change-related impacts to the hydrologic regime are likely to include increased frequency and severity of both flooding and droughts (USEPA 2016, USGCRP 2018). Although flooding conditions may require TVA to adjust reservoir releases to manage additional water from heavy precipitation events, increases in the frequency and severity of flood conditions due to climate change do not have an effect on the proposed alternative since it yields an increased flexibility in the release of water due to the average flow target. Because climate change-related flooding is not expected to affect either of the actions considered, it is not considered further in this evaluation.

3.6.2.1 Alternative A

The prevalence and severity of climate change-induced droughts is expected to grow in the Tennessee Valley (USEPA 2016). Under Alternative A, TVA would continue to operate Normandy Dam according to the current release schedule. This schedule typically requires the release of "excess water" to account for the 18-hour travel time between Normandy Dam and the Shelbyville USGS gage – yielding less water in Normandy Reservoir. Any drought-related adjustments to the current release schedule are made on an as needed basis and do not benefit from a more organized, long-term planning process. Thus, when considering the exacerbating effects of climate change, the continued implementation of Alternative A would have a slightly adverse impact on TVAs ability to balance the competing needs of downstream human and non-human water users (e.g., drinking water, wastewater assimilation, wildlife habitat, listed species).

3.6.2.2 Alternative B

Alternative B constitutes a revision of the minimum threshold flow tolerance at Shelbyville along with achieving a weekly average flow target rather than an instantaneous measurement as per current operations. The implementation of Alternative B would result in Normandy Reservoir elevations that are up to 2 ft higher than those expected from the continued implementation of Alternative A during drought conditions. While the exact manifestation of climate change in Tennessee is unknown, it is likely that drought conditions will increase in frequency, duration, and severity. Additional water stored in Normandy Reservoir would better ensure that more water is available under prolonged drought conditions to help reduce potential impacts to the Duck River and its users. Thus, despite probable impacts from global climate change, the additional reservoir water provided by the implementation of Alternative B would give TVA greater flexibility to meet its operational goals and would have a slightly beneficial impact on Duck River habitat and downstream water users, especially during prolonged drought conditions.

3.7 Cultural Resources

3.7.1 Affected Environment

Section 106 of the National Historic Preservation Act (NHPA) of 1966 requires that historic properties be taken into consideration during the federal agency planning process. Historic properties are defined as archaeological sites or historic structures that are eligible or potentially eligible for listing in the National Register of Historic Places (NRHP). The NRHP is the official list of historic properties throughout the nation that are worthy of preservation because of their cultural significance and research potential in American history, architecture, and archaeology. Section 110 of the NHPA pertains to historic properties owned by federal agencies and provides responsibility to federal agencies for the identification, evaluation, and protection of these resources.

The Tennessee Valley has a rich cultural heritage. The temperate climate and abundant resources attracted nomadic hunters into the region as early as 12,000 years ago. Through centuries of continuity and conflict, a rich diversity of Native American cultures evolved. This evolution is evidenced by over 11,500 archaeological sites and approximately 5,320 historic structures that have been recorded on or near TVA lands (TVA 2011). The cultural chronology of TVA reservoir lands is typically divided into five broad periods: Paleoindian (10000-8000 BC), Archaic (8000-1000 BC), Woodland (1000 BC-AD 900), Mississippian (AD 900-1600), and Historic (AD 1600 to present).

Efforts to study the pre-history of the Normandy Dam Reservoir started before the dam was constructed. The Normandy Reservoir Salvage Project started in 1970 and was a long-term effort to study the pre-history of the Normandy Dam area. This effort resulted in numerous publications describing the cultural resources of this location (Willard 1982; Brown 1982; Chapman 1978; Faulkner 1977; Faulkner 1978; Faulkner and McCollough 1973; Faulkner and McCollough 1974, Crites 1978; Duggan 1982; DuVall 1977).

Records show that there are several recorded archaeological sites above the normal summer reservoir elevation and also many inundated sites at Normandy Reservoir (TVA 2011). In addition, 93 recorded historic structures have been identified at the reservoir, five of these structures are NRHP-listed and one structure is eligible or potentially eligible for inclusion in the NRHP. Normandy Dam was added to the NRHP on August 11, 2017.

Archaeological resources along the Duck River downstream of the dam have also been identified by Hall (1992), Gordon (1973), and Brakenridge (1982), and include both prehistoric and historic sites.

Federal agencies are required by the National Historic Preservation Act (NHPA) and by the NEPA to consider the possible effects of their undertakings on historic properties. The term "undertaking" means any project, activity, or program that is funded under the direct or indirect jurisdiction of a federal agency or is licensed, permitted, or assisted by a federal agency. An agency may fulfill its statutory obligations under NEPA by following the process outlined in the regulations implementing Section 106 of NHPA, at 36 CFR Part 800. Under these regulations, considering an undertaking's possible effects on historic properties is accomplished through a four-step review process: (1) initiation (defining the undertaking and the area of potential effects (APE), and identifying the consulting parties); (2) identification (studies to determine whether cultural resources are present in the APE and whether they qualify as historic properties); (3) assessment of adverse effects (determining whether the undertaking would damage the qualities that make the property eligible for the National Register of Historic Places (NRHP); and (4) resolution of adverse effects (by avoidance, minimization, or mitigation). An undertaking may have effects on a historic property that are not adverse, if those effects do not diminish the qualities of the property that identify it as eligible for listing on the NRHP. However, if the agency determines (in consultation) that the undertaking's effect on a historic property within the APE would diminish any of the qualities that make the property eligible for the NRHP (based on the criteria for evaluation at 36 CFR 60.4), the effect is said to be adverse. Adverse effects to archaeological sites are typically mitigated by means of excavation to recover the important scientific information contained within the site. Mitigation of adverse effects to historic structures sometimes involves thorough documentation of the structure by compiling historic records, studies, and photographs. Agencies are required to consult with the State of Tennessee Historical Commission, federally recognized Indian tribes, and others throughout the Section 106 process and to document adverse effects to historic properties resulting from agency undertakings.

3.7.2 Environmental Effects of Alternative A

With Alternative A, the selected recommendation in the ONRR would not be implemented and TVA would continue to operate releases from the dam at Normandy Reservoir according to the current release schedule. Because environmental factors influencing the condition of cultural resources would remain unchanged, there would be no effect of Alternative A on these resources.

3.7.3 Environmental Effects of Alternative B

During periods of low water (e.g., reservoir elevation below the winter/summer flood guide target), Alternative B is predicted to yield an increase in reservoir elevation approximately 25% of the time compared to Alternative A (Figure 5). This difference in reservoir elevation may reach as much as 2 ft under Alternative B (Figure 5). With future water demands, Duck River flows are predicted to decrease by a maximum of 5 to 10 cfs, relative to the lowest flow from Alternative A, with a change in flow from Alternative A anticipated to occur ≤ 37% of the time. Depending on the modeling scenario (i.e., recent/future demands, summer/winter) and river location, this decrease in Duck River flow would yield an average decrease in the lowest wetted perimeter of 0.75 ft (range 0 to 1.5 ft) relative to Alternative A measured at Tarpley Bluff, Lillard Mill, Venable Spring, Hooper Island, and Riverside Park.

Reservoir shoreline erosion can disturb or destroy intact archaeological deposits, resulting in a loss of site integrity and adversely affecting site significance. However, the implementation of Alternative B will not result in an increase in reservoir elevation above the summer flood guide target (875 feet) for this reservoir (i.e., an elevation maintained by TVA by releasing excess water to the Duck River). Therefore, Alternative B would not cause archaeological deposits to be subject to new erosional forces. However, when the reservoir is low - below the winter flood guide target (864 feet) - Alternative B is predicted to yield an increase in reservoir elevations approximately 25% of the time compared to Alternative A. This increase has the potential to decrease impacts to cultural resources by decreasing exposure of archaeological sites to vandalism, looting, and inadvertent disturbance from recreational activity.

Under Alternative B, the predicted decrease in Duck River flow is likely to decrease river shoreline erosional forces but increase the amount of exposed shoreline along the Duck River. Relative to Alternative A, the slight reductions in the Duck River flow rate (5 to 10 cfs) associated with Alternative B would not cause erosional impacts to downstream cultural resources. The predicted decrease in flow and wetted perimeter in the Duck River has the potential to increase exposure of downstream cultural resources to vandalism, looting, and recreational activity. However, only a small change in the wetted perimeter is expected under this alternative (0 to 1.5 ft). Therefore, TVA concluded that the implementation of Alternative B will have no impact on the cultural resources associated with Normandy Reservoir or the Duck River. TVA will consult with the State of Tennessee Historical Commission and federally-recognized Indian tribes regarding this determination.

3.8 Socioeconomics, Visual Resources, and Recreation

3.8.1 Affected Environment

3.8.1.1 Socioeconomics

This section focuses on the potential impacts of the proposed alternative on the local socioeconomic character. For the purposes of this assessment, socioeconomic indicators include population change, the Center for Disease Control (CDC) social vulnerability index, and agricultural production were considered.

Rising population drives the demand of many resources, including water. Higher populations, and therefore higher demand, can increase the risk of not having enough water to meet the demands of the community. The population of Tennessee increased by 9.8% from 2010 to 2021 - over 6.9 million people lived in Tennessee in 2021 (Census Bureau, 2022). The populations of Bedford, Coffee, Marshall, and Maury Counties grew by 13.4%, 9.6%, 12.1%, and 24.7%, between 2010 and 2021, respectively.

Socially vulnerable populations may be adversely impacted by rising costs due to drought conditions. Social vulnerability is defined by the CDC as the resilience of communities when experiencing stresses on human health, natural disasters, and disease outbreaks (CDC, 2022). Social vulnerability can further exacerbate economic loss and human suffering during times of elevated stress. The CDC uses 15 United States Census variables, including poverty, lack of vehicle access and crowded housing, to generate a Social Vulnerability Index. Bedford County has an index rating of 0.78, which falls into the High Vulnerability Index. The Social Vulnerability Index scores for Coffee, Marshall, and Maury Counties are 0.54, 0.49, and 0.33, respectively. Therefore, there is a significant population that falls into the socially vulnerable category, which may be adversely impacted by water availability and rising costs due to drought conditions.

Agricultural production is also impacted by drought conditions. When prolonged, farmers may need to haul water from other sources, or pay increasing prices to keep their fields producing valuable crops. This may lead to decreased crop yields, and increased prices for the consumers of those products.

TVA reservoirs and the land surrounding them support a variety of recreational activities including camping, hiking, fishing, swimming, and boating. These opportunities attract millions of visitors each year which has positive direct and indirect impact on the local economies around the reservoirs (TVA 2016). Positive direct impacts include expenditures at marinas, hotels and other businesses. Indirect impacts of tourism affect most sectors of the economy including secondary sales, income and employment within the region.

3.8.1.2 Visual resources

Scenic attractiveness is a measure of scenic quality and its importance based on the perception of natural beauty that is expressed in the features of a landscape. An important attribute of scenic attractiveness for the project area is the distinct shoreline that is present for the reservoir and river, as these are clearly visible zones where water features make their mark on the land (Burton et al. 1974).

The Normandy Reservoir and Duck River area is a landscape marked by its scenic features and attractiveness. In addition to the distinct shoreline, the area includes a variety of landscapes and natural features, including floodplains, wetlands, forests, rolling hills, and the river corridor. The water bodies are the most distinct and outstanding aesthetic features. Various combinations of development and land use patterns that are present in the viewed landscapes along the reservoir shoreline or river corridor contribute to the overall visual character of the area. Slopes and ridgelines seen from the reservoir are generally heavily vegetated with mature hardwood and evergreen trees and provide positive visual contrast to the reservoirs. While residential or commercial development in the area generally creates a lower level of scenic integrity, most of the reservoir and river shorelines appear natural. The prevalence of lands used for agricultural uses in the area generally contributes to the natural setting and scenic qualities.

3.8.1.3 Recreation

Recreation such as fishing, paddling, and boating along the Duck River and Normandy Reservoir attract visitors from across Tennessee and beyond. In 2020, the total outdoor recreation value added in Tennessee was $7.2 billion (Rzeznik and Washington 2021).

Normandy Reservoir has four boat launch access points, one paddle access point at Barton Springs Recreation Area, and fishing access at Normandy Dam. There are two recreation areas, the Barton Springs Recreation Area, and the Cedar Point Recreation area, which have fishing and boat access, small beaches, and campground areas. There are many opportunities along the Reservoir for bank fishing. Anglers mainly come to the Reservoir to fish for Black Bass and Crappie, while stocked Walleye and Catfish can also be found (Tennessee Wildlife Resources Agency 2021).

According to The Nature Conservancy (2024) the Duck River “supports an estimated 150,000 anglers, kayakers, canoers, and boaters annually, and attracts outdoors enthusiasts from across the state.” The Duck River Scenic Floatway begins at Normandy Dam and ends at the confluence of the Tennessee River, with multiple access points along the Duck River. Much of the lower section is flatwater, with some small rapids and faster currents along the upper reach below Normandy Dam (Tennessee Wildlife Resources Agency, 2021). There are also two boat launches along this stretch of the river, at Shelbyville City Park, and the VFW Ramp. There are paddle access points at Fisherman’s Park and Mullens Mill Bridge.

3.8.2 Environmental Effects of Alternative A

With Alternative A, the selected recommendation in the ONRR would not be implemented and TVA would continue to operate releases from the dam at Normandy Reservoir according to the current release schedule. Environmental conditions influencing socioeconomics, visual resources, and recreation would remain unchanged.

3.8.3 Environmental Effects of Alternative B

Under Alternative B, increased reservoir elevations during periods of drought would provide TVA with greater flexibility to meet their operational goals, which have socioeconomic components (potable water costs; water available for agricultural use; reservoir and downstream recreational uses, etc.). For example, under Alternative B during drought conditions, the DRUC would be able to pump raw water from a higher reservoir elevation where the water quality is generally better. The DRUC’s pumping and treatment costs would likely be lower under this scenario and these cost savings could be passed on to water users. Although minor, the benefits from the implementation of Alternative B would support continued recreation and small businesses in the region.

The fact that the reservoir elevation under Alternative B would be similar to or higher than Alternative A, indicates that the preferred alternative would have a slightly beneficial impact on the aesthetic appeal of the reservoir. Conversely, the predicted decrease in wetted perimeter associated with Alternative B has the potential to slightly decrease the aesthetic appeal of the Duck River due to the minor increase in shoreline exposure. Such a visual effect is likely to be negligible to minor. Under drought conditions, TVA would have more water available under Alternative B to ensure minimum flows in the Duck River and reduce potential visual impacts.

The higher reservoir elevations in Normandy Reservoir that would result from the implementation of the Alternative B would have a slightly beneficial impact on recreation by increasing the reservoir surface area for boating and fishing, facilitating boat launch access, and facilitating bank fishing. It is also possible that Alternative B would have a slightly beneficial impact on recreational activities in the Duck River under drought conditions as more, high quality water could be released from Normandy Reservoir to enhance boating and fishing activities. The minor nature of these effects to recreation in the area are unlikely to result in socioeconomic effects.

3.9 Cumulative Impacts

Cumulative impacts are defined as the effects of the proposed action when considered together with other past, present, and reasonably foreseeable future actions. Reasonably foreseeable projects and actions that have the potential to affect the water quantity and quality of the Normandy Reservoir and the Duck River may include but are not limited to: water withdrawal efforts, water discharge permits, ecosystem restoration projects, and changes in surrounding land use. The future increase in water demands or withdrawals was considered in this EA by modeling reservoir elevations and river flows using projected 2040 water demands.

During periods of low water, the OASIS model predicts that Alternative B would conserve more water in Normandy during times of drought, resulting in an increase in reservoir elevation approximately 25% of the time compared to Alternative A. This additional reservoir water provides TVA with additional flexibility to manage water quantity or quality issues in the Duck River (e.g., severe drought, unacceptable nutrient levels, algal blooms, etc.). Sections 3.1 through 3.8 above conclude that the implementation of Alternative B would have either no effect or a slightly beneficial impact to the resource categories evaluated in this EA. Therefore, it is concluded that the implementation of Alternative B is likely to contribute to material beneficial cumulative impacts to the water quantity and quality of the Normandy Reservoir and the Duck River, especially during critical drought conditions.

3.10 Irreversible and Irretrievable Commitments of Resources

An irreversible or irretrievable commitment of resources refers to impacts on or losses to resources that cannot be recovered or reversed. Irreversible is a term that describes the loss of future options and applies primarily to the effects of the use of nonrenewable resources that are only renewable over long periods of time. Irretrievable is a term that applies to the loss of production of renewable resources such as timber, agricultural land, or wildlife habitat as a result of the proposed action. TVA's proposed action, to modify how water is released from Normandy Dam into the Duck River system, would not result in an irreversible or irretrievable commitment of resources. Potential effects would be minor, temporary, and reversible.

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APPENDIX A – DUCK RIVER OASIS MODEL DESCRIPTION

Modeling Water Quantity Operations of the Duck River Basin with OASIS

Prepared by Hazen and Sawyer for the Duck River Agency
September 2020

This report describes how OASIS (developed previously by HydroLogics, now Hazen and Sawyer) was used to model water quantity operations of the Duck River Basin. OASIS is a mass-balance simulation and optimization model. It is important to note that OASIS is not a physically based hydrologic model or a hydraulic or flood routing model.

The Duck River OASIS model runs in simulation mode on a daily time step. That is, a user-defined set of demands and operating policies is modeled as if they had been in place for the entire period of the available hydrologic record, which spans from 1921 – 2016 based on available USGS gaging records in the basin (to be described later). The outputs from the simulations have been used to inform the analysis described elsewhere in this environmental assessment.

The OASIS model of the Duck River Basin was originally developed in 2002 and has been subsequently updated numerous times. The most recent update was to support analysis for this Environmental Assessment. Section 5 describes the significant updates to the model compared to previous versions.

Section 1. Description of the System as Modeled

A schematic of the system as modeled is shown in Figure 1. The model includes nodes for Normandy reservoir, surface water demands, time-of-travel reservoirs, and numerous junction nodes which represent points of interest in the system such as surface water intakes or sites of environmental interest. All nodes are listed in Table 1. Purple arrows represent points where natural inflows flow into the model. The calculation of inflows are described in Section 2. The representation of Normandy Reservoir, withdrawals and wastewater returns are described in Section 3. The black arcs connecting nodes indicate the direction of flow between those nodes.

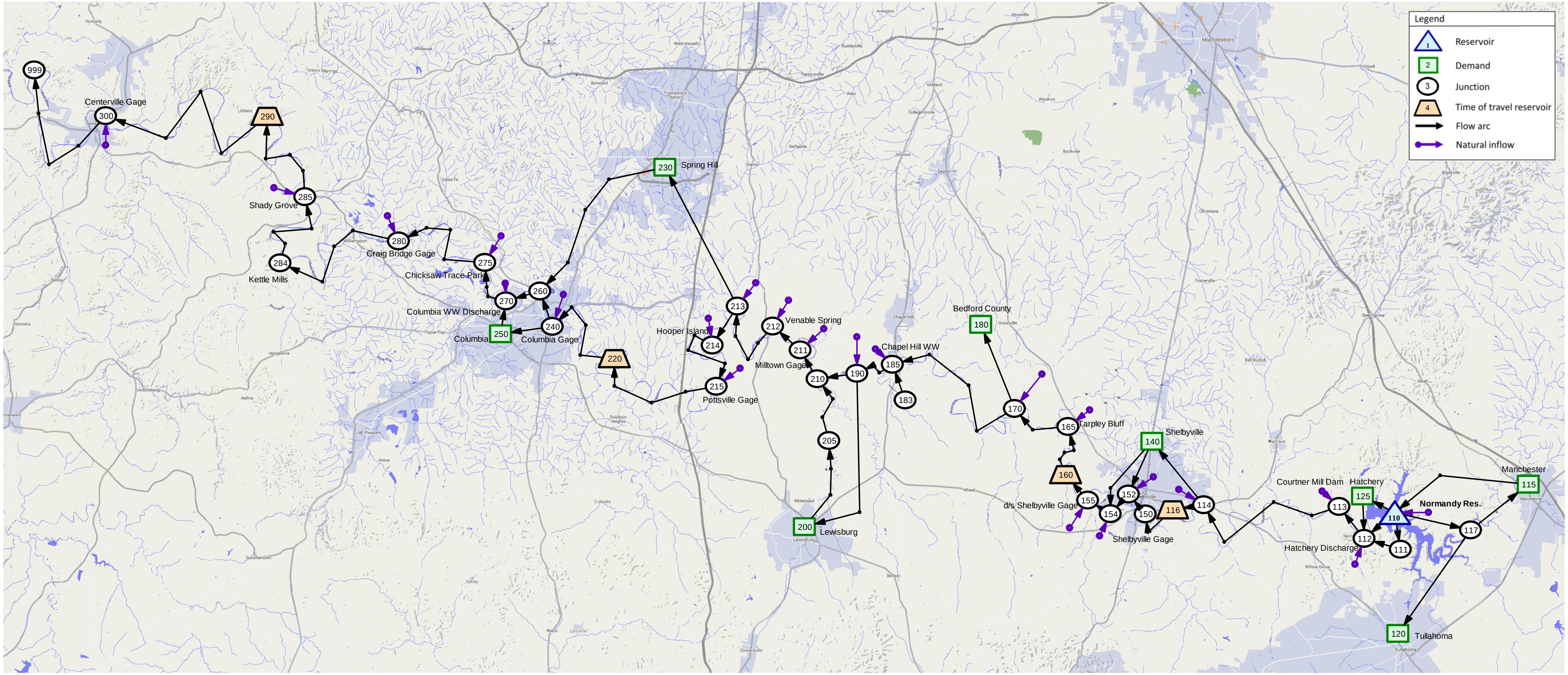


Figure 1. Schematic of the Duck River Basin as modeled with OASIS

Table 1. Model Nodes

Node Number	Type	Name
110	Reservoir	Normandy Reservoir
111	Junction	Normandy Reservoir Spill
112	Junction	Normandy Hatchery Discharge
113	Junction	Courtner Mill Dam
114	Junction	Shel Gage Inflow
115	Demand	Manchester Demand
116	Reservoir	Normandy to Shelbyville ToT
117	Junction	DRUC Intake
120	Demand	Tullahoma Demand
125	Demand	Normandy Hatchery Demand
140	Demand	Shelbyville Demand
150	Junction	at Shelbyville Gage
152	Junction	Shelbyville WW Ret
154	Junction	Tyson WW Ret
155	Junction	nr Shelbyville Gage
160	Time-of-Travel	Shelbyville to Milltown ToT
165	Junction	Tarpley Bluff
170	Junction	Bedford Co. Intake
180	Demand	Bedford County Demand
183	Junction	Chapel Hill WW Disch.
185	Junction	Chapel Hill WW Ret
190	Junction	Lewisburg Intake
200	Demand	Lewisburg Demand
205	Junction	Lewisburg WW Ret
210	Junction	Big Rock Conf
211	Junction	Milltown Gage
212	Junction	Venable Spring
213	Junction	Spring Hill Intake
214	Junction	Hooper Island
215	Junction	Pottsville Gage
220	Time-of-Travel	Milltown to Columbia ToT
230	Demand	Spring Hill Demand
240	Junction	Columbia Gage
250	Demand	Columbia
260	Junction	Columbia WW Ret
270	Junction	Columbia WW Discharge
275	Junction	Chicksaw Trace Park
280	Junction	Craig Bridge Gage
284	Junction	Kettle Mills
285	Junction	Shady Grove Gage
290	Time-of-Travel	Columbia to Centerville ToT
300	Junction	Centerville Gage
999	Junction	Terminal

Section 2. Development of Inflows

Inflows to the Duck River OASIS model are based on available USGS gage records, as well as TVA computed inflows for Normandy Reservoir. All inflow locations in the model are listed in Table 2 – the locations in bold are the gages where unregulated (natural) inflows were developed, and then those inflows are distributed by drainage area ratio to the other inflow points in the model.

Table 2. Model inflow locations

OASIS Node #	Site Name	Total Drainage Area (sq. mi.)	Incremental Drainage Area (sq. mi.)
110	**Normandy Reservoir**	**195.0**	**195.0**
112	Normandy Fish Hatchery Discharge (RM 248)	199.1	4.1
113	Courtner Mill Dam (river mile 245.03)	214.0	14.9
114	03597860 Duck River at Shelbyville, TN	425.0	211.0
152	Shelbyville WW Discharge (RM 221)	427.7	2.7
154	Tyson WW Discharge (RM 220.2)	428.0	0.3
155	**03598000 Duck River near Shelbyville, TN**	**481.0**	**53.0**
165	Tarpley Bluff (river mile 207.3)	540.6	59.6
170	Bedford Co Intake	584.7	44.1
185	Chapel Hill WW Discharge (RM 185.75)	762.6	177.9
190	Lewisburg Intake	790.3	27.7
211	**03599240 Duck River above Milltown, TN**	**916.0**	**125.7**
212	Venable Spring (river mile 176.8)	948.0	32.0
213	Spring Hill Intake	1016.0	68.0
214	Hooper Island (river mile 163.1)	1018.5	2.5
215	03599419 Duck River at Mile 156 near Pottsville, TN	1029.0	10.5
240	**03599500 Duck River at Columbia, TN**	**1208.0**	**179.0**
270	Columbia WW Discharge (RM 127.2)	1377.4	169.4
275	Chickasaw Trace Park (river mile 125.03)	1396.5	19.1
280	03600358 Duck River at Craig Bridge Rd ab Williamsport, TN	1433.3	36.8
285	03601600 Duck River near Shady Grove, TN	1705.0	271.7
300	**03601990 Duck River at Hwy 100 at Centerville, TN**	**2048.0**	**343.0**

“Impaired” flows are those which have been modified by human behavior, especially impounding water for subsequent release or withdrawing water, consuming some, and returning the remainder to another location on the river. To model alternative operations of Normandy Reservoir (which means simulated rather than historical releases) and different demand scenarios, we need to have “unimpaired” inflows to the reservoir and the “unimpaired” gains between as many nodes as possible downstream. We also need to be able to compute routing coefficients between the model nodes. With the available data, we were able to develop an inflow record beginning in 1921 at the nodes indicated, and then inflows to all of the other points of interest can be estimated by using a drainage area ratio. When a gage was inactive, the local inflow (gain) for that location was filled in using a regression method from a program known as *fillin* from William Alley and Alan Burns[1] of the USGS.

A summary of impairment data used to unimpair the USGS gages follows:

- Daily records of Normandy reservoir elevation, change in storage and releases are available from TVA going back to the dam construction in 1976.
- Withdrawals and discharges: daily data going back to 2000, monthly withdrawal data going back to the 1980’s, and annual data going back to the 1970’s. Prior to that, historic withdrawals/discharges were estimated by regressing annual data back in time and applying a seasonal pattern based on known usage.

The following is a summary of how inflows were computed to each major inflow location:

- Normandy Reservoir
  - 1921 – 1934 : Inflow filled in using monthly regressions with other basin gages
  - 1934 – 1978 : Duck R. at Manchester USGS gage, scaled up by drainage area
  - 1978 – 2016 : Inflow to the reservoir back-calculated using TVA data (change in storage + release + historic net evaporation + historic withdrawals – historic discharges)
- Shelbyville Gage
  - 1921 – 1934 : Inflow filled in using monthly regressions with other nearby gages
  - 1934 – 2016 : Duck R. near Shelbyville USGS gage and minus routed Normandy inflow
  - Note – the “at” Shelbyville gage data since 1991 was used for that location – it does not report high flows so it was filled in with the “near” Shelbyville gage
- Milltown Gage
  - 1921 – 2002 : Local inflow (gain) filled in using monthly regressions with other nearby gages
  - 2002 – 2016 : Duck R. Milltown USGS gage, minus routed Shelbyville flow
- Columbia Gage
  - 1921 – 2002 : Local inflow (gain) filled in using monthly regressions with other nearby gages and unimpaired flows (this is dictated by the fact that the Columbia natural inflow

[1]“Mixed-Station Extension of Monthly Streamflow Records,” *Journal of Hydraulic Engineering*, ASCE, Vol. 109, No. 10, October 1983.

is dependent on the upstream gage)
  - 2002 – 2016 : Duck R. Columbia USGS gage, minus routed Milltown flow
- Centerville Gage
  - 1921 – 1955 : Duck R. Centerville USGS gage, minus routed Columbia flow
  - 1955 – 2001 : Inflow filled in using monthly regressions with other nearby gages
  - 2001 – 2016 : Duck R. Centerville USGS gage, minus routed Columbia flow

Section 3. Description of System Input Data and Operations as Modeled

Normandy Reservoir Operations

Net Evaporation

The Nashville District of the Corps of Engineers provided monthly average pan evaporation data (adjusted using pan-to-lake conversion factors) that was developed for J. Percy Priest Reservoir. For precipitation we obtained Tullahoma daily rainfall beginning in 1900 from the USGS. Starting in 1986 we used daily for Normandy provided by TVA. We made a daily record of net evaporation by converting the mean evaporations by month into a record of daily values and subtracting the daily rainfall. The model applies the net evaporation, in inches, on any given day to the surface area of the Reservoir on that day. On days when rainfall exceeded evaporation, water is added to the reservoir inflow.

Reservoir stage-storage-elevation (SAE) curve and operating guide curve

The SAE curve is shown in Table 3. It is used to convert computed storages in the model to elevations for output and for adhering to the operating guide curve, and for computing the volume of daily net evaporation as described above.

Normandy's operating guide curve – shown in Table 4 – dictates the target operating elevation for the reservoir. It varies from 864 ft in the winter to provide flood storage, and up to 875 ft in the summer to provide more water supply storage. The model will attempt to keep Normandy at the specified operating elevation on a given day, but may not be able to subject to other constraints and operating goals, such as; inflows, minimum flow requirements, and demands.

Table 3. Normandy Storage - Area - Elevation Table

Elevation (ft)	Storage (kaf)	Area (acres)
800	0.78	0.13
810	3.33	0.4
830	18.8	1.2
840	28.1	1.51
842	31.3	1.61
844	34.6	1.71
846	38.2	1.8
848	41.9	1.88
850	45.8	1.98
852	49.9	2.06
854	54.1	2.14
856	58.6	2.24
858	63.2	2.32
860	68	2.4
862	73	2.5
864	78.1	2.6
866	83.4	2.68
868	88.9	2.78
870	94.6	2.88
872	100.5	2.98
874	106.6	3.07
876	112.8	3.13
878	119.3	3.25
880	126.1	3.43
890	165.4	4.24

Table 4. Normandy's Operating Guide Curve

Month	Day	Operating Guide (ft)
1	1	864
2	28	864
4	30	875
10	31	875
11	30	865
12	31	864

Minimum Flows

There are two minimum flow requirements in the system that Normandy is required to make:

- Normandy release, 40 cfs year round

To account for high water temperatures in the summer, TVA recommended raising the minimum flow from June-November to 50 cfs to mimic recent actual operations.

- Shelbyville, 120 cfs December 1 through May 31 and 155 cfs June 1 through November 30.

To account for the approximately 18 hour time of travel from Normandy to Shelbyville, TVA typically is conservative and releases more than the requirement to ensure the Shelbyville target is never violated. As such, the model includes a "buffer" to account for this operational consideration. In consultation with TVA the buffer used is 10 cfs in the winter and 15 cfs in the summer, which effectively raises the minimum flow target in the model at Shelbybille to 130 cfs in the winter and 170 cfs in the summer.

Flood Releases

In consultation with TVA, the OASIS model uses a representative flood policy for Normandy that reasonably emulates flood operations on a daily timestep.

- If Normandy is below 840 feet, release at most the minimum flow described above (40 cfs winter / 50 cfs winter)
- If Normandy is projected to overtop elevation 880 ft within 5 days, release the lesser of one-fifth the amount to get back to rule, or 5000 cfs.
- Otherwise if Normandy is above the operating guide curve, release according to a rating table derived from actual operations in the last 10 years.
- In all situations, prevent outflows from the reservoir from increasing or decreasing by more than 500 cfs per day.

System Demands

There are seven demand nodes in the system: Manchester, Tullahoma, Shelbyville, Bedford County, Lewisburg, Spring Hill and Columbia. Manchester and Tullahoma withdraw water from the DRUC intake on Normandy reservoir; all others withdraw water from river intakes downstream. Demands are represented in the model by an annual average demand, with a seasonal monthly pattern applied. The annual average demands are taken from the base year 2015, and for future planning scenarios are based on 2040 projections. The monthly demand patterns were developed by computing the monthly demand as a fraction of annual average, based on the average of data from 2012-2016. Annual average demands used in model scenarios are shown in Table 5, and the monthly demand patterns are shown in Table 6. The Normandy fish hatchery receives water from an intake in Normandy reservoir, modeled at a constant 1.87 mgd based on of recent data.

Table 5. Annual average demands used in the model

Demand	RRecent (2015) Demands (MGD)	Projected 2040 Demands (MGD)
Tullahoma	3.7	4.4
Manchester	2.7	3.3
Shelbyville	4.6	7.4
Bedford County	2.2	3.4
Lewisburg Water	3.2	4.4
Spring Hill	2.9	4.2
Columbia	9.6	15.6

Table 6. Monthly demand patterns used in the model

	Monthly demand as a fraction of the annual average						
Month	Manchester	Tullahoma	Shelbyville	Bedford Co.	Lewisburg	Spring Hill	Columbia
1	0.976	0.974	0.992	0.884	1.007	0.848	0.970
2	0.944	0.945	0.966	0.898	0.968	0.849	0.954
3	0.943	0.931	0.970	0.872	0.948	0.835	0.943
4	0.984	0.969	0.957	0.917	0.954	0.870	0.972
5	1.018	0.999	1.001	0.982	1.007	1.061	1.034
6	1.058	1.060	1.050	1.061	1.040	1.181	1.088
7	1.055	1.048	1.052	1.068	1.032	1.188	1.080
8	1.091	1.082	1.106	1.154	1.073	1.214	1.126
9	1.024	1.026	1.057	1.032	1.030	1.086	1.021
10	0.998	1.025	0.966	1.121	0.996	1.066	0.963
11	0.959	0.978	0.934	1.108	0.971	0.926	0.924
12	0.945	0.960	0.947	0.897	0.970	0.897	0.921

Wastewater discharges

Wastewater return flows that are associated with a withdrawal in the model are computed using monthly fractions based on actual 2012-2016 data – that is for January, divide the volume of wastewater discharged by the volume of water withdrawn for that utility, and so on. These return fractions are shown in Table 7. The Chapel Hill WWTP is not associated with a withdrawal in the model, and as such is modeled as in “inflow” into the system with an average annual return of 0.18 mgd and a monthly pattern based on available recent years of reported discharges. The Normandy fish hatchery is assumed to return all withdrawn water to the river downstream of Normandy dam.

Table 7. Wastewater return patterns for returns associated with withdrawals

	Monthly WW return as a fraction of monthly withdrawal				
Month	**Manchester**	**Shelbyville**	**Lewisburg**	**Spring Hill**	**Columbia**
1	1.075	1.167	0.985	1.029	0.970
2	1.325	1.352	1.191	1.044	0.954
3	1.148	1.117	1.022	0.845	0.943
4	1.120	1.026	0.946	0.816	0.972
5	0.806	0.927	0.757	0.553	1.034
6	0.743	0.804	0.689	0.453	1.088
7	0.791	0.791	0.615	0.465	1.080
8	0.705	0.721	0.604	0.439	1.126
9	0.803	0.802	0.617	0.548	1.021
10	0.817	0.836	0.607	0.593	0.963
11	0.965	1.014	0.849	0.773	0.924
12	1.123	1.214	1.044	0.980	0.921

Time of Travel

While OASIS is not a hydraulic routing model, it can account for time of travel by utilizing routing reservoirs which will lag the flow of water from upstream to downstream using a defined equation. The routing equations used for each gain are as follows:

Normandy to Shelbyville:
Routed Normandy outflow = 0.4*yesterday + 0.6*today

Shelbyville to Milltown:
Today's routed Shelbyville flow = 0.8*yesterday + 1*today

Milltown to Columbia:
Today's routed Milltown flow = 0.7*yesterday + 0.3*yesterday

Columbia to Centerville:
Today's routed Columbia flow = 0.8*yesterday + 0.2*today

Section 4. Uncertainty in model inputs

The primary uncertainty in the model inputs are in the underlying USGS gage flows which are used to develop the inflows to the model. Generally, the gages in the basin are rated as "good" by USGS, which means that about 95 percent of the daily discharges are estimated to within 10% of the true value. For any years where a gage is rated as "fair" the potential error increases to 15%. The spatial distribution of incremental inflows between the known gage flows by drainage area introduce some uncertainty, as it does not account for land use and geological differences within those reaches. The use of historical gaging records also assumes stationarity, although the historical record may not be representative of future conditions. However, this uncertainty is reduced by having a long inflow record, in this case about 100 years in length that capture a wide range of hydrologic variability.

For demands and discharges, the model is relying on historical use to develop repeating patterns applied in a repeating fashion across the historical record. In reality those use patterns will vary year-to-year.

Section 5. Sensitivity Analysis

For the sensitivity analysis, the annual average daily demands in the OASIS model for the 2040 scenarios were both increased and decreased by 10%, Table 8 below shows the projected 2040 demands in the model and the demands with the 10% adjustments for the sensitivity analysis. By adjusting the annual average demands, the linked wastewater discharges in the model are also automatically increased in the model by the same percentages. For scenarios where conversation reductions to demand are modeled, the sensitivity adjustments are first made on the full demand, and then the reductions due to conservation at different drought stages are made.

Table 8. Demands for the sensitivity analysis

Demand	Projected 2040 demands MGD	2040 demand with 10% increase MGD	2040 demand with 10% decrease MGD
Tullahoma	4.4	4.8	4.0
Manchester	3.3	3.6	3.0
Shelbyville	7.4	8.1	6.7
Bedford County	3.4	3.7	3.1
Lewisburg Water	4.4	4.8	4.0
Spring Hill	4.2	4.6	3.8
Columbia (CPWS)	15.6	17.2	14.0

Section 6. Changes from previous versions of the Duck River OASIS Model

As previously mentioned, the model has been updated from its previous use in development of the 2013 DMP for use for analysis in this environmental assessment. The primary changes are:

- Addition of more incremental inflow nodes as previously discussed to capture more points of interest for this analysis. Also the Milltown gage flow was directly used in inflow calculations (previously there was not enough years of record at that gage to be useful in gage development).

- Normandy operations refined in consultation with TVA (discussed previously).

- Demands (annual average and monthly patterns) were updated to reflect more recent years of data.

Section 7. Model verification

This section shows plots comparing modeled Normandy reservoir elevation and flows at gages downstream to actual values during the 2007-2008 drought. Note that the simulated outputs follow the standard operations and demands/discharges previously discussed, whereas in 2007-2008 the actual withdrawals and discharges will have varied, and in the fall the release from Normandy was reduced to conserve storage. As a result, flow at Shelbyville below the target flow. Therefore, In certain months, computed elevations would be lower than historic, and downstream, computed flows would be higher than historic, helping explain differences between computed and historic results.

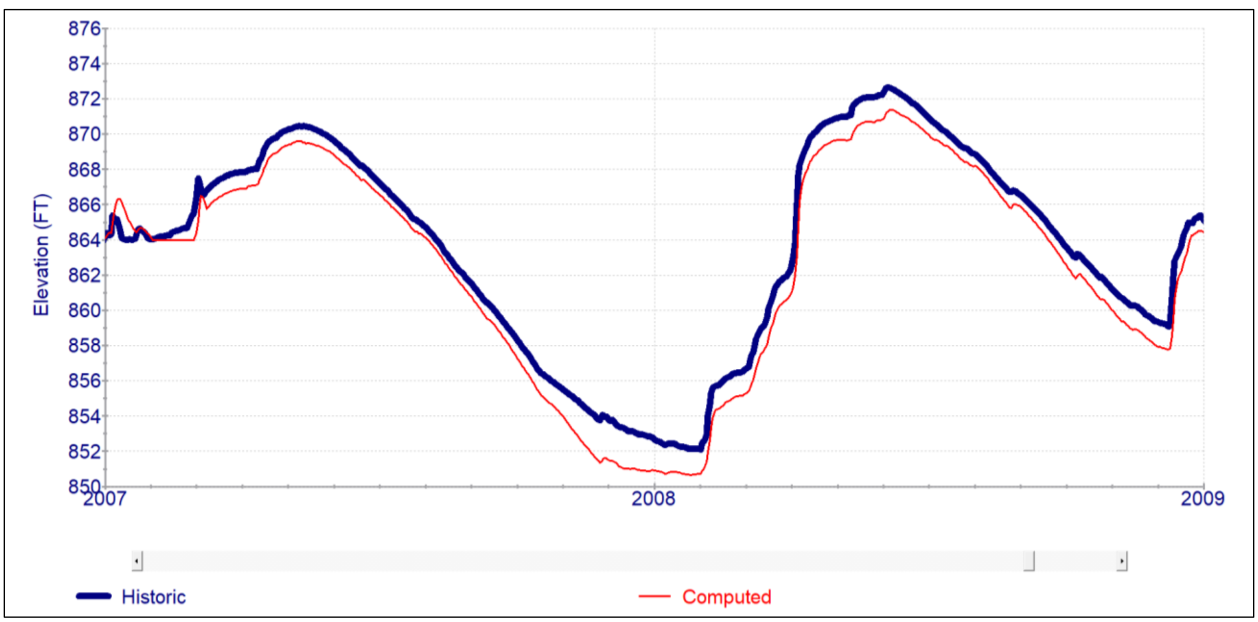


Figure 2. Normandy Elevation – 2007-2008 Historic and Computed

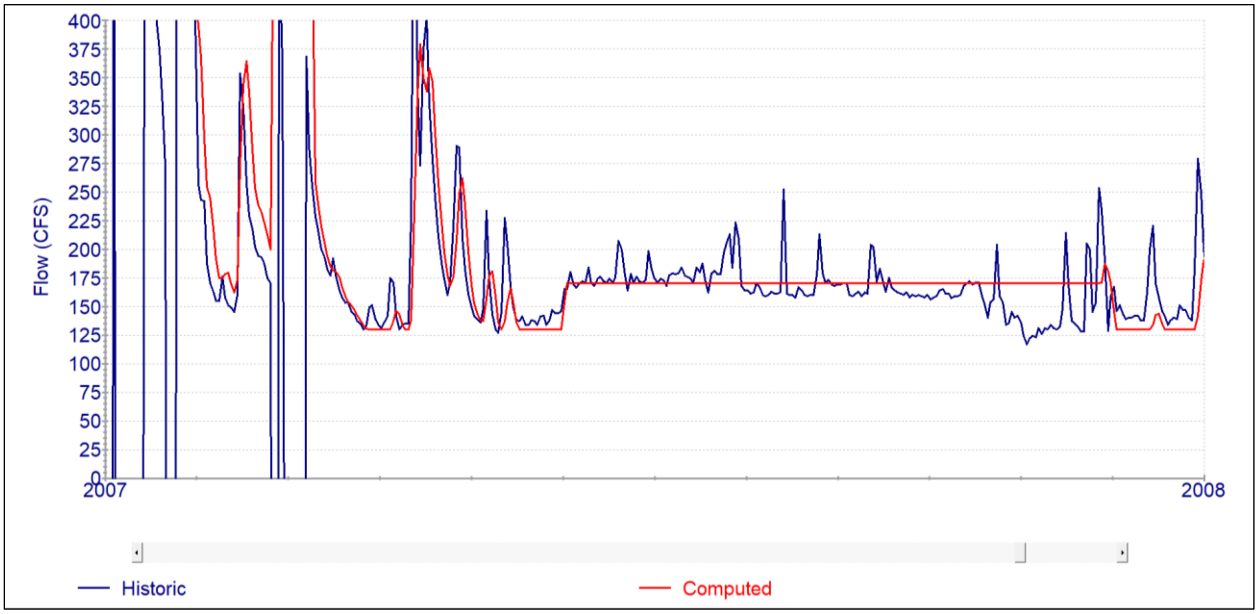


Figure 3. 03597860 Duck River at Shelbyville, TN – 2007-2008 Historic and Computed
(Note – this gage does not record high flows, so there are gaps in the early months of the year)

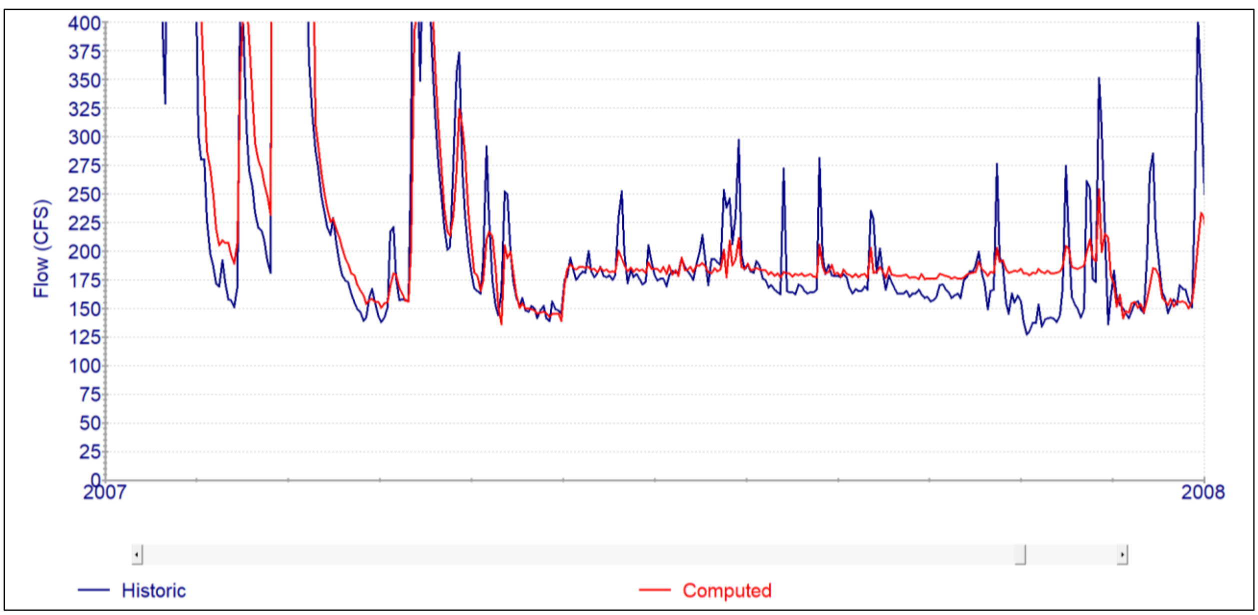


Figure 4. 03598000 Duck River near Shelbyville, TN – 2007-2008 Historic and Computed

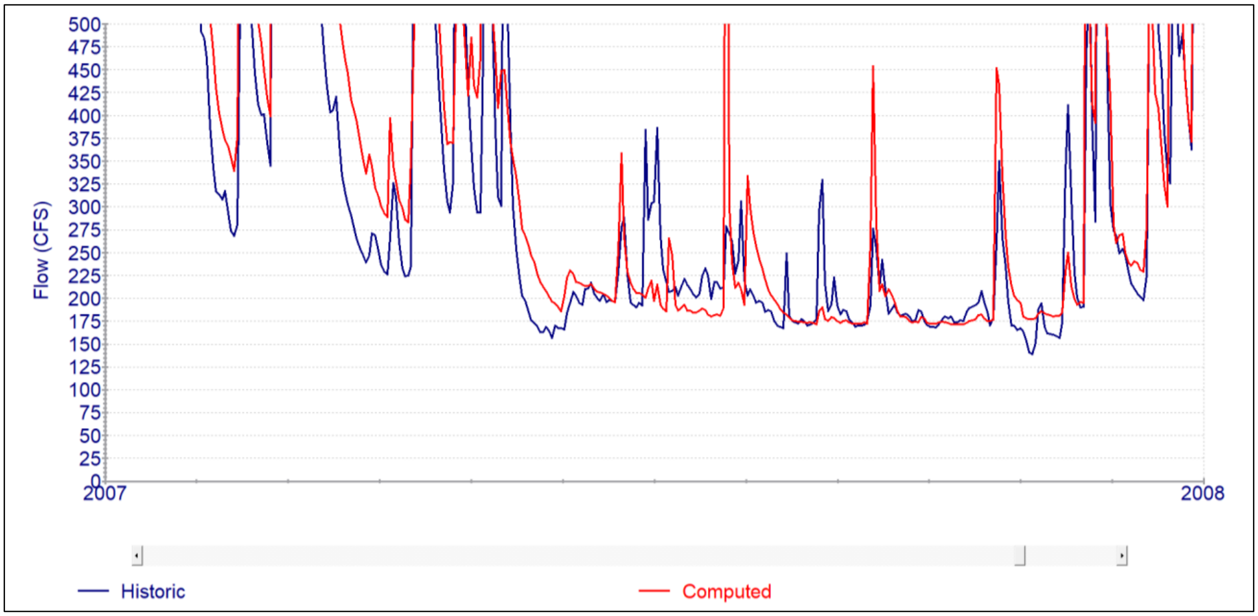


Figure 5. 03599240 Duck River above Milltown, TN – 2007-2008 Historic and Computed

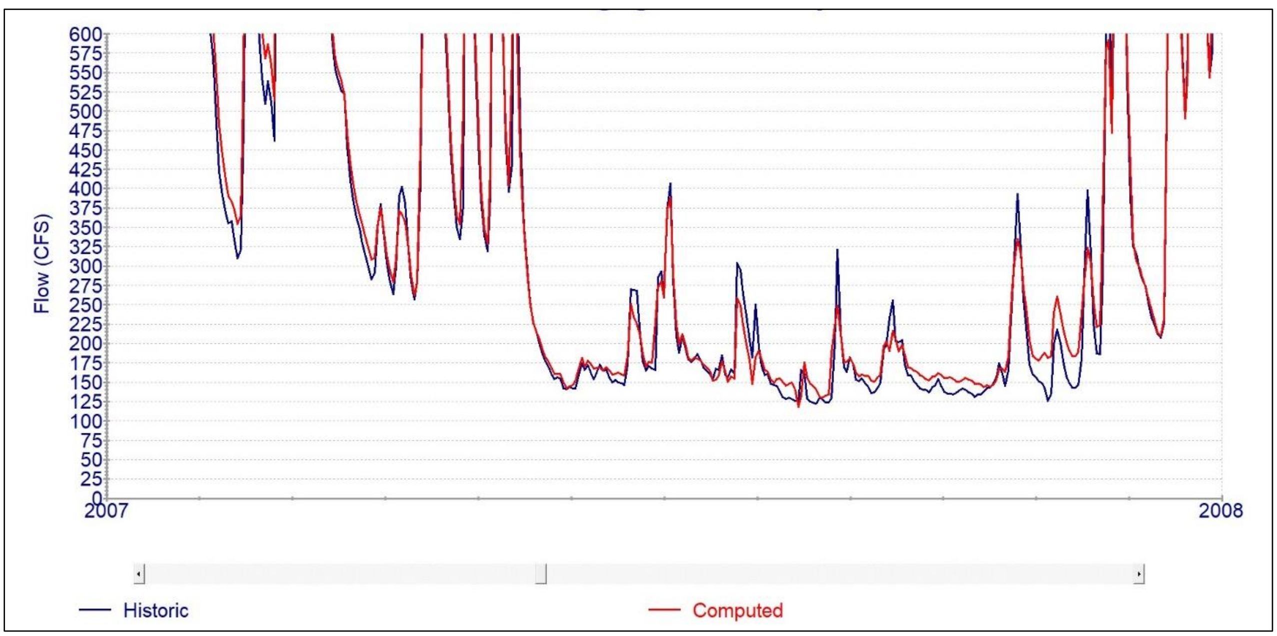


Figure 6. 03599500 Duck River at Columbia, TN – 2007-2008 Historic and Computed

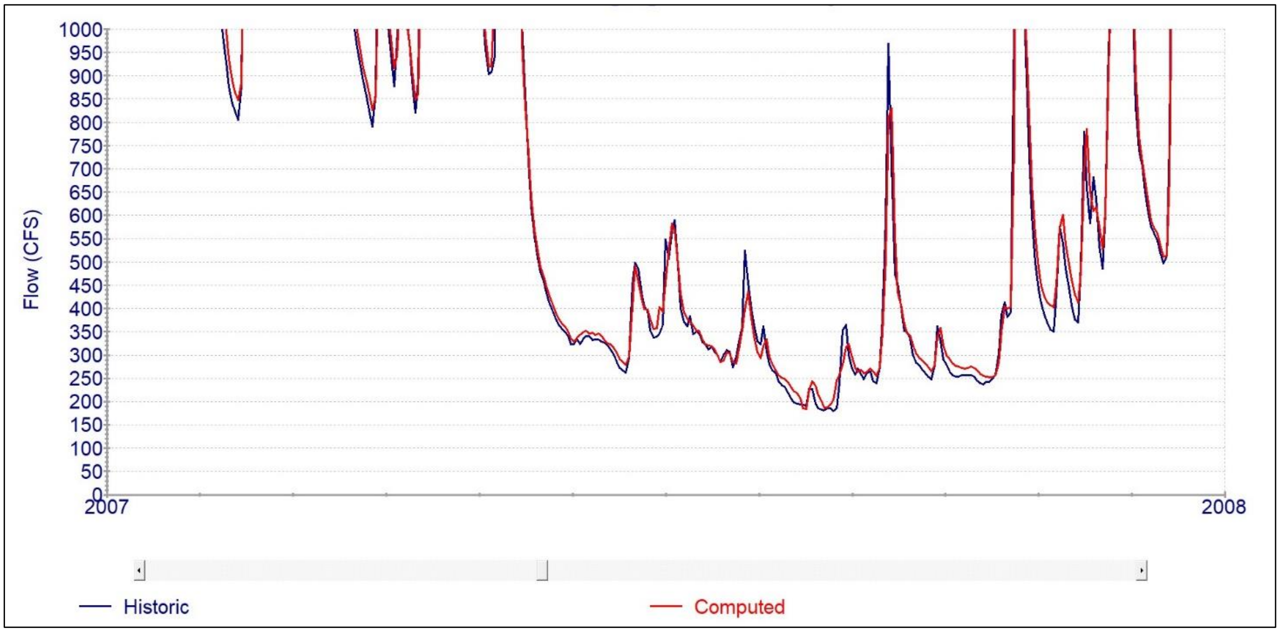


Figure 7. 03601990 Duck River at Hwy 100 at Centerville, TN – 2007-2008 Historic and Computed

APPENDIX B – DUCK RIVER FLOW FIGURES

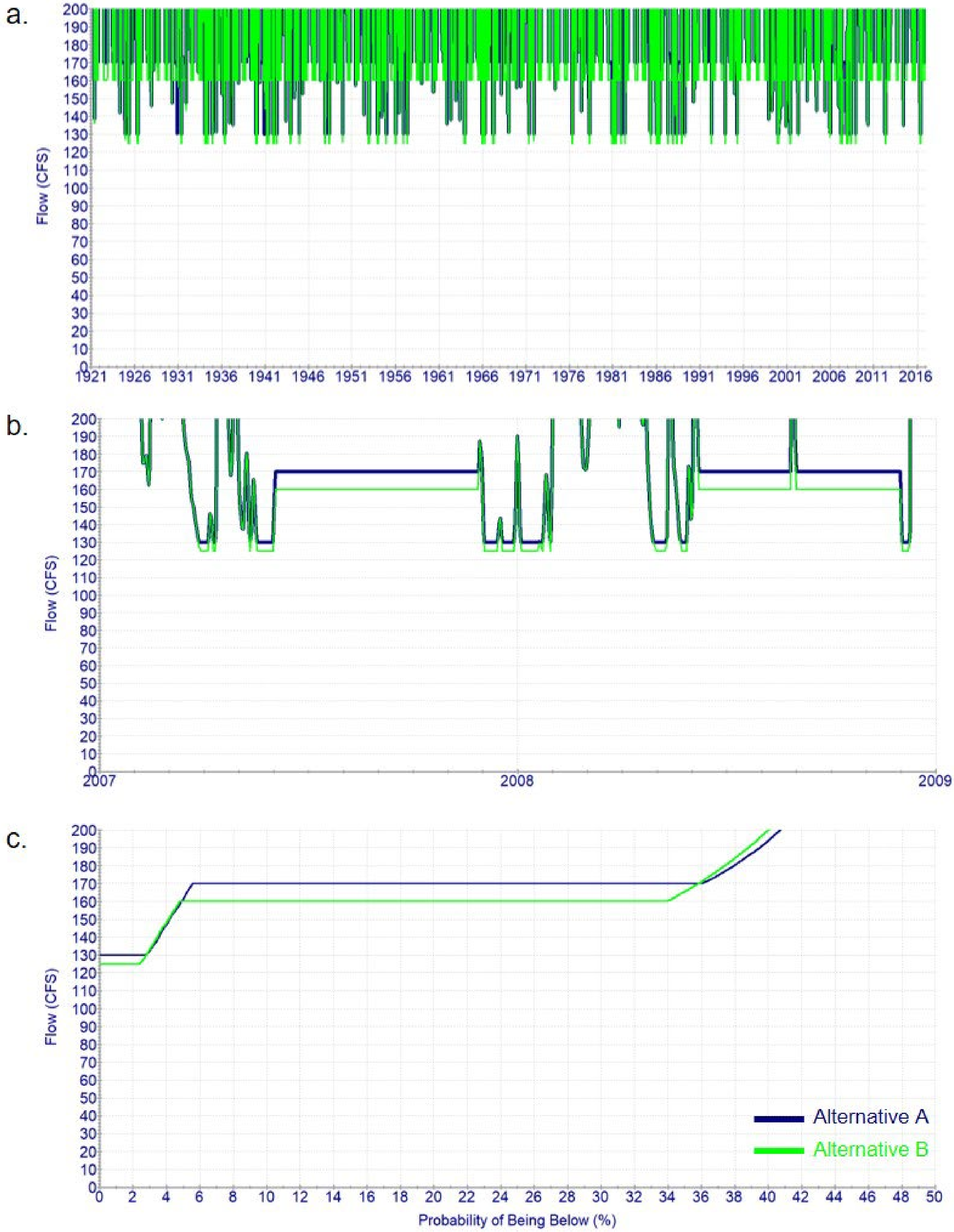


Figure B-1, Simulated flows at the Shelbyville USGS gage (03597860): (a) Simulated flow (cfs) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) with recent water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with recent water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with recent water demands.

Figure B-2, Simulated flows at the USGS gage near Shelbyville (03598000): (a) Simulated flow (cfs) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) with recent water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with recent water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with recent water demands.

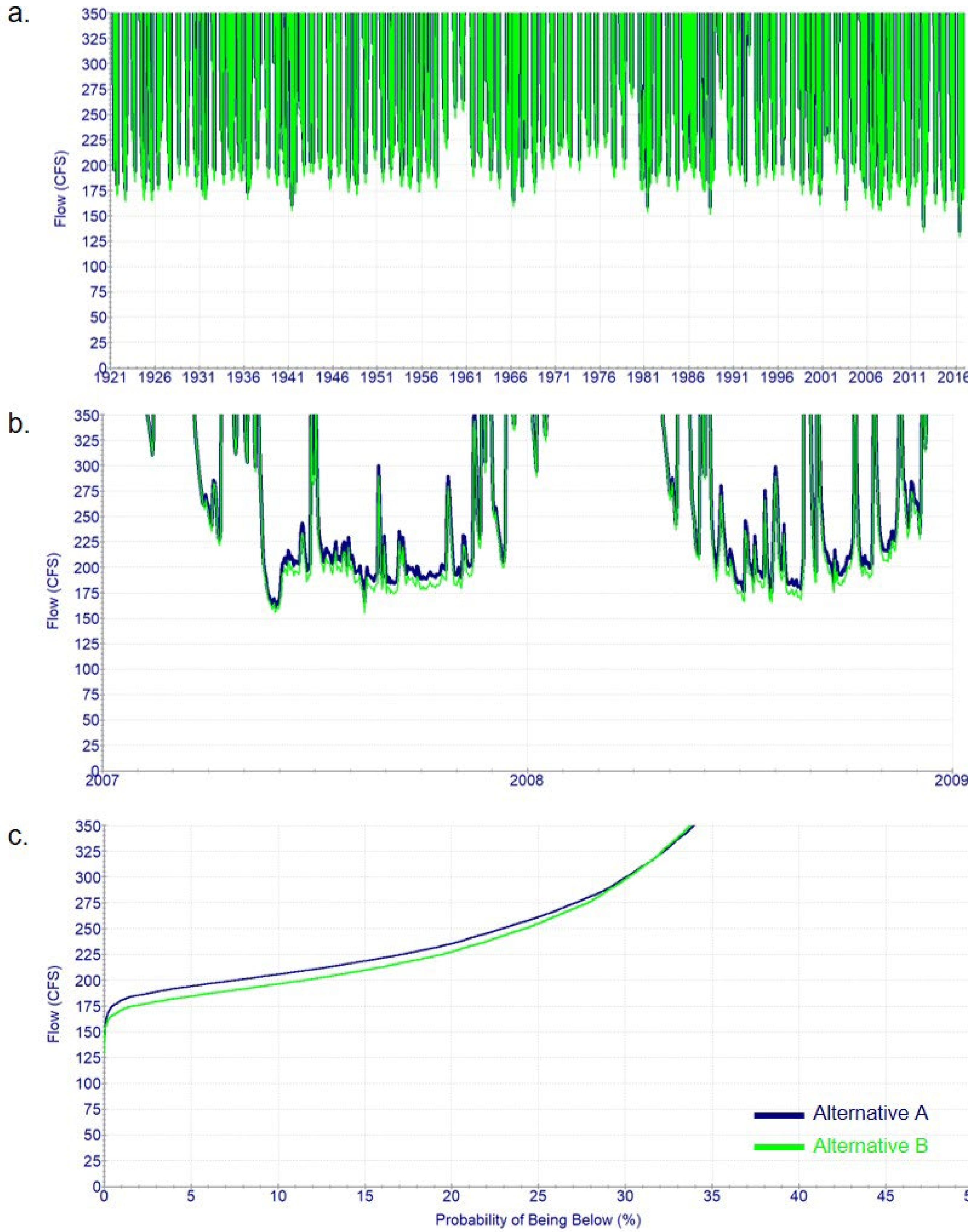
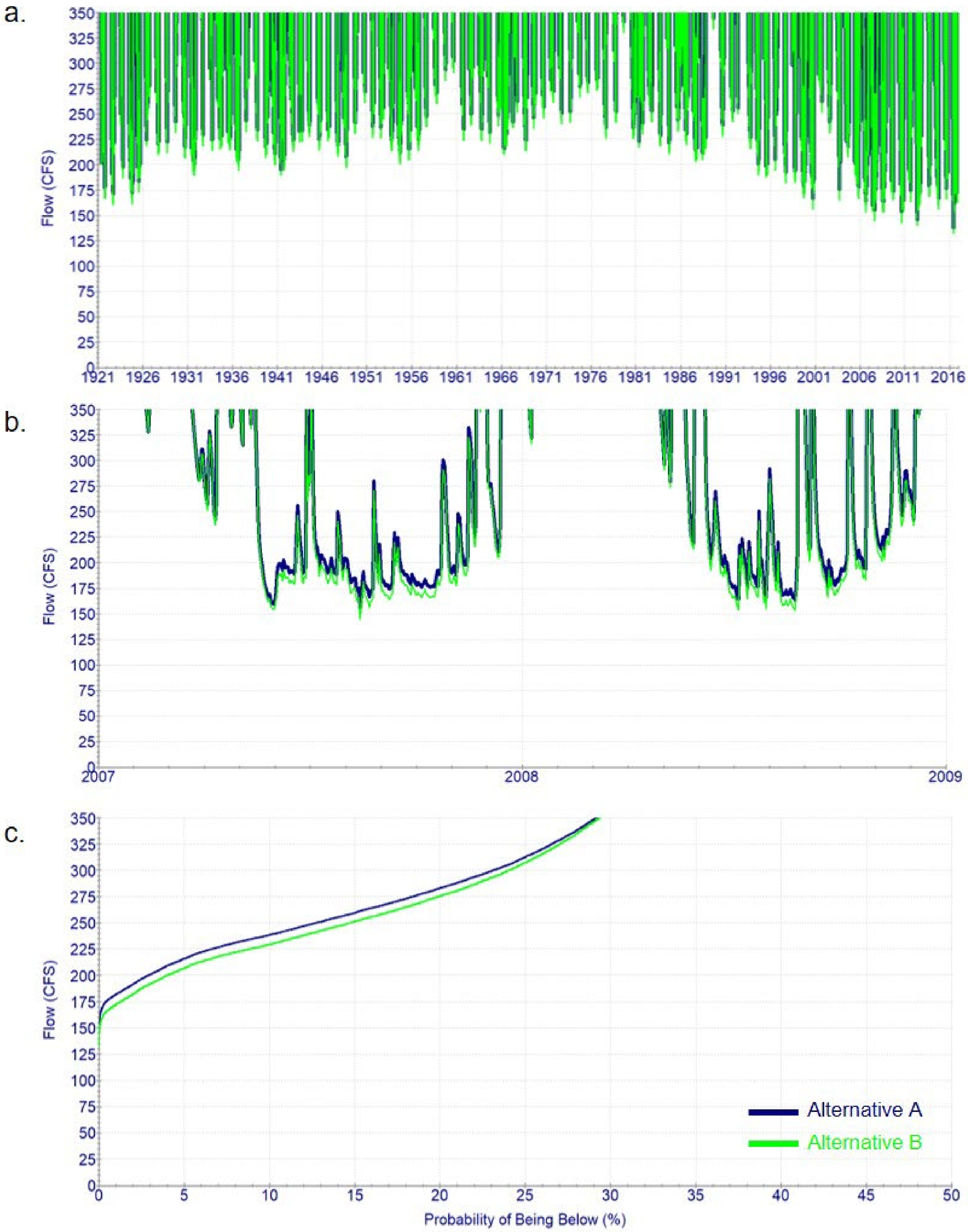


Figure B-3, Simulated flows at the USGS gage above Milltown (03599240): (a) Simulated flow (cfs) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) with recent water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with recent water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with recent water demands.



Figure

Figure B-4, Simulated flows at the USGS gage near Pottsville (03599419): (a) Simulated flow (cfs) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) with recent water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with recent water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with recent water demands.

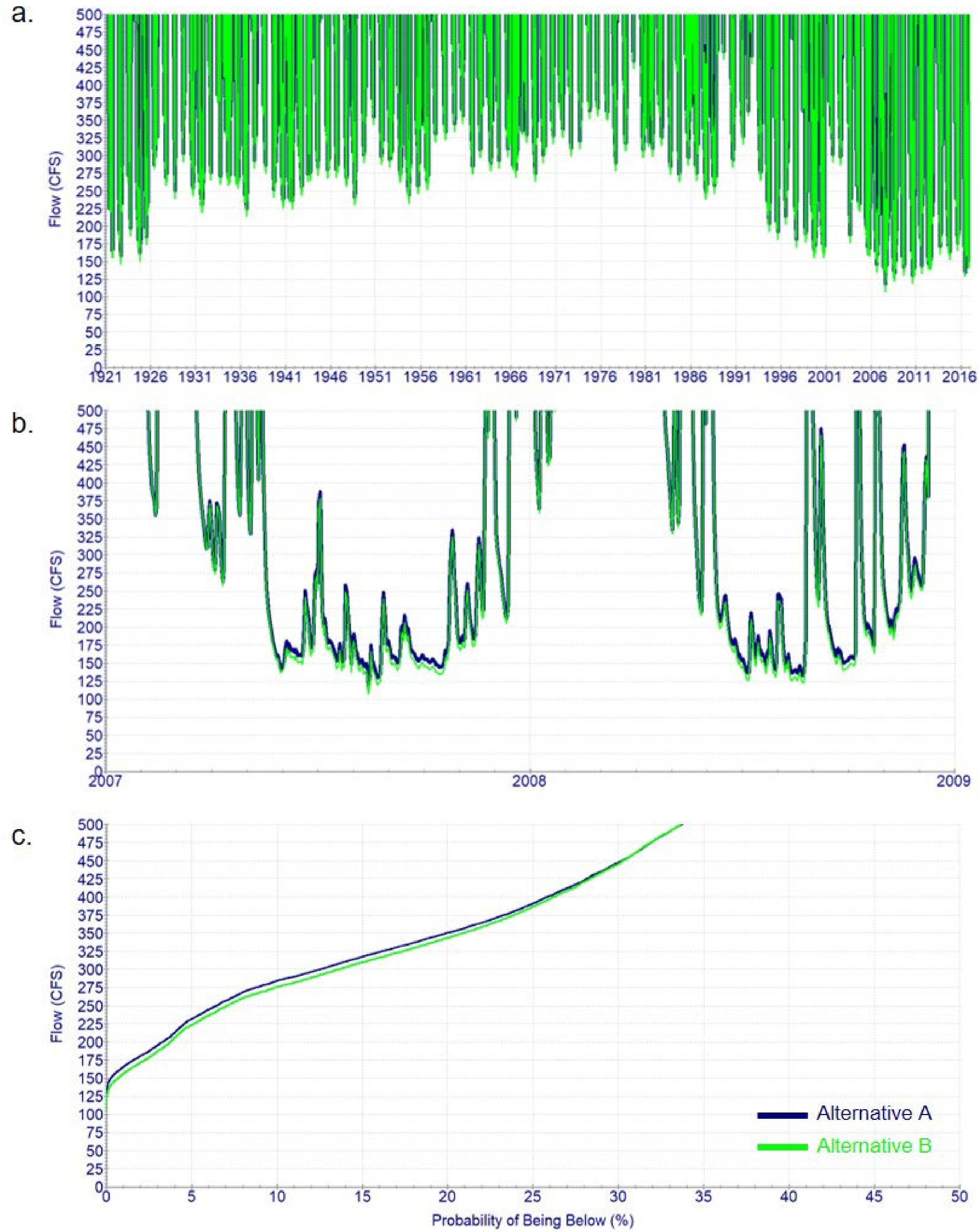


Figure B-5, Simulated flows at the USGS gage at Columbia (03599500): (a) Simulated flow (cfs) for the long-term hydrologic record (1921 to 2016) for recent operations and for Alternative B with recent water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with recent water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with recent water demands.

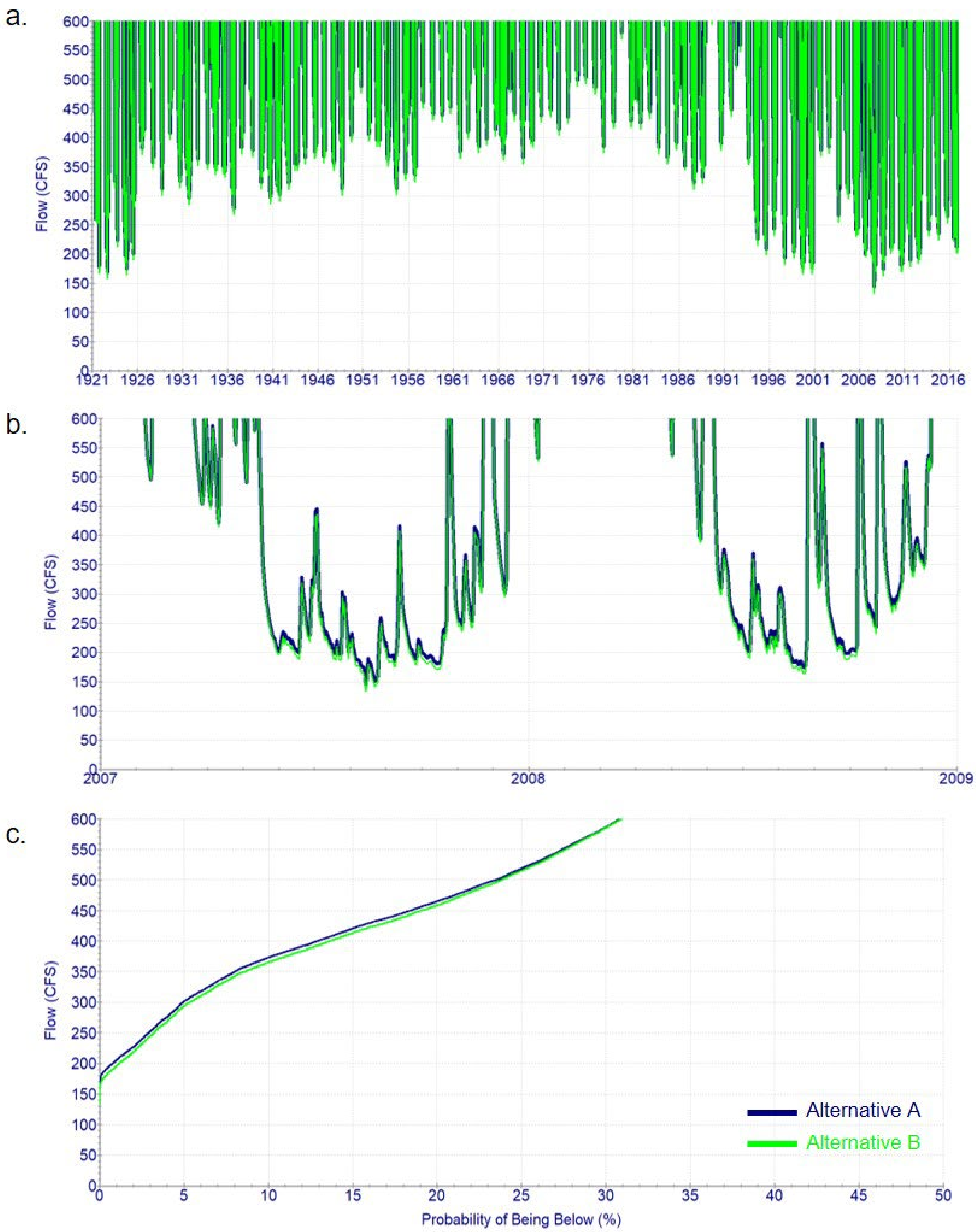


Figure B-6, Simulated flows at the USGS gage at Craig Bridge Road (03600358): (a) Simulated flow (cfs) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) with recent water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with recent water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with recent water demands.

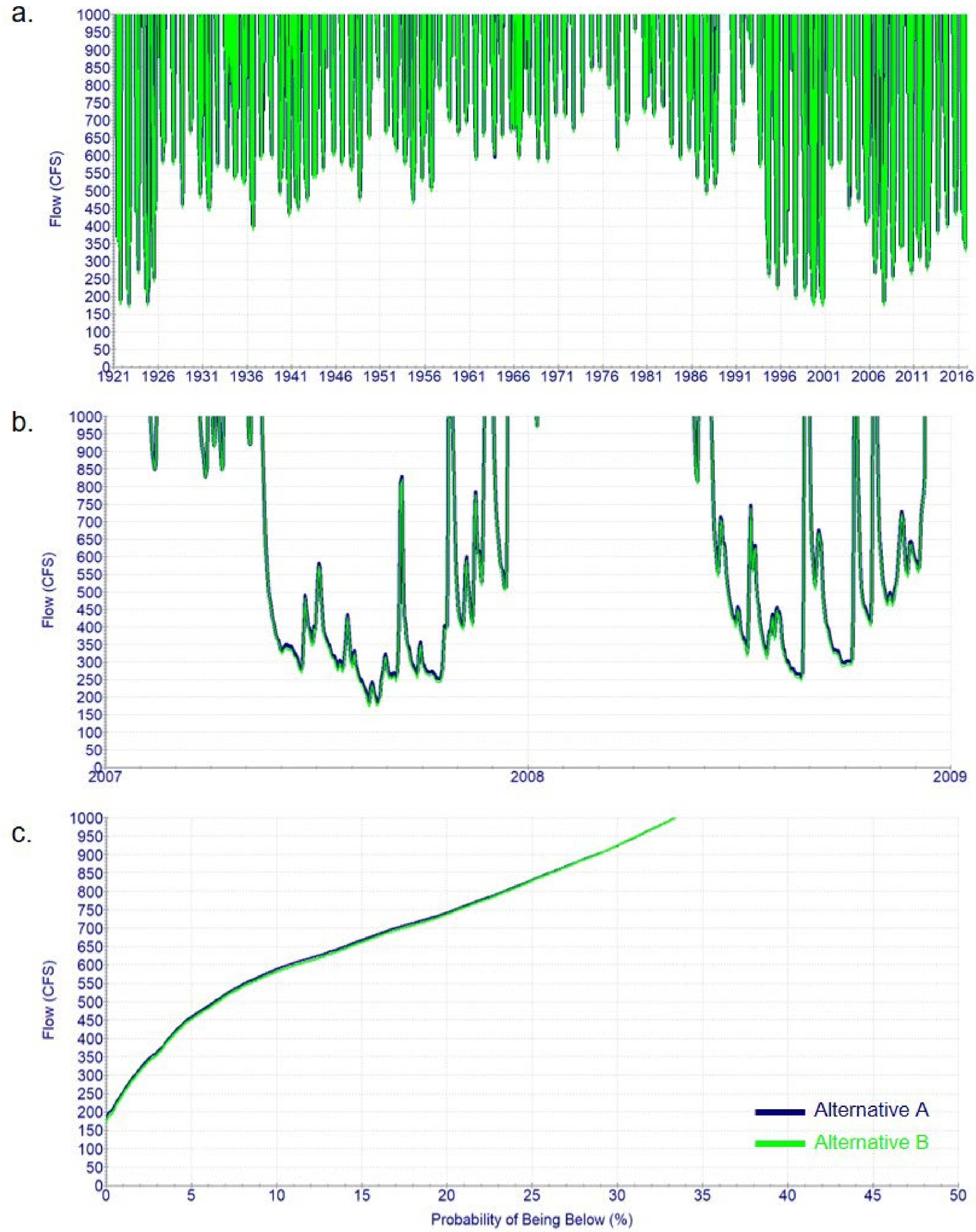


Figure B-7, Simulated flows at the USGS gage at Highway 100 at Centerville (03601990): (a) Simulated flow (cfs) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) with recent water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with recent water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with recent water demands.

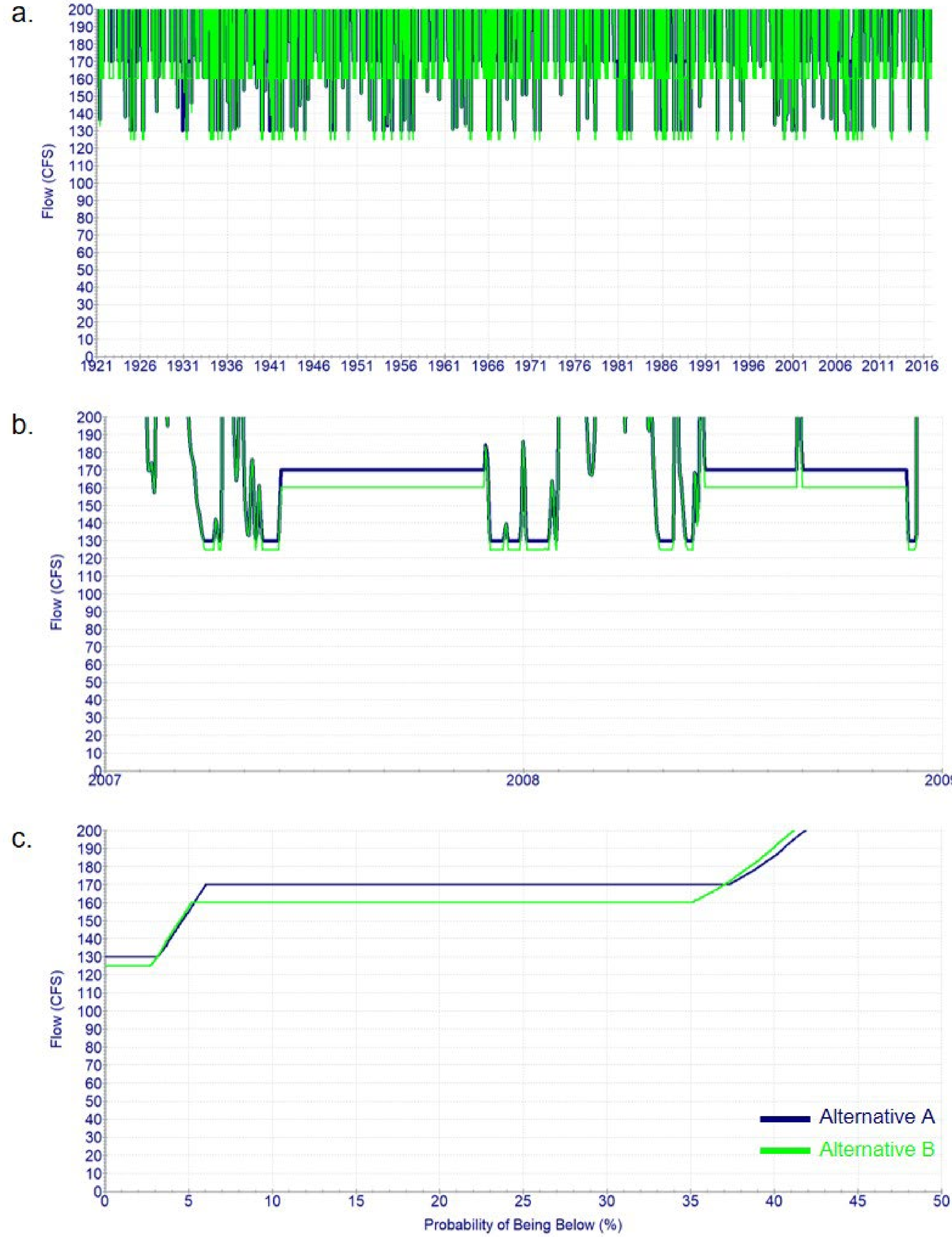


Figure B-8, Simulated flows at the USGS gage at Shelbyville (03597860): (a) Simulated flow (cfs) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) with future water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with future water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with future water demands.

a.

b.

c.

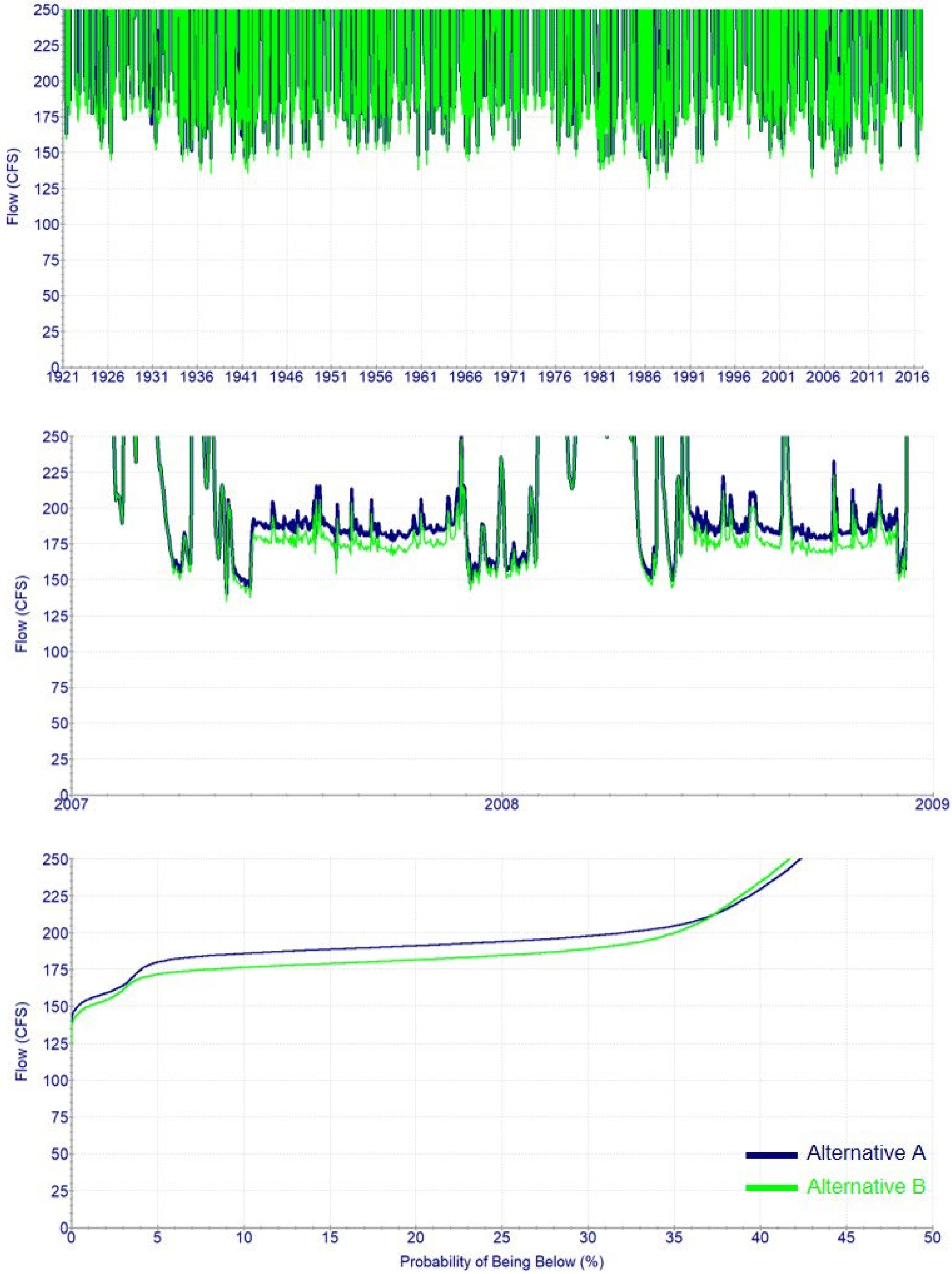


Figure B-9, Simulated flows at the USGS gage near Shelbyville (03598000): (a) Simulated flow (cfs) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) with future water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with future water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with future water demands.

Figure B-10, Simulated flows at the USGS gage above Milltown (03599240): (a) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) for future water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with future water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with future water demands.

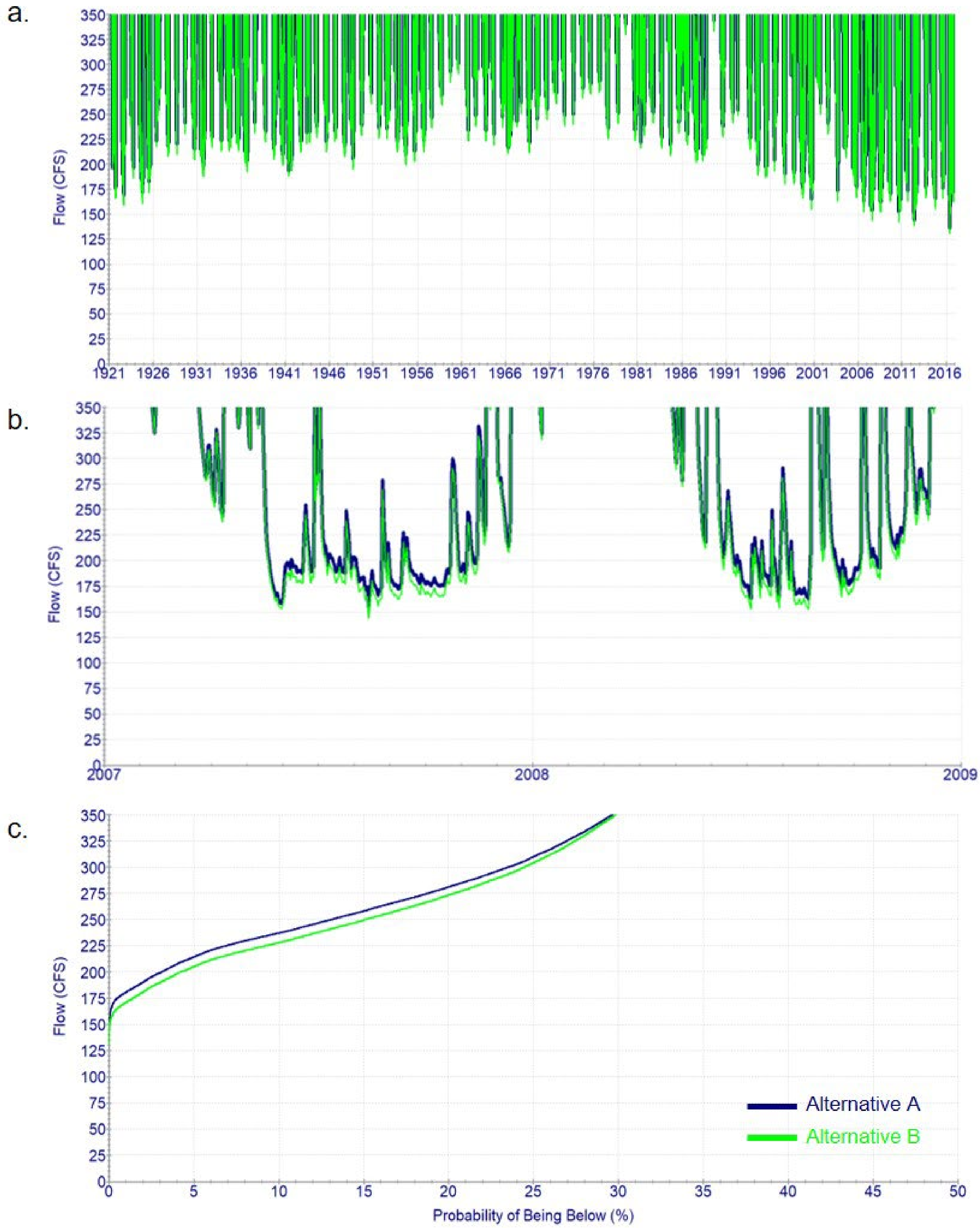


Figure B-11, Simulated flows at the USGS gage near Pottsville (03599419): (a) Simulated flow (cfs) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) with future water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with future water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with future water demands.

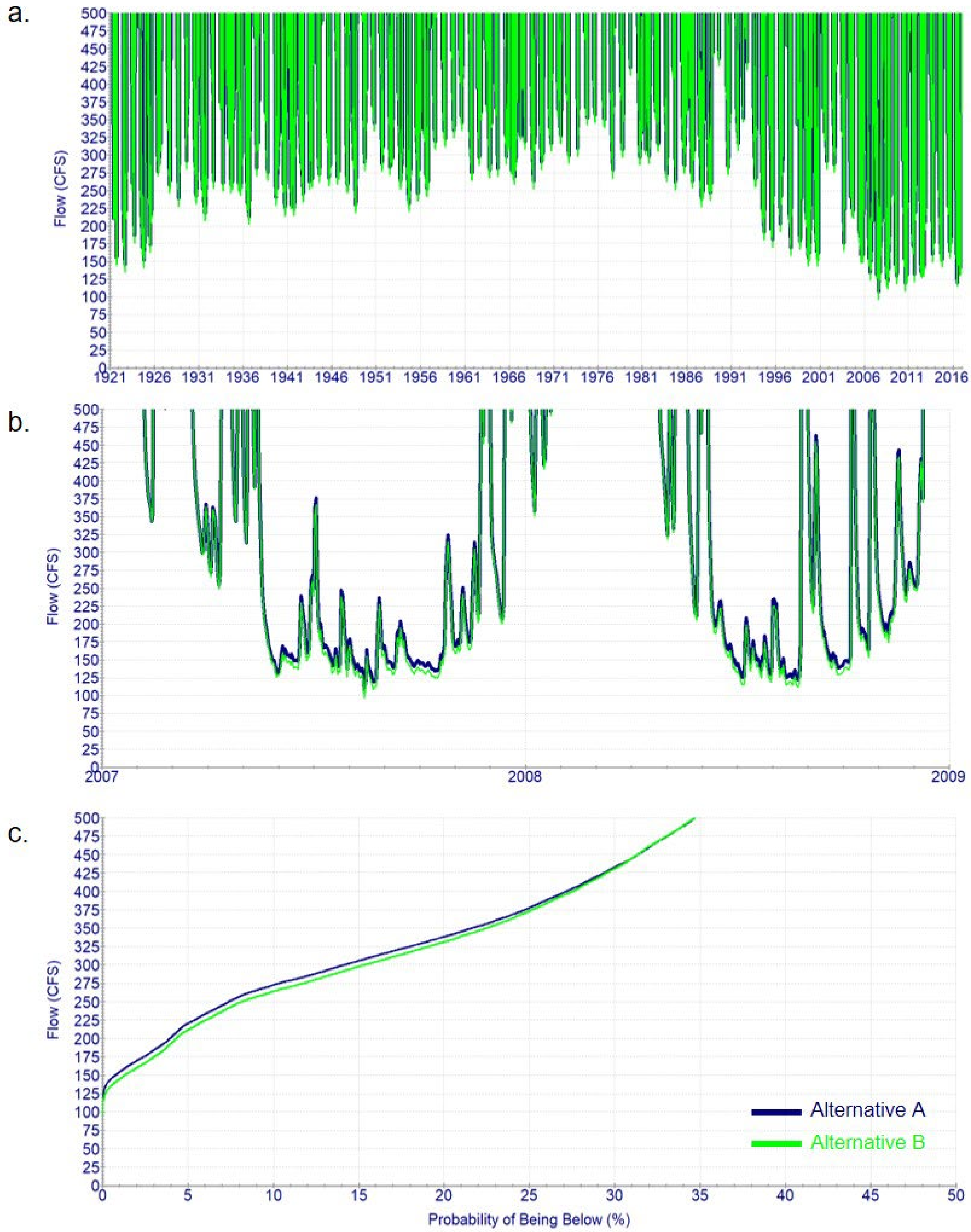


Figure B-12, Simulated flows at the USGS gage at Columbia (03599500): (a) Simulated flow (cfs) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) with future water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with future water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with future water demands.

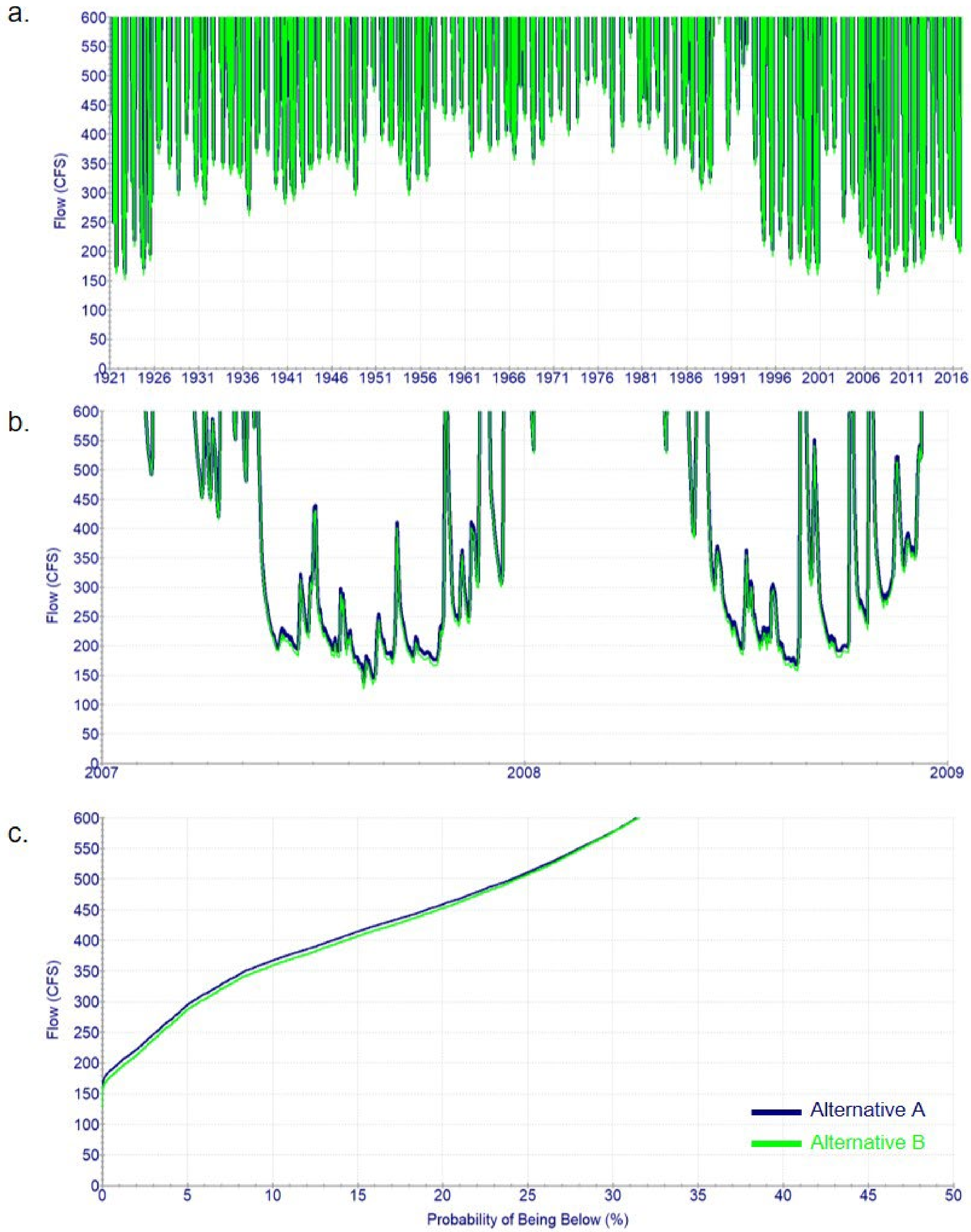


Figure B-13, Simulated flows at the USGS gage at Craig Bridge Road: (a) Simulated flow (cfs) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) with future water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with future water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with future water demands.

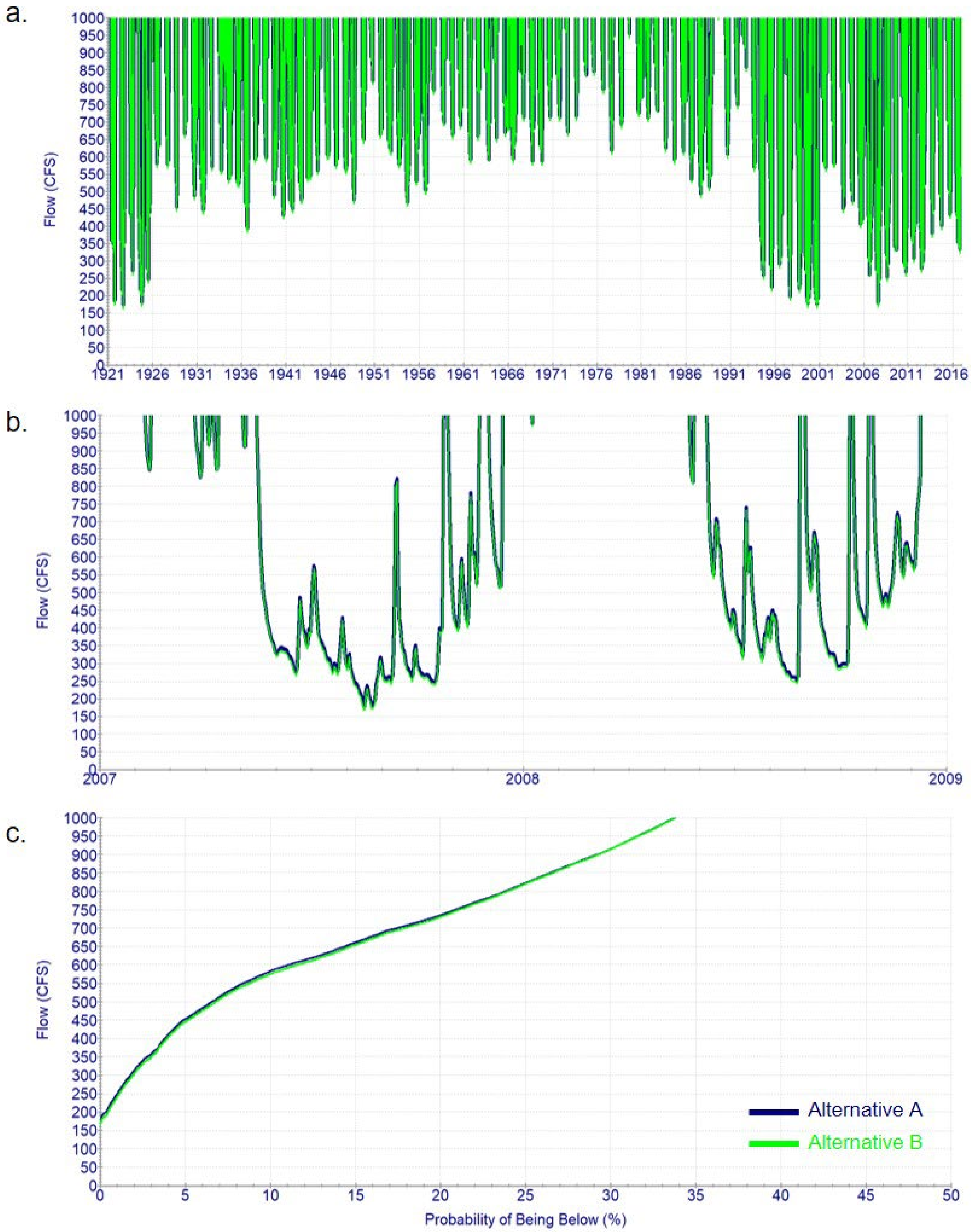


Figure B-14, Simulated flows at the USGS gage at Centerville (03601990): (a) Simulated flow (cfs) for Alternative A and Alternative B based on the long-term hydrologic record (1921 to 2016) with future water demands. (b) Simulated flow from 2007 to 2009 for Alternative A and Alternative B with future water demands. (c) Probabilities of Duck River flow (cfs) based on the number of days in the historic hydrologic record for Alternative A and Alternative B with future water demands.

APPENDIX C – TDEC WATER QUALITY EVALUATION RESULTS FOR THE DUCK RIVER BASIN

TDEC Water Quality Evaluation Results for the Duck River Basin Environmental Assessment

The Tennessee Valley Authority (TVA) and the Duck River Development Agency (DRA) are preparing a Duck River Basin Environmental Assessment (EA) to consider various alternatives for (flow) releases from Normandy Dam. The proposed changes in the operation of Normandy Dam would subsequently change minimum flow constraints and impact water quality on the Duck River below the dam. This document describes the approach and results of the analyses conducted by the Tennessee Department of Environment and Conservation (TDEC) to evaluate the extent of water quality impacts from proposed operational changes of Normandy Dam in support of the Duck River EA.

The minimum flow constraints, as measured at the USGS gage, Duck River at Shelbyville (03597860), under existing conditions and those resulting from TVA's proposed changes, are presented in Table 1 and illustrated in Figure 1. Alternative flows being considered for the EA are Normandy Dam operational alternatives (A and B) and Drought Management Plan (DMP) response scenarios (Stages 3 and 4) proposed by TVA. These are described in Appendix A. Note that Alternative A is the "no action" alternative, meaning that TVA would not implement a change to their current operations. In addition, the regulatory flow ($1Q_{10}$), for calculation of assimilative capacity for NPDES Permit applications, is also an important flow constraint for water quality in the Duck River. The site-specific $1Q_{10}$ represents the basis for calculation of wasteload allocations for permit limits. All of these "critical" flow conditions were evaluated for impacts to water quality.

Table 1. Flow Constraints at Shelbyville gage (USGS 03597860) for Duck River EA Water Quality Analyses.

Flow Constraint Scenario	Minimum Flow (cfs)[1]	Description
Alternative A	155	Existing Conditions Operational Flow Target (No Action Alternative)
$1Q_{10}$[2]	139	Flow for application of Water Quality Criteria in Permits for Regulated Streams (critical flow occurring, on average, once in 10 years)
Alternative B	135	Revised Operational Flow Target
Stage 3	120	Stage 3 Trigger of Drought Management Plan (Applicable to Alternatives C and D)
Stage 4	80	Stage 4 Trigger of Drought Management Plan (Applicable to Alternatives C and D)

[1] Critical worst-case low-flow conditions for each scenario.
[2] See Appendix B, 0400-40-03-.05, Interpretation of Criteria.

An important consideration for the Duck River EA is the impact the proposed changes would have on water quality in the Duck River downstream from Normandy Dam. TDEC's analysis of this potential impact was twofold: to evaluate impacts with respect to 1) ammonia toxicity and 2) assimilative capacity of the Duck River. Ammonia toxicity criteria are established to protect aquatic life from acute (CMC) and chronic (CCC) effects of ammonia in freshwater ecosystems (EPA, 2013). Ammonia toxicity criterion values (both acute and chronic) vary continuously based on ammonia concentration, pH, and temperature. Assimilative capacity is the natural capacity of a stream to receive organic wastes without decreasing the stream dissolved oxygen (DO) concentrations below the State minimum criterion of 5.0 mg/L. The DO criterion is interpreted instantaneously and shall not be less than 5.0 mg/L. See Appendix B for additional information regarding Water Quality Criteria for Ammonia and Dissolved Oxygen. The following sections describe TDEC's methodology and subsequent results of the two analyses.

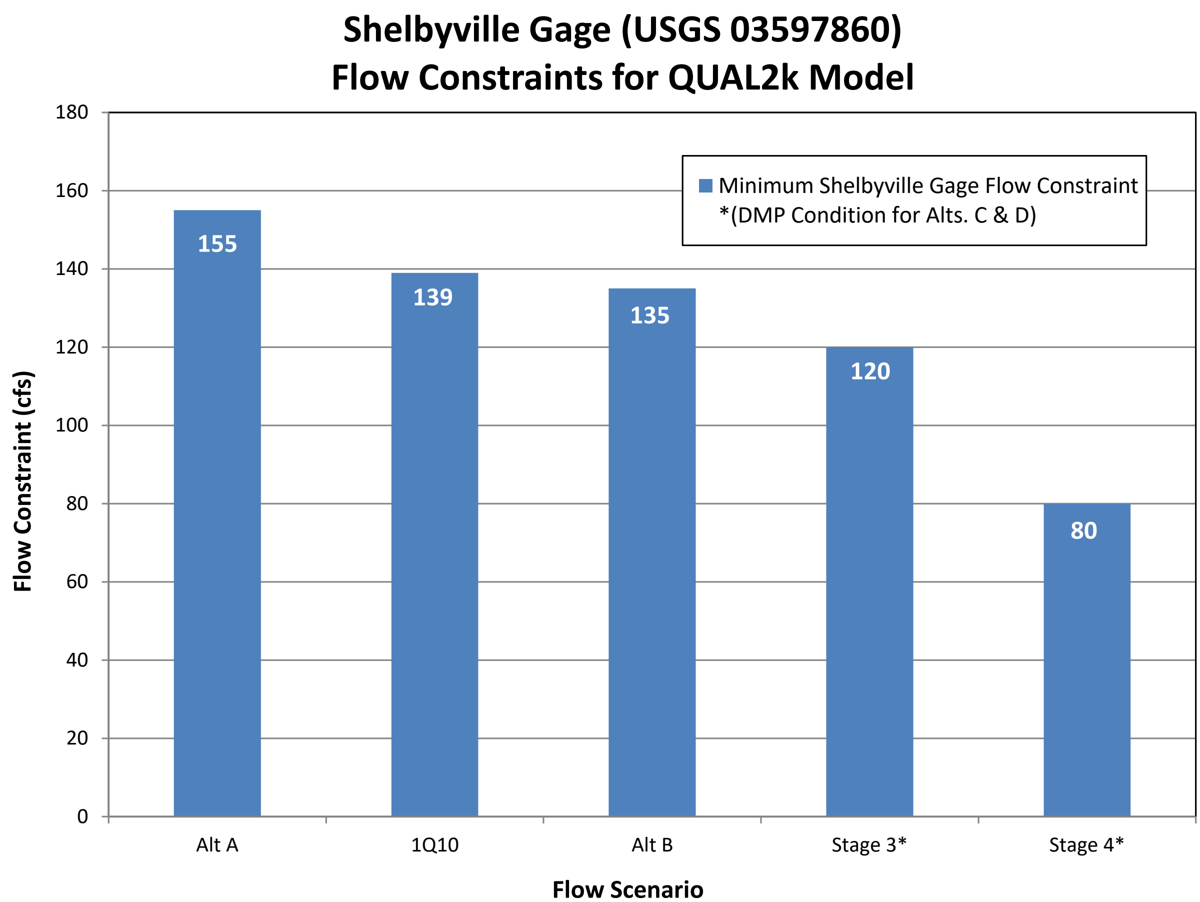


Figure 1. **Flow Constraint Scenarios at Shelbyville gage (USGS 03597860) for Duck River EA Water Quality Analyses.**

1) Ammonia (NH_3) Toxicity:

Normandy Dam CE-QUAL-W2 model output

TVA utilized the CE-QUAL-W2 model to simulate Normandy Dam Reservoir and Dam releases (flow and water quality) for three recent years, representing wet (2018) and dry (2016) conditions and one of the driest years on record (2007). Simulations included existing conditions and potential changes in water quality due to proposed changes in the operation of Normandy Dam resulting from alternative operational flow targets and response scenarios under regional drought conditions.

For the years 2016 and 2018, both existing conditions (Alternative A), with a minimum instantaneous flow at the Shelbyville gage of 155 cfs for the period May-November, and the proposed minimum instantaneous discharge of 135 cfs (Alternative B) for the same six-month period, were simulated to determine potential ammonia toxicity below Normandy Dam. It was not possible to simulate Stages 3 and 4 Triggers based on DMP conditions (for Alternatives C and D) for the years 2016 and 2018 because both were too wet, hydrologically. However, for 2007, all flow conditions, including the Stage 3 trigger (minimum instantaneous discharge of 120 cfs) and the Stage 4 trigger (minimum instantaneous discharge of 80 cfs), were simulated to determine potential ammonia toxicity below Normandy Dam. See Figures 15-38, Appendix C for results.

Under each of the Alternative (A and B) and Drought Management (Stages 3 and 4) scenarios, there were no conditions of ammonia toxicity at any time. Therefore, no conditions of ammonia toxicity would be expected between Normandy dam and the Shelbyville STP under any of the scenarios. Figures 2-4 illustrate the changes in relative ammonia toxicity (ammonia/ammonia toxicity) fractions between the various alternatives and drought condition scenarios. Note that a value of 1.0 represents the threshold of toxicity and none of the plot lines reach that value. However, higher values indicate conditions approaching toxicity. Acute conditions were chosen for comparison because they most closely approach toxic conditions.

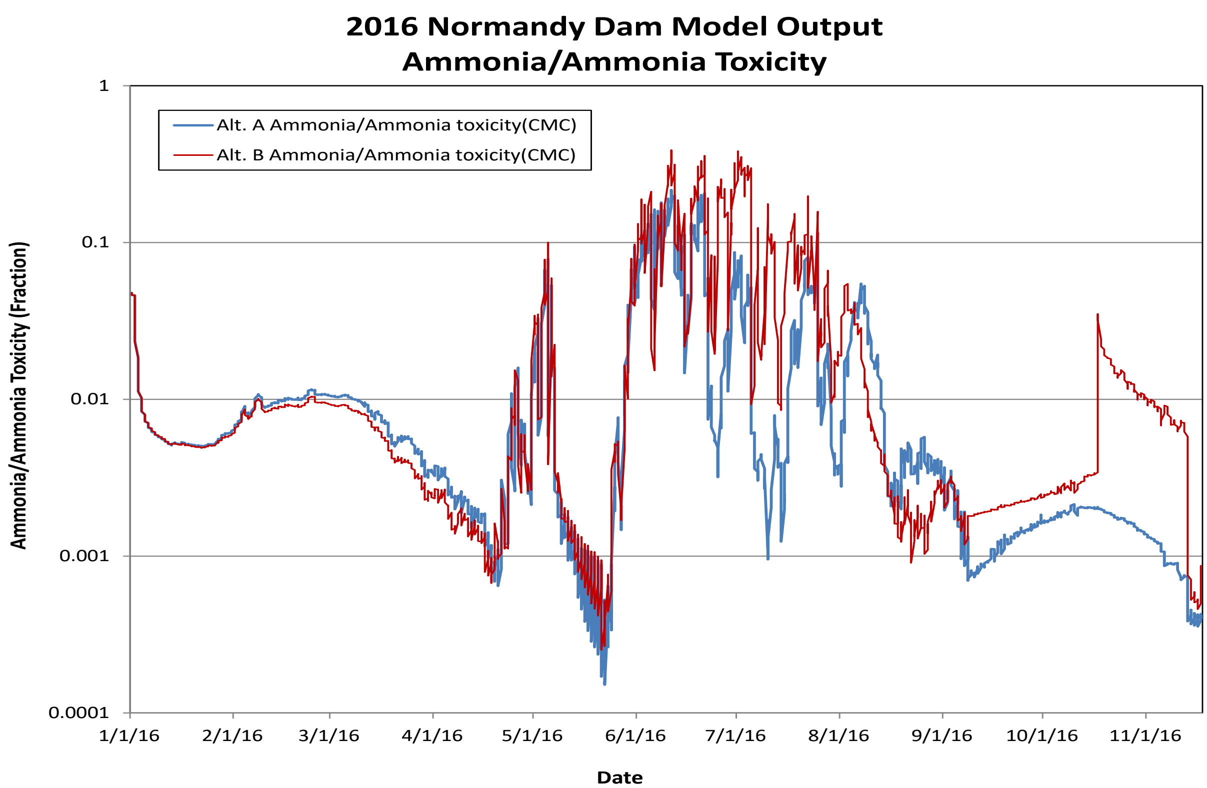


Figure 2. 2016 Normandy Dam Model Output – Alternatives A vs. B – Acute Ammonia Toxicity Criterion.

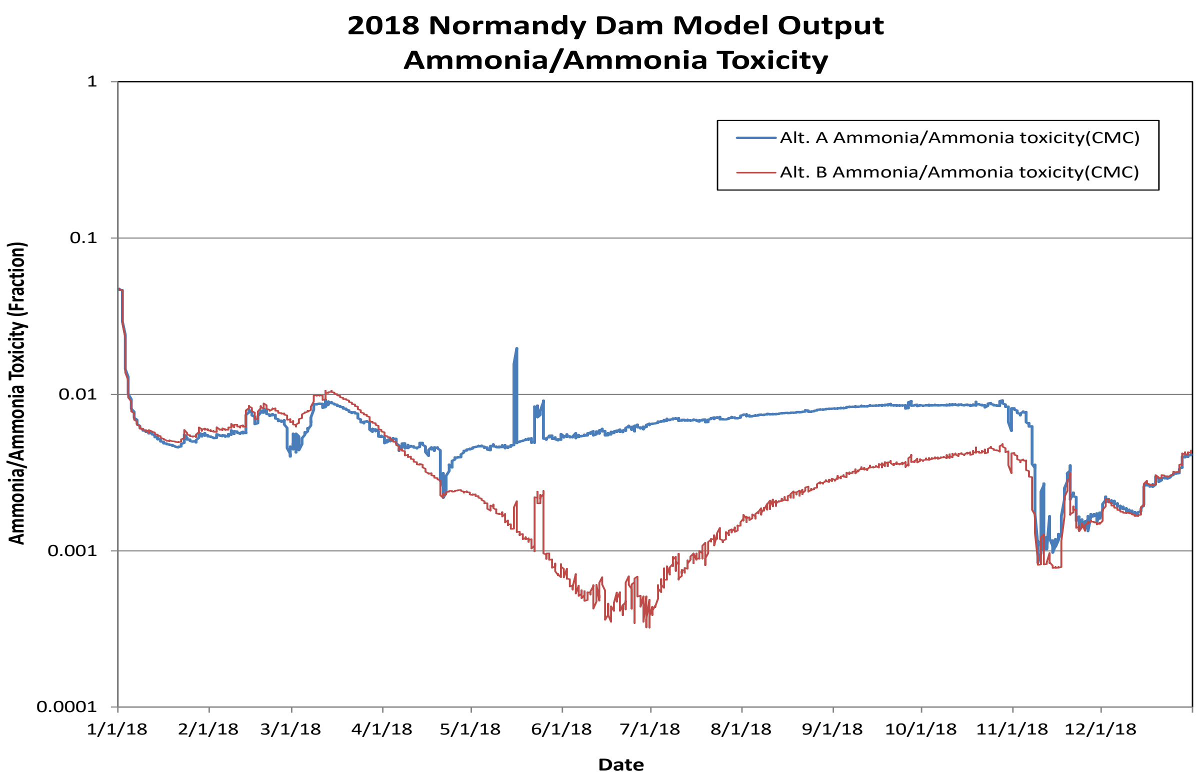


Figure 3. 2018 Normandy Dam Model Output – Alternatives A vs. B – Acute Ammonia Toxicity Criterion.

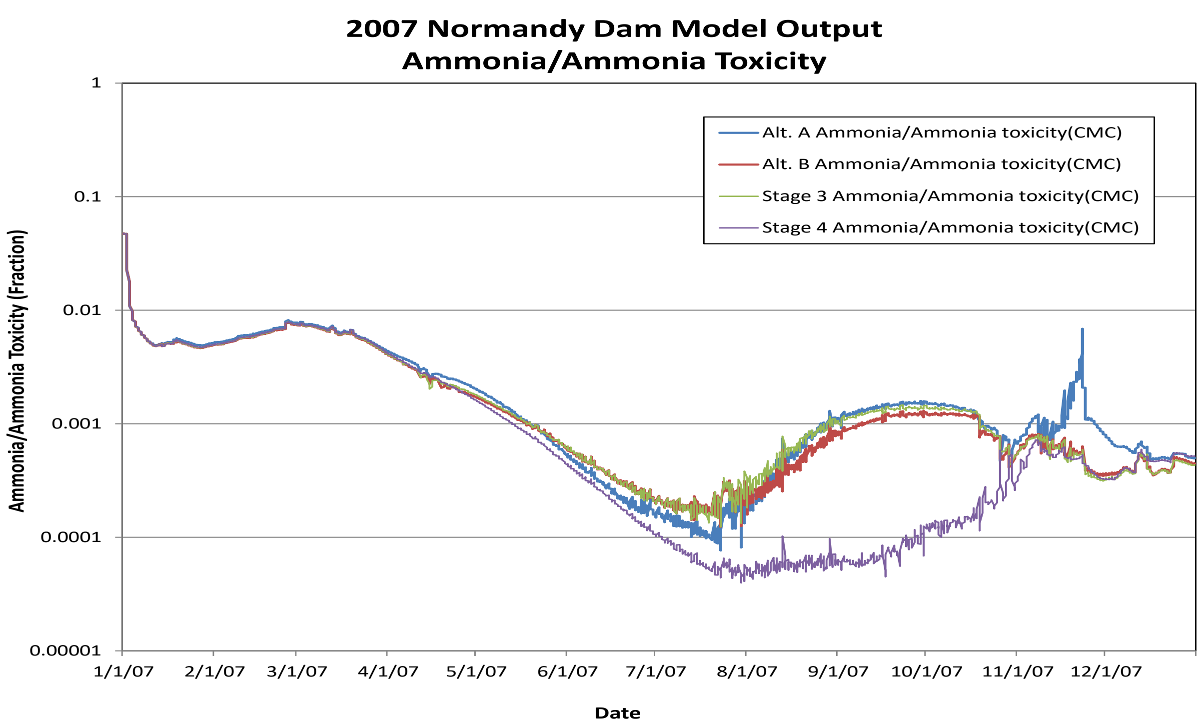


Figure 4. 2007 Normandy Dam Model Output – Alternatives A vs. B vs. Stages 3 and 4 – Acute Ammonia Toxicity Criterion.

Point Source Facilities effluent

Each primary NPDES point source facility discharging to the Shelbyville segment of the Duck River was included in the QUAL2k steady state model (Appendix D) developed to evaluate ammonia toxicity and assimilative capacity. However, all point sources included in the QUAL2k model are evaluated in-stream and are considered to be fully mixed at the point of discharge. The following analyses are evaluations of the point sources at the point of discharge, before being released to the Duck River and the subsequent ammonia toxicity immediately after release, before mixing. In addition, the analyses are presented for existing/historical effluent releases for each facility. For the Shelbyville STP and Tyson Farms, effluent permit limits are significantly higher (concentrations and loading) and would potentially represent higher levels of (relative) toxicity. See longitudinal profile results in the Section below titled *River Segment Below Shelbyville STP* for impacts resulting from scenarios simulated with maximum permit limits.

Shelbyville STP (Duck River mile 221)

End-of-pipe ammonia (NH_3) toxicity analyses were conducted on daily MOR data (ammonia concentration, pH, and temperature) for the period 2016-2018 to determine if toxicity occurs at the point of discharge. See Figures 51-59, Appendix E. If no toxicity occurs at end-of-pipe, it is unlikely that toxicity would occur at a point in the immediate vicinity of the outfall or in the segment of the river downstream. The analyses of MOR data indicated no end-of pipe ammonia toxicity due to Shelbyville STP effluent. Note that the dilution ratio in the river is significant (≈ 10:1); therefore, any improbable near-field toxic conditions occurring due to Shelbyville STP effluent would be expected to be infrequent, minor and short-lived.

Tyson Farms, Shelbyville Processing Plant (Duck River mile 220.2)

Similar to the Shelbyville STP, above, end-of-pipe ammonia (NH_3) toxicity analyses were conducted on daily MOR data (ammonia concentration and pH) for the period 2017-2018 to determine if toxicity occurs at the point of discharge. However, because no temperature data were available; theoretical toxicity curves for potential critical temperatures (25˚, 27˚, and 30˚C) were developed. See Figures 60-65, Appendix F. The analyses of MOR data indicated end-of-pipe ammonia toxicity due to Tyson Farms effluent would occur periodically under any of the three critical temperature conditions.

The dilution ratio in the river is high (≈ 75:1); therefore, at complete mixing, ammonia concentrations are expected to be non-toxic. However, complete mixing does not occur instantaneously; therefore, a mixing zone exists downstream from the effluent discharge where ammonia concentrations would likely be periodically toxic under conditions described above. The level of toxicity, under critical conditions, will be exacerbated by lower flows due to proposed changes in operation of Normandy Reservoir. However, these ammonia toxicity issues should be addressed through the State (TDEC) NPDES permitting process.

Chapel Hill WWTP (Duck River mile 185.5)

A basic end-of-pipe ammonia (NH_3) toxicity analysis was conducted based on limited ammonia concentration data, from approximately 2018, submitted with the Chapel Hill facility expansion application in 2019. These data consisted of three effluent ammonia grab samples with an average concentration of 3.12 mg/L and a maximum concentration of 4.89 mg/L. No pH or temperature data were available; therefore, toxicity curves for potential critical temperatures (25˚, 27˚, and 30˚C) and pH (6, 8, and 10) were developed, assuming the average concentration of ammonia (3.12 mg/L). See Figures 66 and 67 and Tables 5 and 6, Appendix G. The analyses of Permit application data indicated end-of-pipe ammonia toxicity due to Chapel Hill WWTP effluent would occur at least periodically, if not continuously for extended periods of time, under all of the multiple critical temperature conditions and all but the lowest pH (= 6) conditions.

The dilution ratio in the river is very high (> 100:1); therefore, at complete mixing, ammonia concentrations are expected to be non-toxic. Complete mixing does not occur instantaneously; therefore, a mixing zone exists downstream from the effluent discharge where ammonia concentrations are expected to be periodically, if not persistently, toxic. The level of toxicity, under critical conditions, will be exacerbated by lower flows due to proposed changes in operation of Normandy Reservoir. These ammonia toxicity issues are being addressed through the State (TDEC) NPDES permitting process.

River Segment below Shelbyville STP

TDEC developed a QUAL2k steady state model to evaluate the water quality impacts due to the proposed changes in the operation of Normandy Dam. The goal of the model is to assess the impact on water quality due to changes in flow constraints at the Shelbyville USGS gage (03597860). The calibrated model was utilized to simulate critical conditions for Normandy Dam operational alternatives (A and B) and drought response scenarios (Stages 3 and 4) proposed by TVA for each of the two boundary DO concentrations (6.0 mg/L and 7.13 mg/L). See Section 2 for further discussion about model boundary conditions and Appendix F for additional information regarding water quality parameters for the calibrated critical condition QUAL2k model developed for ammonia toxicity and assimilative capacity analyses in the Shelbyville segment of the Duck River.

Temperature and pH output from the calibrated model were used to calculate acute (CMC) and chronic (CCC) ammonia toxicity criteria which were compared with modeled ammonia concentration to determine ammonia toxicity exceedance. Model results (Figures 5 and 6) indicate that ammonia toxicity occurs when the boundary flow is below 120 cfs because of a decrease in ammonia toxicity criteria concentration values caused by an increase in water temperature. When boundary flow decreases, the river is more susceptible to atmospheric changes and has less ability to assimilate the changes. During summer critical conditions, river temperature can rise above 30°C which subsequently lowers the acute ammonia toxicity concentration criterion. Model results do not indicate significant changes in ammonia and acute toxicity concentrations due to changes in dissolved oxygen concentration.

At stage 3 drought (120 cfs), acute ammonia toxicity occurs near river miles (RMs) 217 and 206 with a minimum CMC of 0.33 and 0.28 mg/L, respectively. See Figure 5. At stage 4 drought (80cfs) acute ammonia toxicity occurs between RMs 219 and 212 and downstream from RM 209. See Figure 6. See Figures 68-75, Appendix H for complete results.

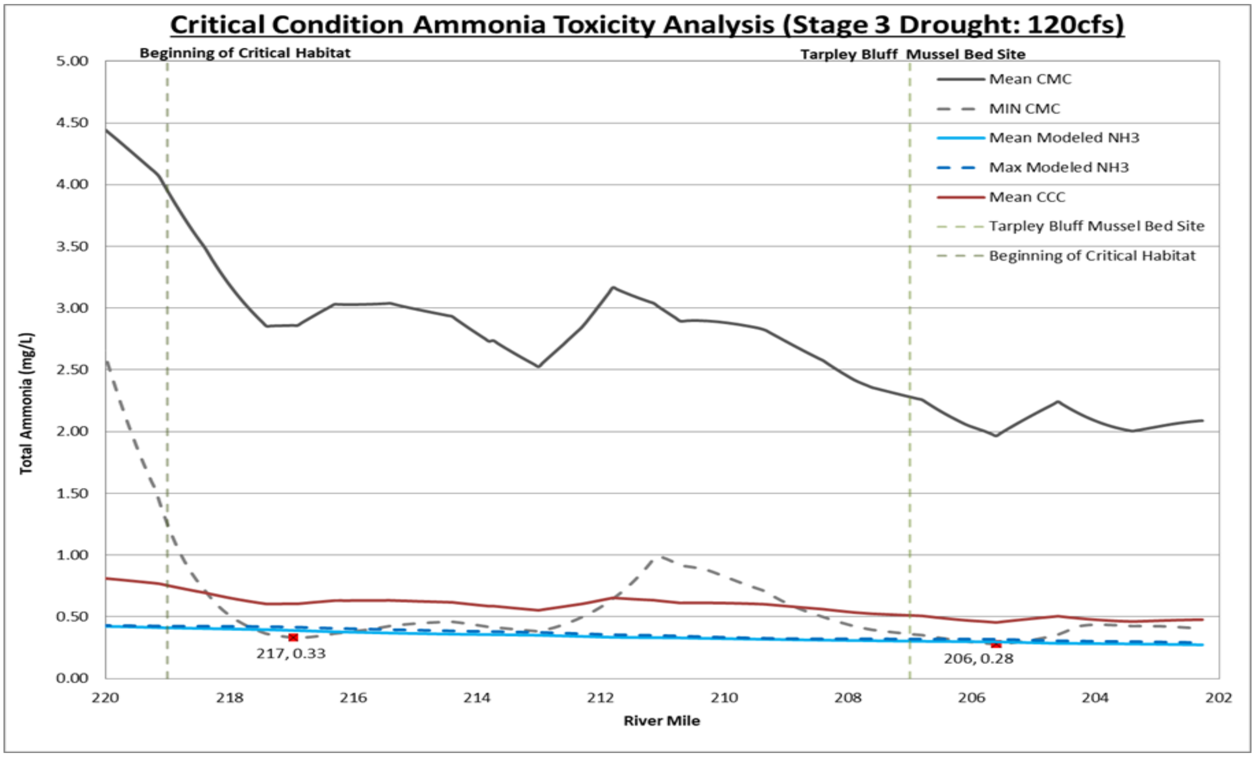


Figure 5. **Predicted Acute Ammonia Toxicity and Modeled Ammonia Concentration for Stage 3 Drought Management Condition (120cfs).**

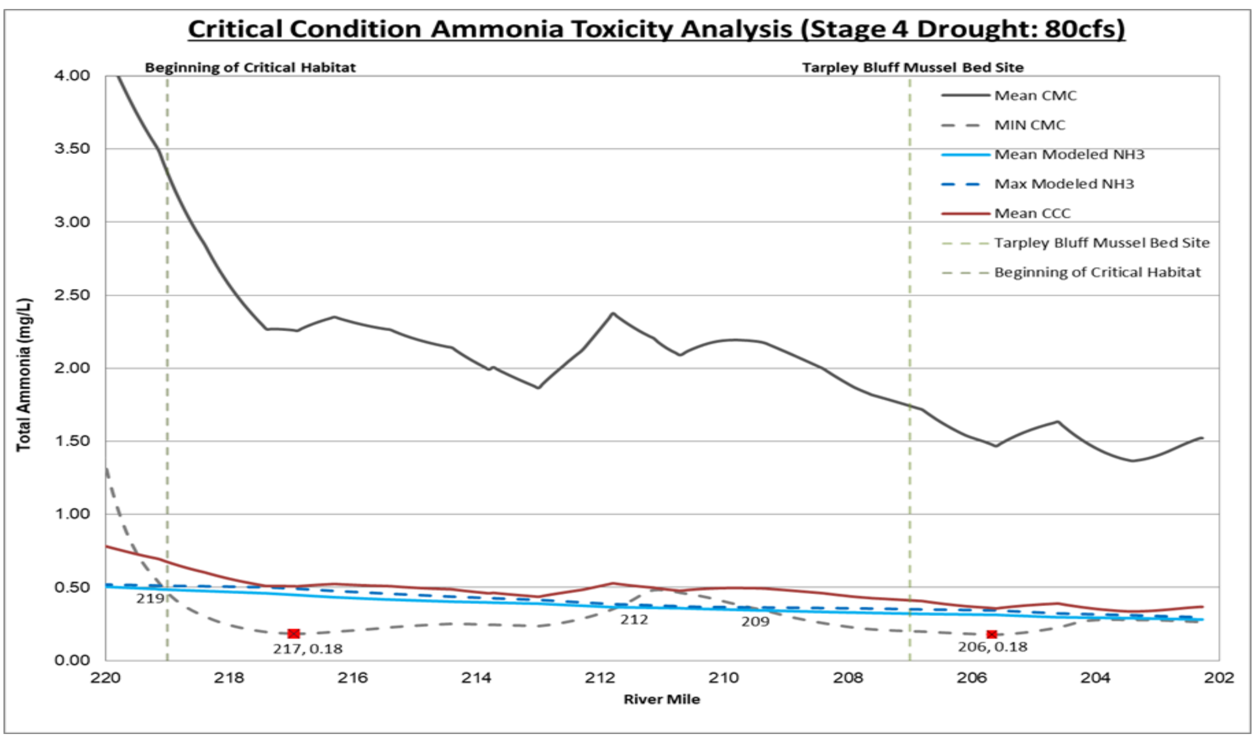


Figure 6. **Predicted Acute Ammonia Toxicity and Modeled Ammonia Concentration for Stage 4 Drought Management Condition (80cfs).**

2) Assimilative Capacity for Dissolved Oxygen:

The goal of the assimilative capacity analysis is to assess the impact on DO due to changes in flow conditions and point source discharges under critical conditions. Scenarios with various proposed alternative flow constraints (described previously), plus the$1Q_{10}$ regulatory flow, (155 cfs, 139 cfs, 135 cfs, 120 cfs, and 80 cfs) and boundary DO concentrations (6.0 mg/L and 7.13 mg/L) were simulated. The DO boundary concentration of 6.0 mg/L is the State-EPA agreed recommended value for critical condition model input and 7.1 mg/L is the minimum recorded DO concentration based on 2016 field data collection. Model simulations are presented for both DO boundary conditions (6.0 mg/L and 7.1 mg/L) because 7.1 mg/L is a reasonable minimum for existing conditions but is not a conservative/protective assumed critical boundary condition for scenarios simulating unobserved, lower flow conditions. See Appendix D for description of the QUAL2k model calibration process.

For the scenarios with boundary DO of 6.0 mg/L, minimum DO drops below the DO standard of 5.0 mg/L when the flow constraint is at or below 135 cfs. Note that the regulatory critical condition flow ($1Q_{10}$) for determination of wasteload allocations/permit limits is 139 cfs. The modeled DO profiles for the alternative B flow (135 cfs) and the $1Q_{10}$ (139 cfs) do not vary significantly. Therefore, the two conditions are effectively equivalent for the purposes of this report. Figures 7-12 show changes under various proposed flow conditions. A contributing cause of the DO standard exceedance is increased retention time due to lower flow and subsequent longer travel times. The model output shows that longer retention times provide increased opportunity for algae to be in contact with nutrients which subsequently enhances algal growth and causes a higher DO deficit during respiration.

See Appendix H, Figures 76-85, for longitudinal DO profile plots of each flow constraint scenario for 6.0 mg/L vs. 7.1 mg/L boundary conditions.

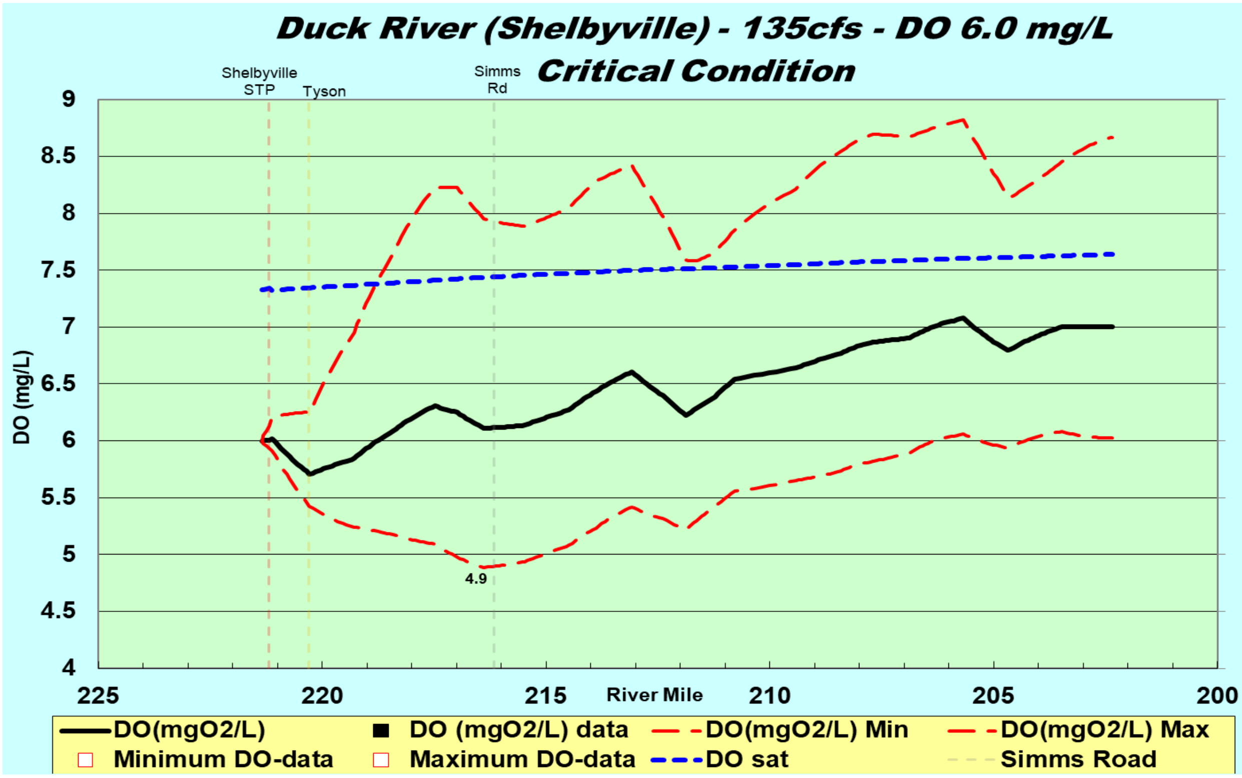


Figure 7. QUAL2k Assimilative Capacity Model (Alternative B) – 135 cfs/Boundary DO = 6.0 mg/L.

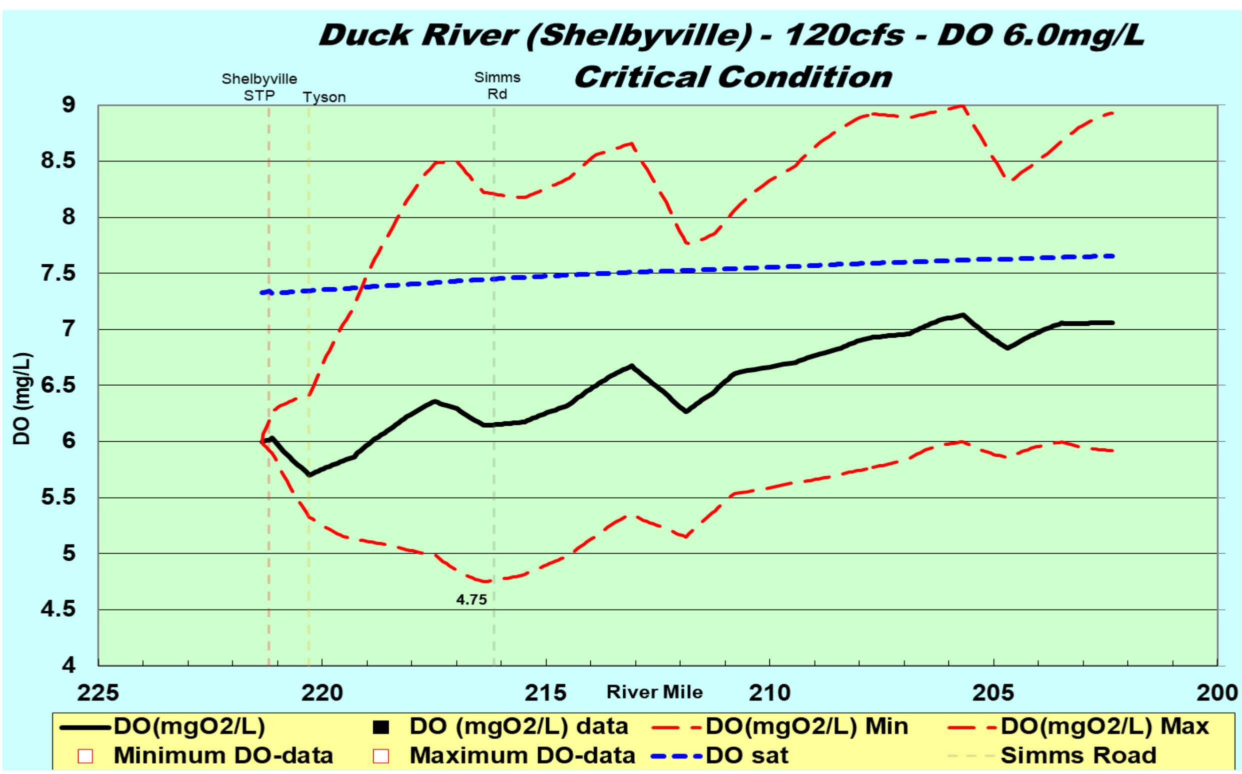


Figure 8. QUAL2k Assimilative Capacity Model (Stage 3) – 120 cfs/Boundary DO = 6.0 mg/L.

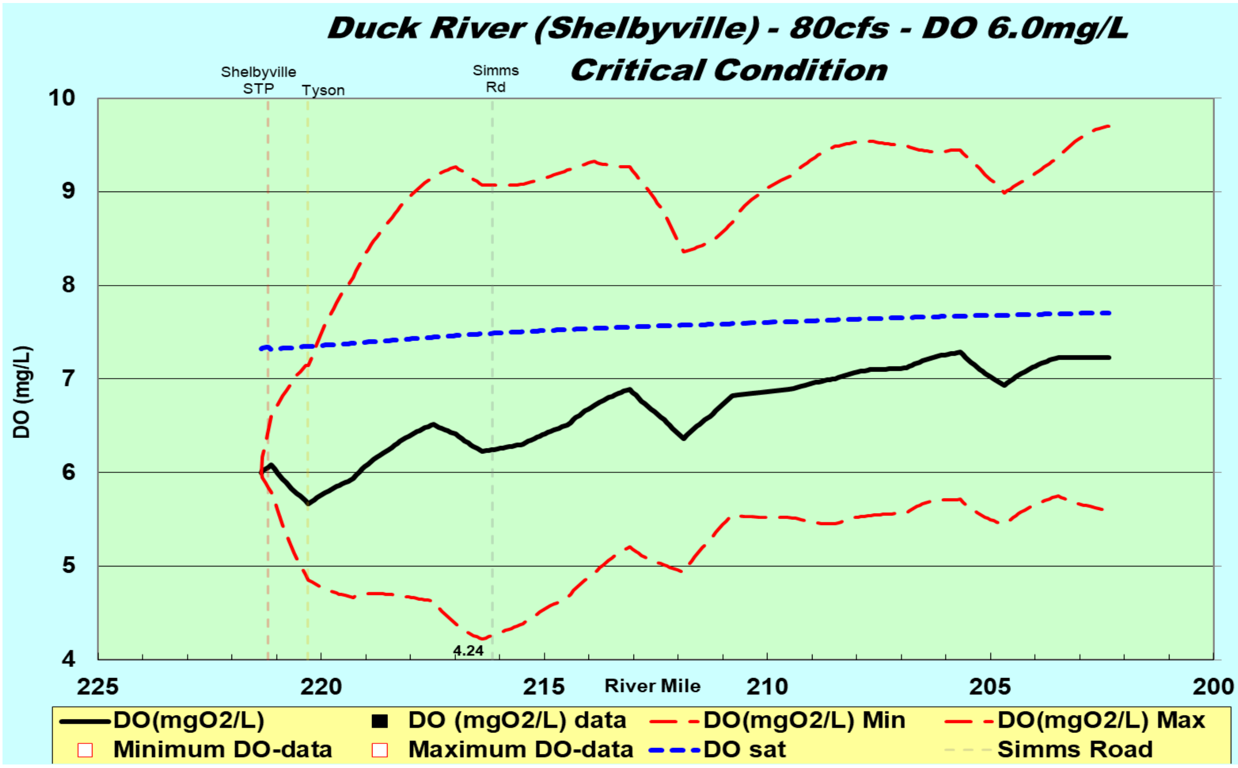


Figure 9. QUAL2k Assimilative Capacity Model (Stage 4) – 80 cfs/Boundary DO = 6.0 mg/L.

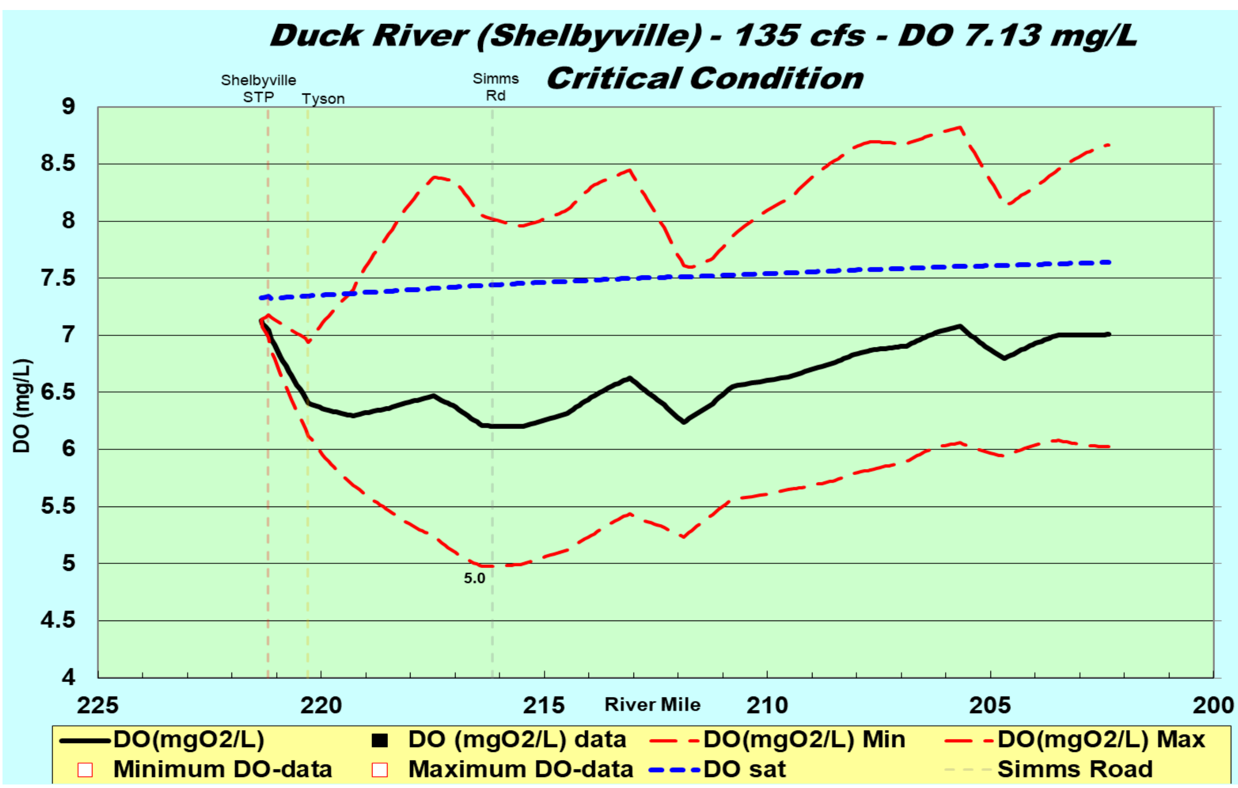


Figure 10. QUAL2k Assimilative Capacity Model (Alternative B) – 135 cfs/Boundary DO = 7.1 mg/L.

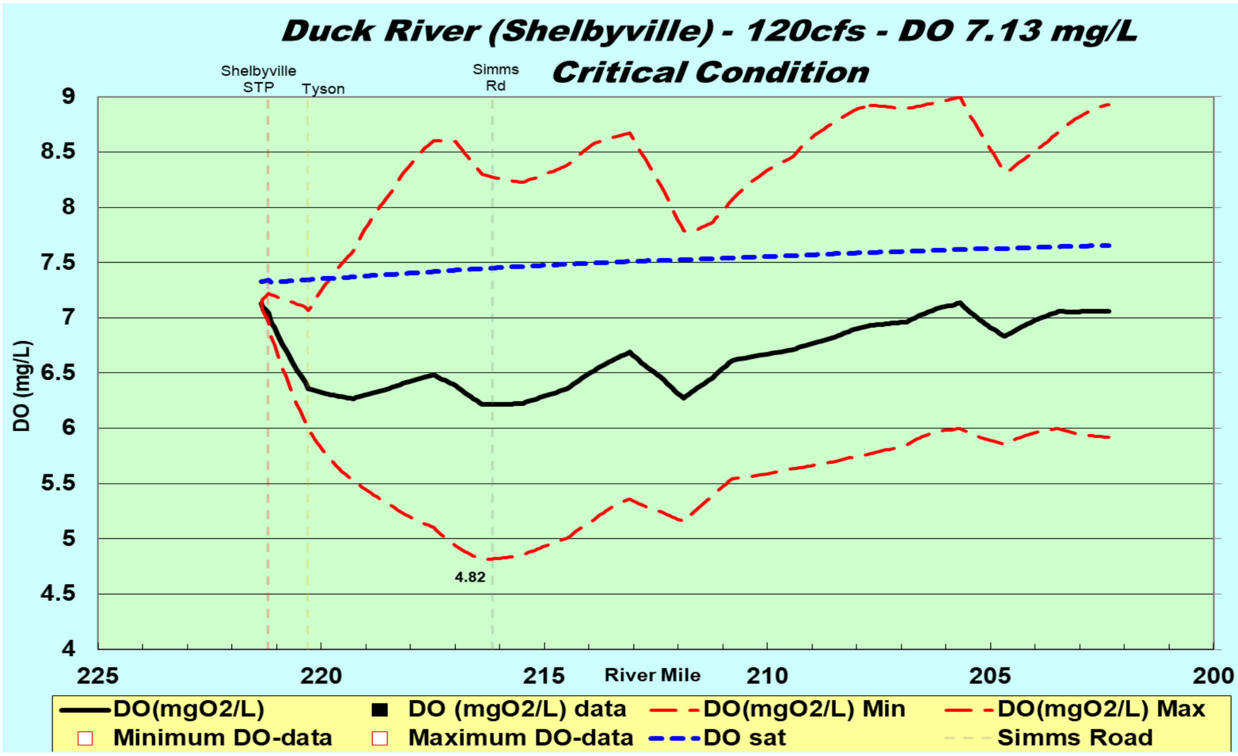


Figure 11. QUAL2k Assimilative Capacity Model (Stage 3) – 120 cfs/Boundary DO = 7.1 mg/L.

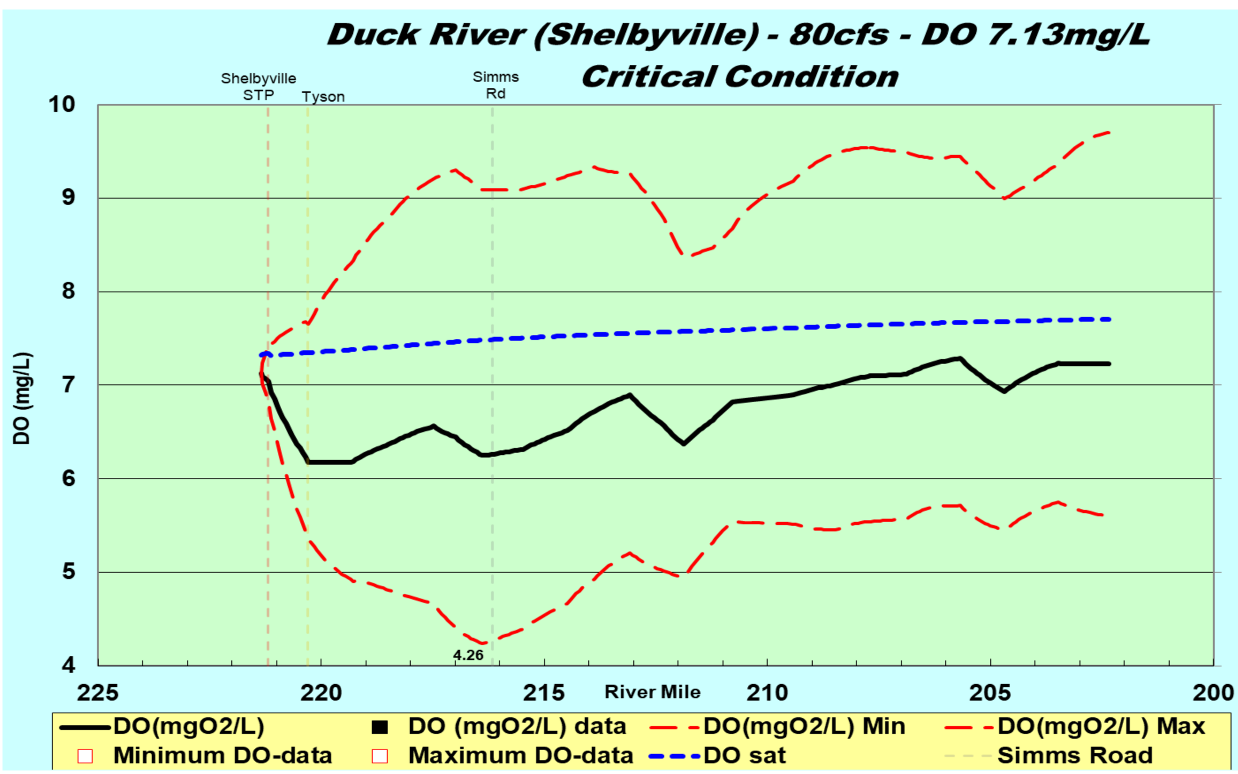


Figure 12. QUAL2k Assimilative Capacity Model (Stage 4) – 80 cfs/Boundary DO = 7.1 mg/L.

Results and Conclusions

TDEC conducted water quality analyses in support of the Duck River EA to evaluate the impacts of proposed changes in the operation of Normandy Dam in response to increased demands on regional water supply and efforts to improve drought management planning. The results of TDEC's ammonia toxicity and DO assimilative capacity analyses are presented in Table 2. Results indicate, in general, that water quality criteria (WQC), with respect to ammonia toxicity and DO, are currently being met under existing operating conditions and the current regulatory flow condition (i.e., $1Q_{10}$). However, at reduced flow constraint scenarios, specifically proposed Stages 3 and 4 minimum flows for drought response, WQC are likely to be exceeded (or violated) for both ammonia toxicity and DO. Model results suggest assimilative capacity of the Duck River is currently fully allocated (or nearly so) by NPDES discharger permit limits in the vicinity of the Shelbyville segment.

The portion of the Duck River designated as critical habitat for endangered mussel species, by the U.S. Fish and Wildlife Service (USFWS), extends from RM 219 at the confluence with Flat Creek (approximately 3 miles upstream from Simms Road [RM 216]), downstream to the Duck River embayment of the Tennessee River (Figure 13). This includes the Tarpley Bluff Mussel Bed at approximately RM 207 and represents a significant portion of the segment referred to herein as the Shelbyville segment of the Duck River. Figure 14 shows the locations of a number of important features of the Shelbyville segment of the Duck River. Additional information regarding Threatened & Endangered Species Critical Habitat can be found at the following USFWS website:

https://ecos.fws.gov/ecp/report/table/critical-habitat.html

Table 2. Results of Ammonia Toxicity and DO Assimilative Capacity Analyses.

Scenario	Flow (cfs)	Minimum DO (mg/L)[1,2]	River Mile (RM) of Minimum DO[1,2]	RM of DO Recovery (to 5 mg/L)[2]	Ammonia Toxicity (Yes/No)?[2]	RM of last Ammonia Toxicity[2]
Alt. A	155	5.04/5.15	216-217/216	NA/NA	No/No	NA/NA
$1Q_{10}$	139	4.9/5.0	216-217/216	215/NA	No/No	NA/NA
Alt. B	135	4.9/5.0	216-217/216	215/NA	No/No	NA/NA
Stage 3	120	4.75/4.82	216-217/216	214-215/214-215	Yes/Yes	205/205
Stage4	80	4.24/4.26	216-217/216	214-215/214-215	Yes/Yes	DNR[3]

NA = Not Applicable

[1] Minimum DO (sag) occurs in the vicinity of Simms Road (RM ≈ 216)

[2] Two values represented under two boundary DO concentrations (6.0/7.1 mg/L)

[3] Does Not Recover (model simulation ends at RM 202, at which point ammonia toxicity has not recovered)

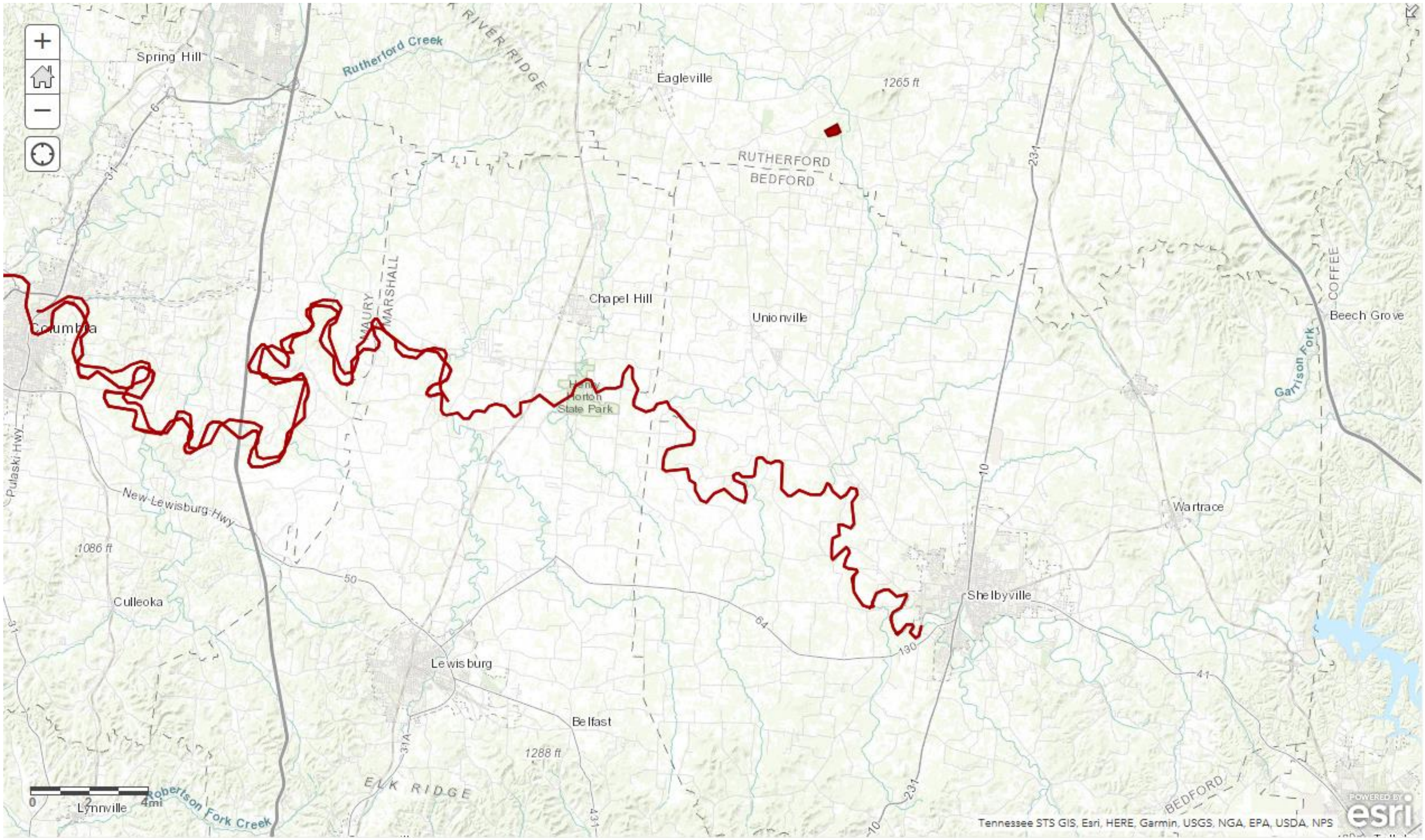


Figure 13. Duck River Critical Habitat for Threatened and Endangered Species (USFWS).

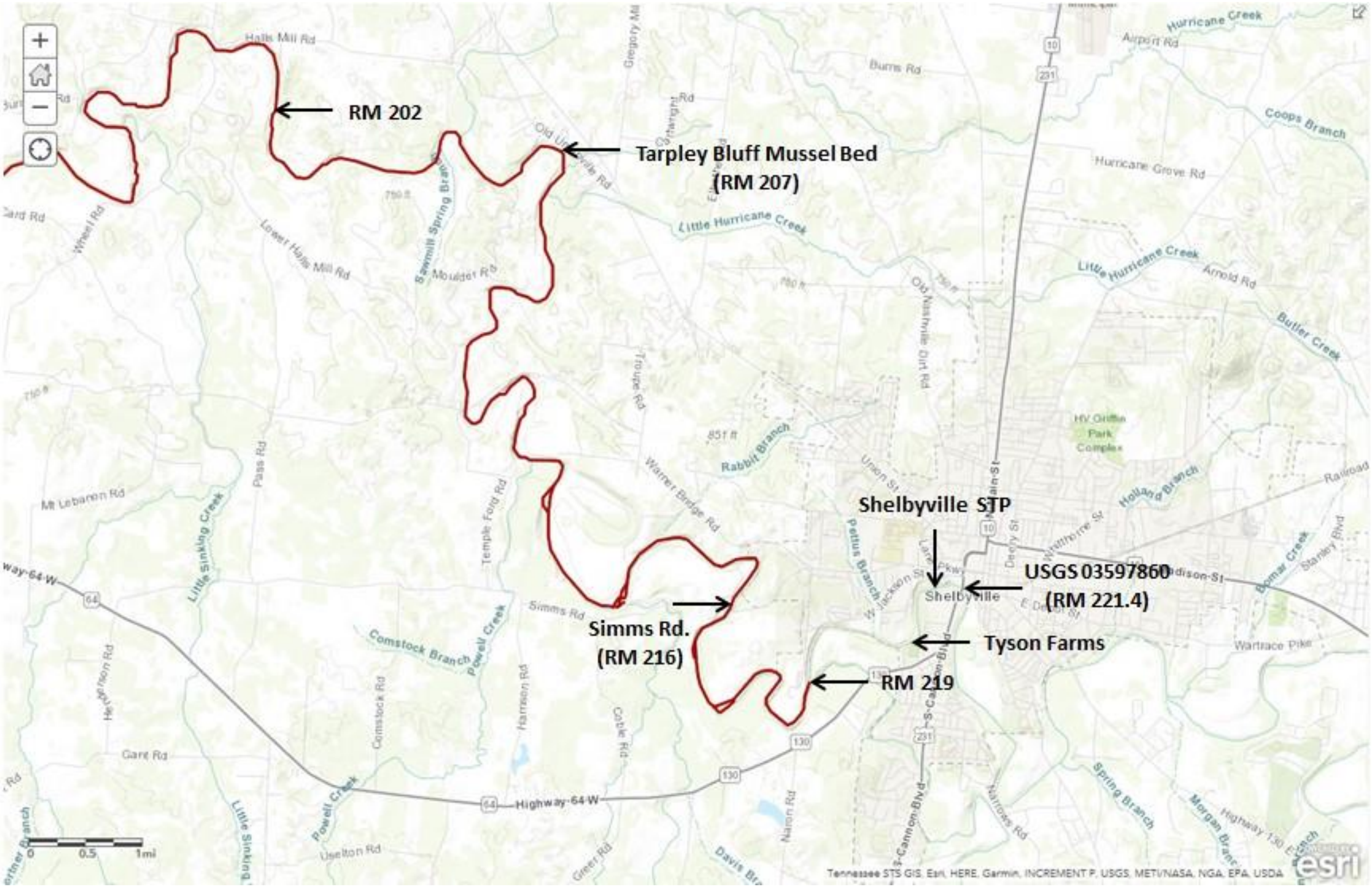


Figure 14. Locations of important features of the Shelbyville segment of the Duck River, extending from RM 221.4 to RM 202.

Further Information

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Appendix A

Excerpts from *Draft Water Quality Modeling Scope for the Duck River Basin Environmental Assessment* (OBG, 2019):

SECTION 2. ALTERNATIVES TO BE MODELED

The following alternatives are being considered for the EA.

Alternative 1: No Action

TVA would continue to operate Normandy Dam per the current operating rule curve and procedures. Under this No Action Alternative, TVA would continue to provide an instantaneous flow of 155 cfs at Shelbyville from June through November, and 120 cfs from December through May. A minimum flow of 40 cfs from Normandy Dam would continue to be maintained.

Alternative 2: Revised Flow Target at Shelbyville (Optimization of Flow)

TVA would modify its operation of Normandy Reservoir and typical flow releases from Normandy Dam would change. TVA's current operational target at Shelbyville would be revised from the current instantaneous flow target to a weekly average flow target, coupled with a flow tolerance minimum threshold. Under this Alternative, the revised flow target at Shelbyville would consist of the following:

Weekly average flow of 120 cfs measured at midnight on Sunday for the period of December 1 through May 31 with a minimum instantaneous flow of 100 cfs during this period;

Weekly average flow of 155 cfs measured at midnight on Sunday for the period of June 1 through November 30 with a minimum instantaneous flow of 135 cfs during this period;

Any partial weeks resulting from the change in target average flows at midnight on June 1 and at midnight on December 1 shall be treated as full weeks with respect to compliance with the required weekly average flow targets.

Appendix B

Additional Information Related to Tennessee and EPA Water Quality Criteria for Dissolved Oxygen and Ammonia

Excerpts from *State of Tennessee Water Quality standards, General Water Quality Criteria* (TDEC, 2019):

0400-40-03-.03 CRITERIA FOR WATER USES.

(3) The criteria for the use of Fish and Aquatic Life are the following.

(a) Dissolved Oxygen - The dissolved oxygen shall not be less than 5.0 mg/l with the following exceptions.

1. In streams identified as trout streams, including tailwaters, dissolved oxygen shall not be less than 6.0 mg/L.

2. The dissolved oxygen concentration of trout waters identified as supporting a naturally reproducing population shall not be less than 8.0 mg/L. (Tributaries to trout streams or naturally reproducing trout streams should be considered to be trout streams or naturally reproducing trout streams, unless demonstrated otherwise. Additionally, all streams within the Great Smoky Mountains National Park should be considered naturally reproducing trout streams.)

3. In wadeable streams in subecoregion 73a, dissolved oxygen levels shall not be less than a daily average of 5.0 mg/L with a minimum dissolved oxygen level of 4.0 mg/L.

4. The dissolved oxygen level of streams in ecoregion 66 (Blue Ridge Mountains) not identified as naturally reproducing trout streams shall not be less than 7.0 mg/L.

Substantial and/or frequent variations in dissolved oxygen levels, including diel fluctuations, are undesirable if caused by man-induced conditions. Diel fluctuations in wadeable streams shall not be substantially different than the fluctuations noted in reference streams in that region.

In lakes and reservoirs, the dissolved oxygen concentrations shall be measured at mid-depth in waters having a total depth of 10 feet or less, and at a depth of five feet in waters having a total depth of greater than 10 feet and shall not be less than 5.0 mg/L.

(j) Ammonia - The concentration of total ammonia nitrogen (in mg N/L) shall not exceed the CMC (acute criterion) calculated using the following equation:

$$CMC = MIN\left(\left(\frac{0.275}{1+10^{7.204-pH}}+\frac{39.0}{1+10^{pH-7.204}}\right),\right.$$
$$\left.\left(0.7249\times\left(\frac{0.0114}{1+10^{7.204-pH}}+\frac{1.6181}{1+10^{pH-7.204}}\right)\times\left(23.12\times 10^{0.036\times(20-T)}\right)\right)\right)$$

The 30-day average concentration of total ammonia nitrogen (in mg N/L) shall not exceed the CCC (chronic criterion) calculated using the following equation:

$$CCC = 0.8876\times\left(\frac{0.0278}{1+10^{7.688-pH}}+\frac{1.1994}{1+10^{pH-7.688}}\right)\times\left(2.126\times 10^{0.028\times(20-MAX(T,7))}\right)$$

In addition, the highest four-day average within the 30-day period shall not exceed 2.5 times the CCC.

0400-40-03-.05 INTERPRETATION OF CRITERIA.

(4) Water quality criteria for fish and aquatic life and livestock watering and wildlife set forth shall generally be applied in permits on the basis of the following stream flows: unregulated streams - stream flows equal to or exceeding the seven-day minimum, 10-year recurrence interval; regulated streams - all flows in excess of the minimum critical flow occurring once in 10 years as determined by the Division. All other criteria shall be applied in permits on the basis of stream flows equal to or exceeding the 30-day minimum five year recurrence interval.

Excerpts from *Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater 2013* (EPA, 2013):

The 1999 recommended aquatic life criteria for ammonia were based on the most sensitive endpoints known at the time: the acute criterion was based primarily on effects on salmonids (where present) or other fish, and the chronic criterion was based primarily on reproductive effects on the benthic invertebrate *Hyalella* or on survival and growth of fish early life stages (when present), depending on temperature and season.

The 2013 recommended criteria of this document take into account data for several sensitive freshwater mussel species in the Family Unionidae that had not previously been tested. Many states in the continental United States have freshwater unionid mussel fauna in at least some of their waters (Abell et al. 2000, Williams et al. 1993, Williams and Neves 1995). Moreover, approximately one-quarter of approximately 300 freshwater unionid mussel taxa in the United States are Federally-listed as endangered or threatened species. Freshwater mussels are broadly distributed across the U.S. and are now included in the ammonia dataset. Thus, the 2013 freshwater acute and chronic aquatic life criteria for ammonia will more fully protect the aquatic community than previous criteria, and are represented by a single (non-bifurcated) value each for acute and chronic criteria.

The criteria magnitude is affected by pH and temperature. After analysis of the new data, EPA determined that the pH and temperature relationships established in the 1999 ammonia criterion document still hold. When expressed as total ammonia nitrogen (TAN), the effect concentrations for fish are normalized only for pH, reflecting the minimal influence of temperature on TAN toxicity to fish. For invertebrates, TAN effect concentrations are normalized for both pH and temperature. At water temperatures greater than 15.7°C, the 2013 acute criterion magnitude is determined primarily by effects on freshwater unionid mussels. At lower temperatures the acute criterion magnitude is based primarily on effects on salmonids and other fish. Throughout the temperature range, the 2013 chronic criterion magnitude is determined primarily by the effects on freshwater mollusks, particularly unionid mussels.

The decreases in acute and chronic criteria magnitudes below those of 1999 reflect the inclusion of the new data discussed above.

The acute criterion duration represents a one-hour average. The chronic criterion duration represents a 30-day rolling average with the additional restriction that the highest 4-day average within the 30 days be no greater than 2.5 times the chronic criterion magnitude. These values are not to be exceeded more than once in 3 years on average.

Appendix C

Normandy Dam Ammonia Toxicity Analyses

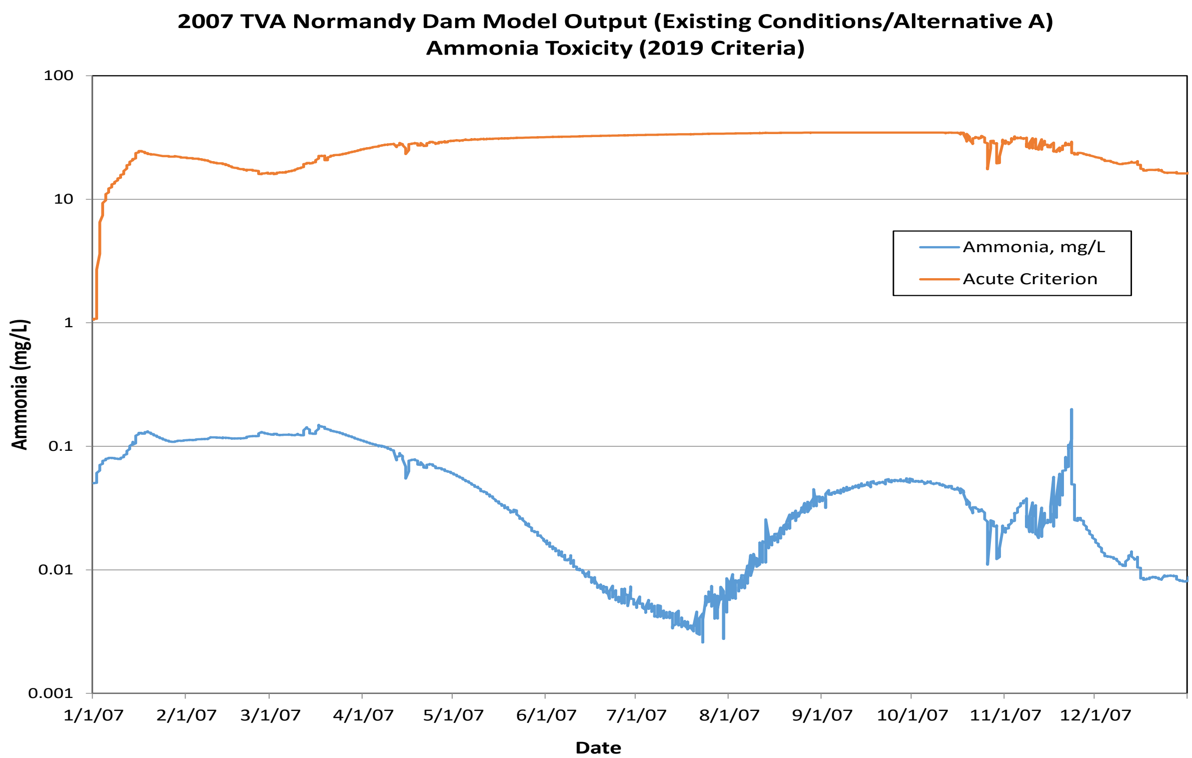


Figure 15. 2007 TVA Normandy Dam Model Output (Alternative A) Ammonia Toxicity - Acute Criterion.

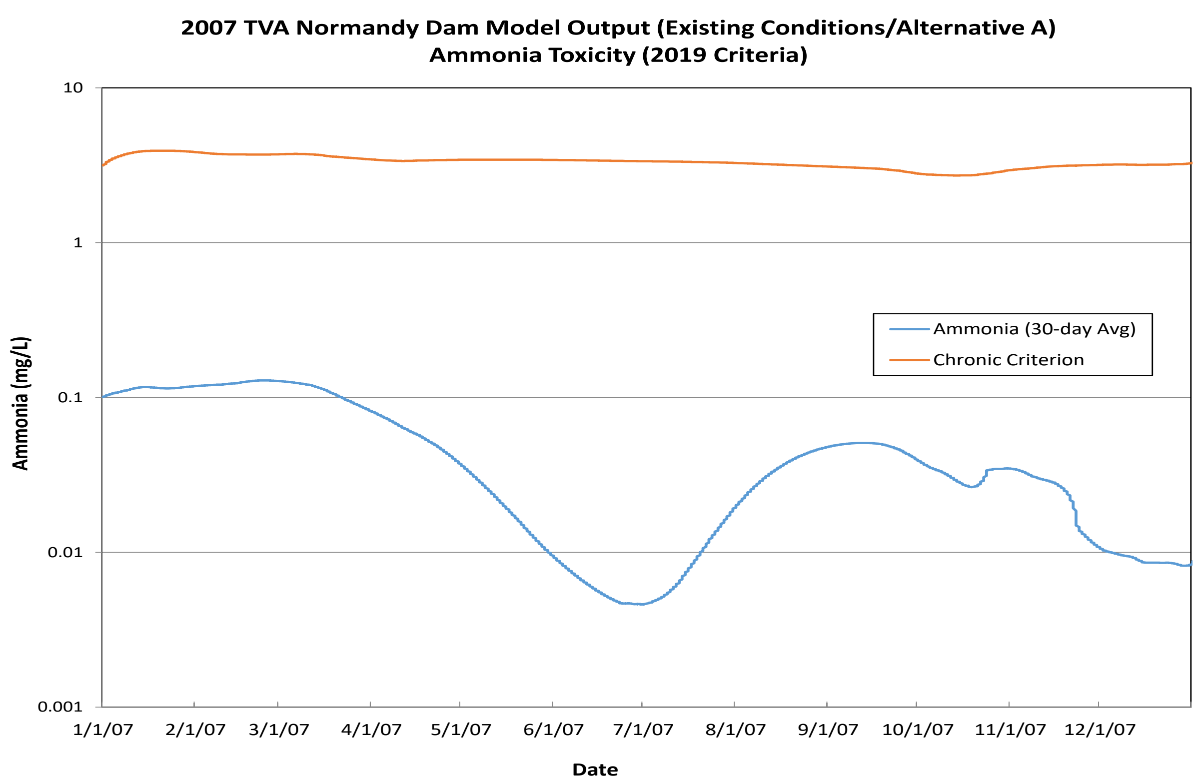


Figure 16. 2007 TVA Normandy Dam Model Output (Alt. A) Ammonia Toxicity – 30-day Chronic Criterion.

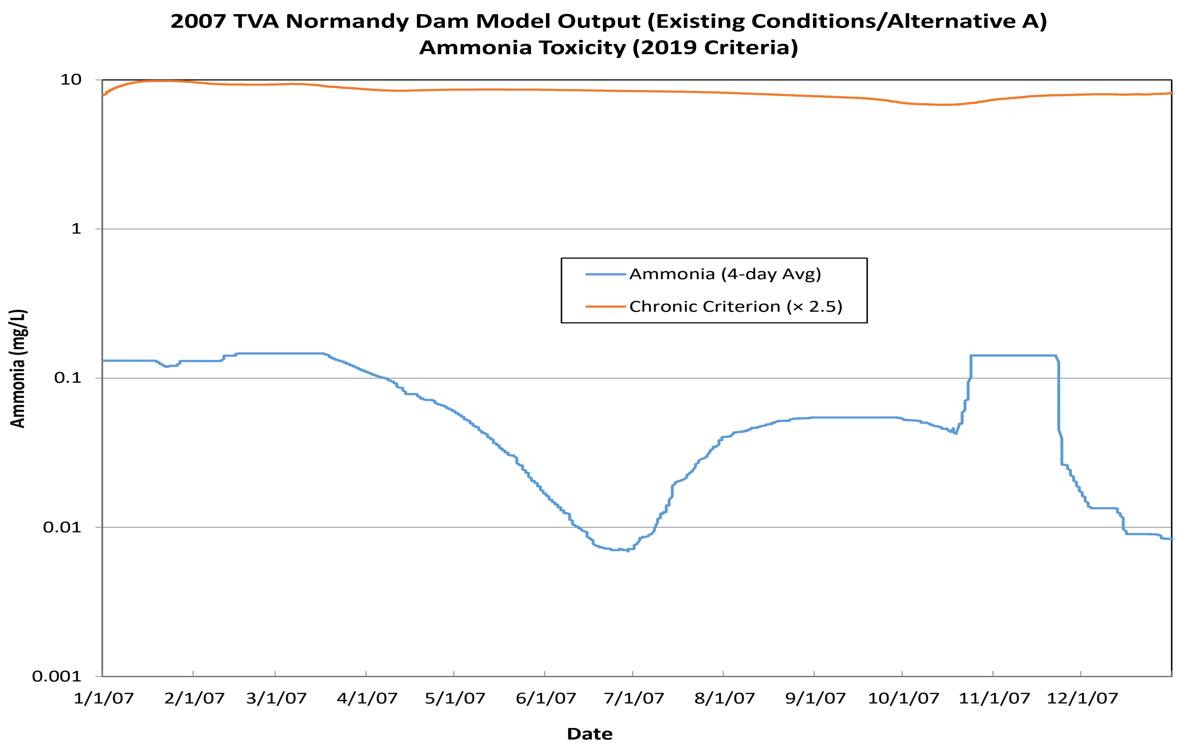


Figure 17. 2007 TVA Normandy Dam Model Output (Alt. A) Ammonia Toxicity – 4-day Chronic Criterion.

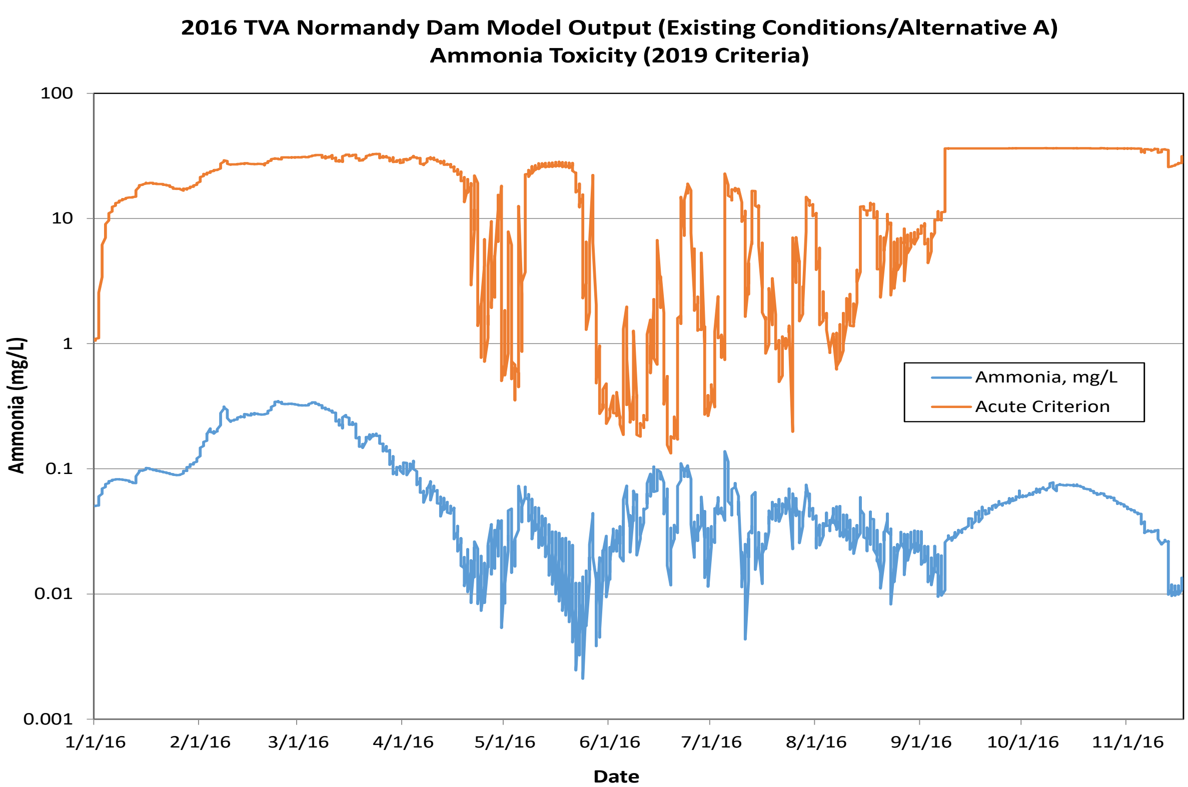


Figure 18. 2016 TVA Normandy Dam Model Output (Alternative A) Ammonia Toxicity - Acute Criterion.

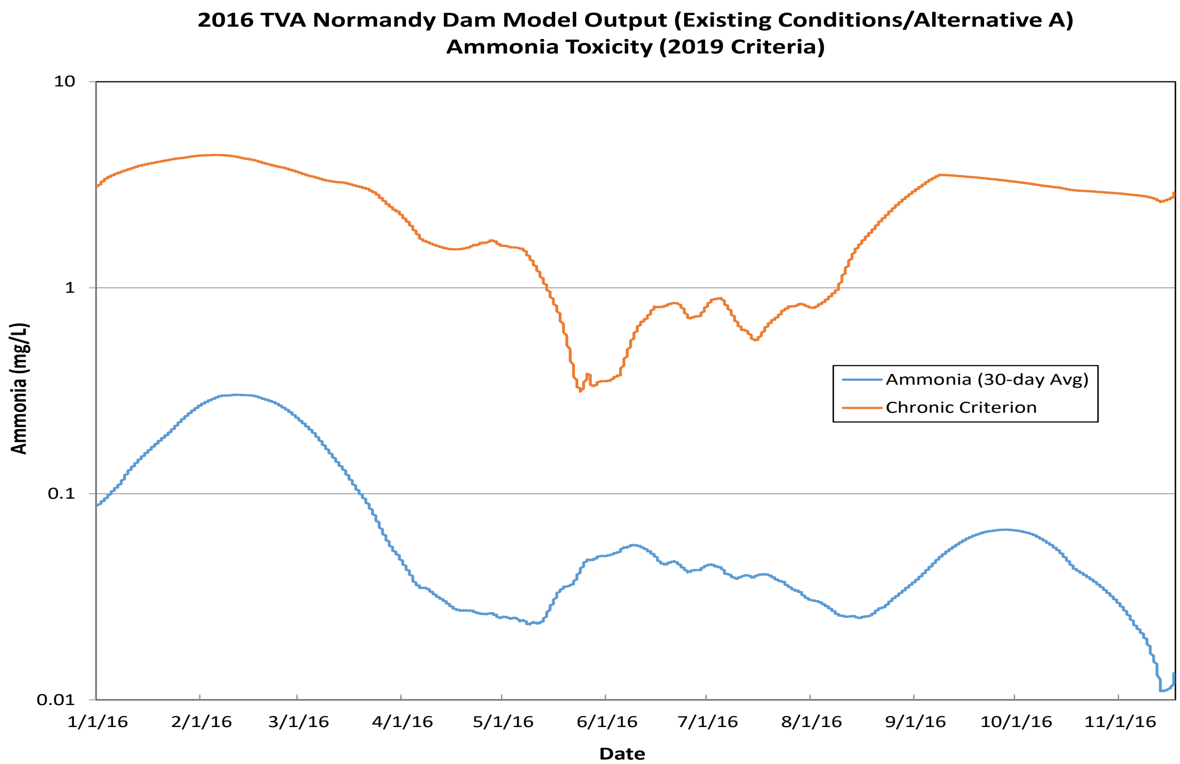


Figure 19. 2016 TVA Normandy Dam Model Output (Alt. A) Ammonia Toxicity – 30-day Chronic Criterion.

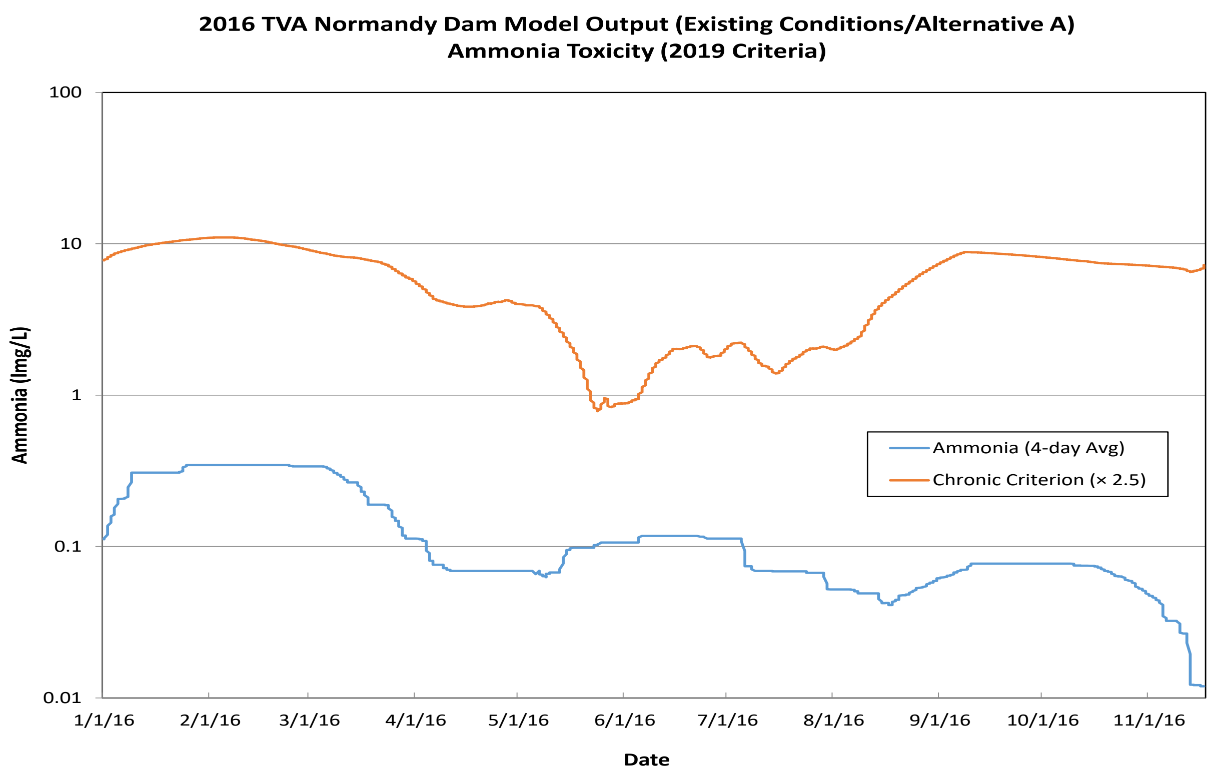


Figure 20. 2016 TVA Normandy Dam Model Output (Alt. A) Ammonia Toxicity – 4-day Chronic Criterion.

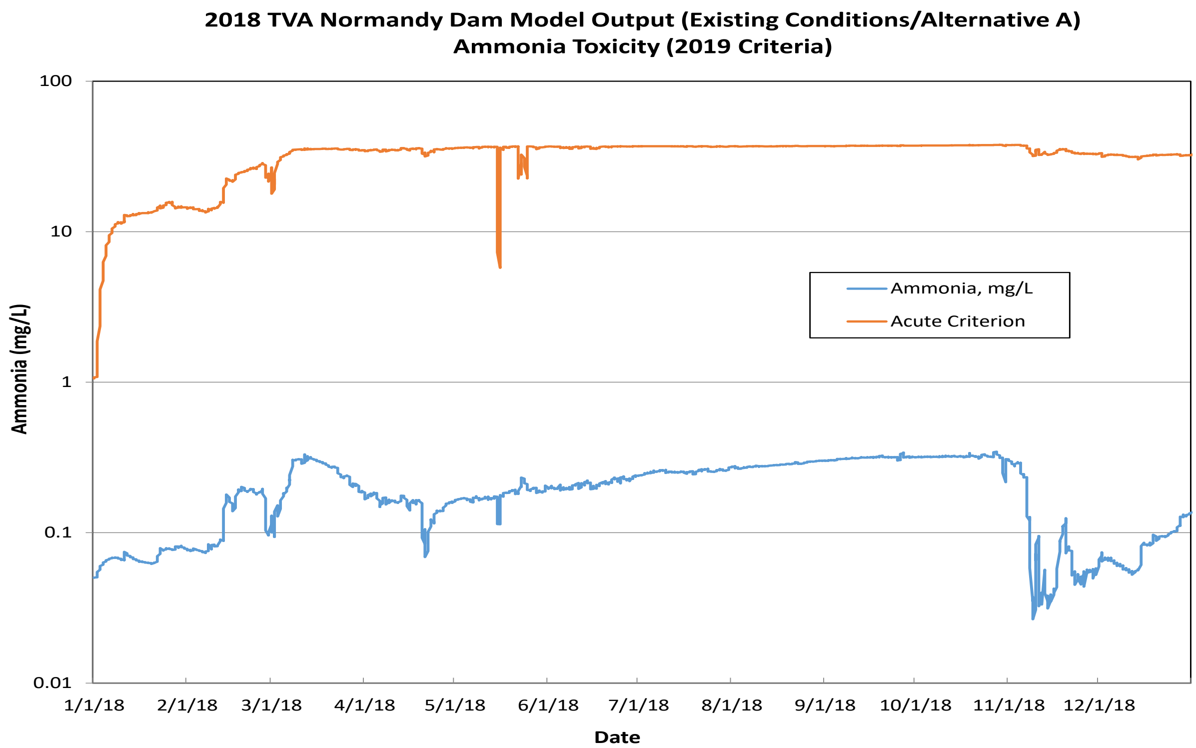


Figure 21. 2018 TVA Normandy Dam Model Output (Alternative A) Ammonia Toxicity - Acute Criterion.

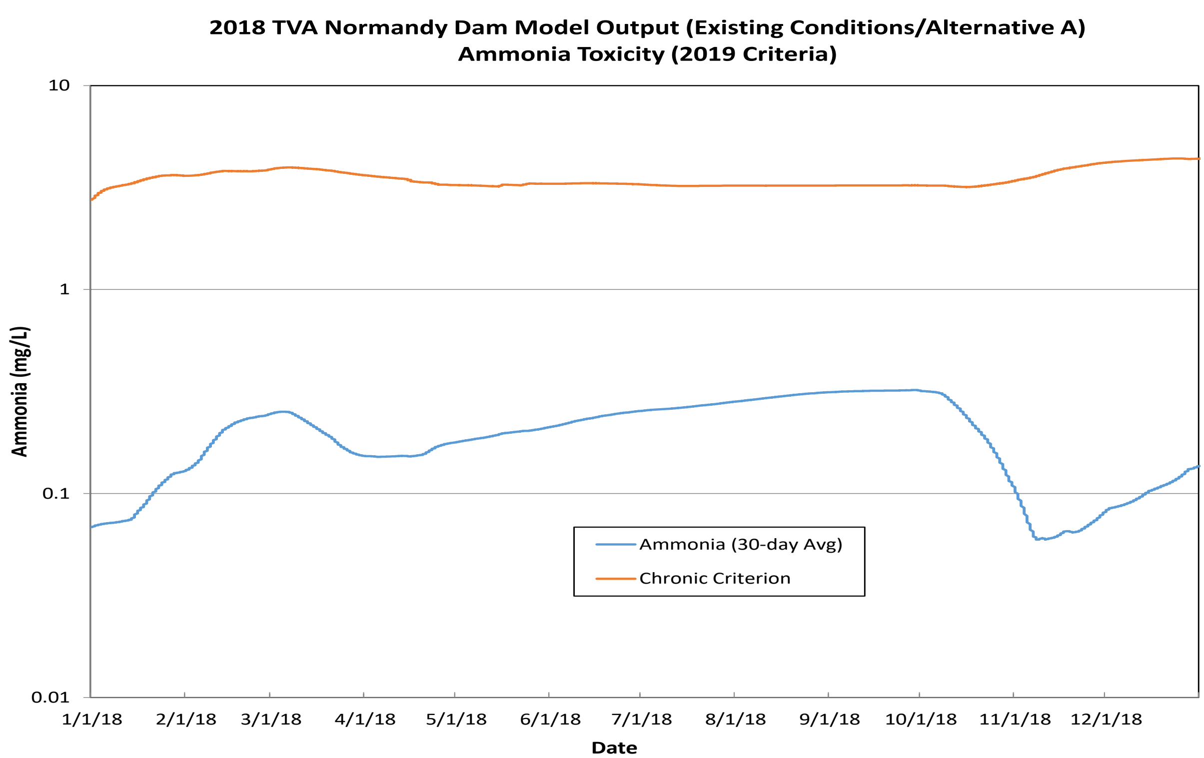


Figure 22. 2018 TVA Normandy Dam Model Output (Alt. A) Ammonia Toxicity – 30-day Chronic Criterion.

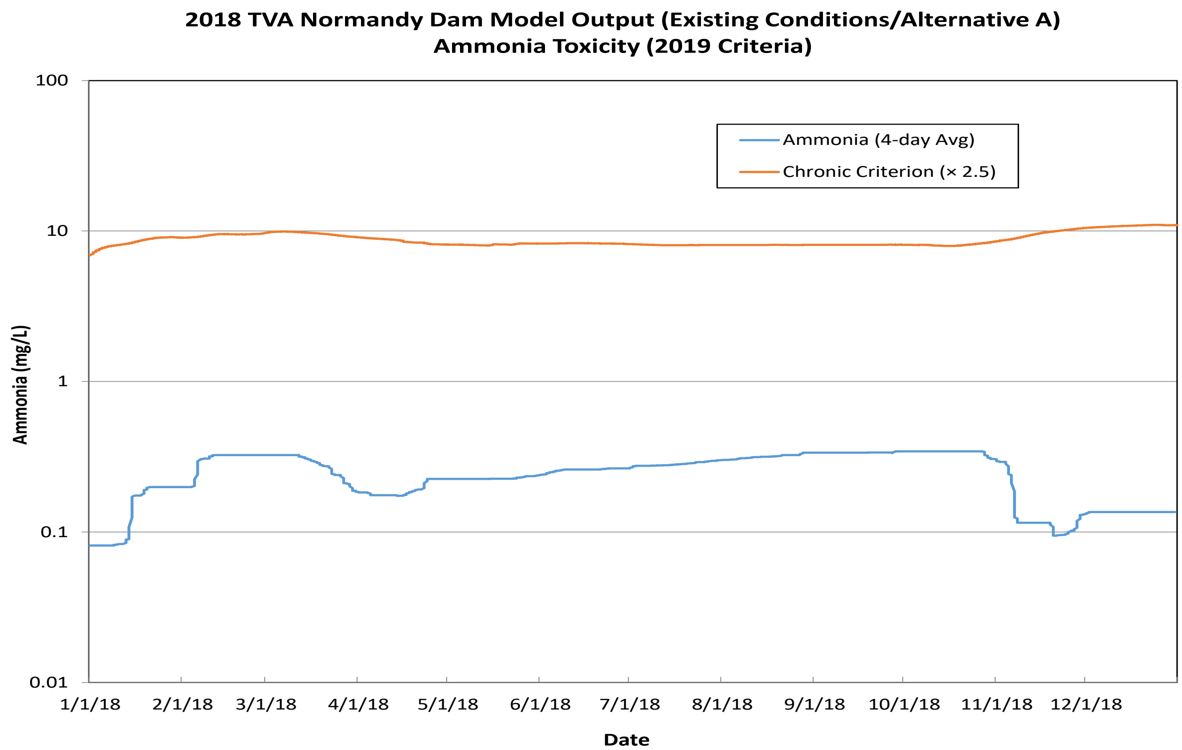


Figure 23. 2018 TVA Normandy Dam Model Output (Alt. A) Ammonia Toxicity – 4-day Chronic Criterion.

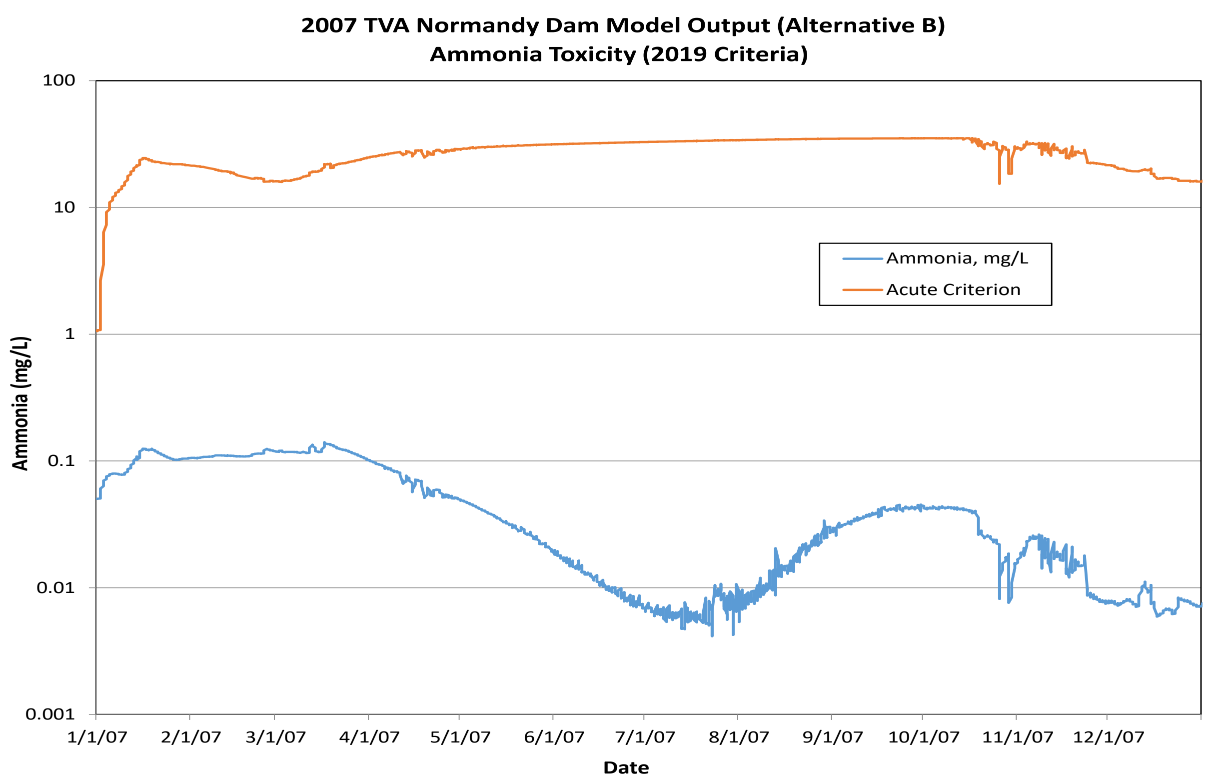


Figure 24. 2007 TVA Normandy Dam Model Output (Alternative B) Ammonia Toxicity - Acute Criterion.

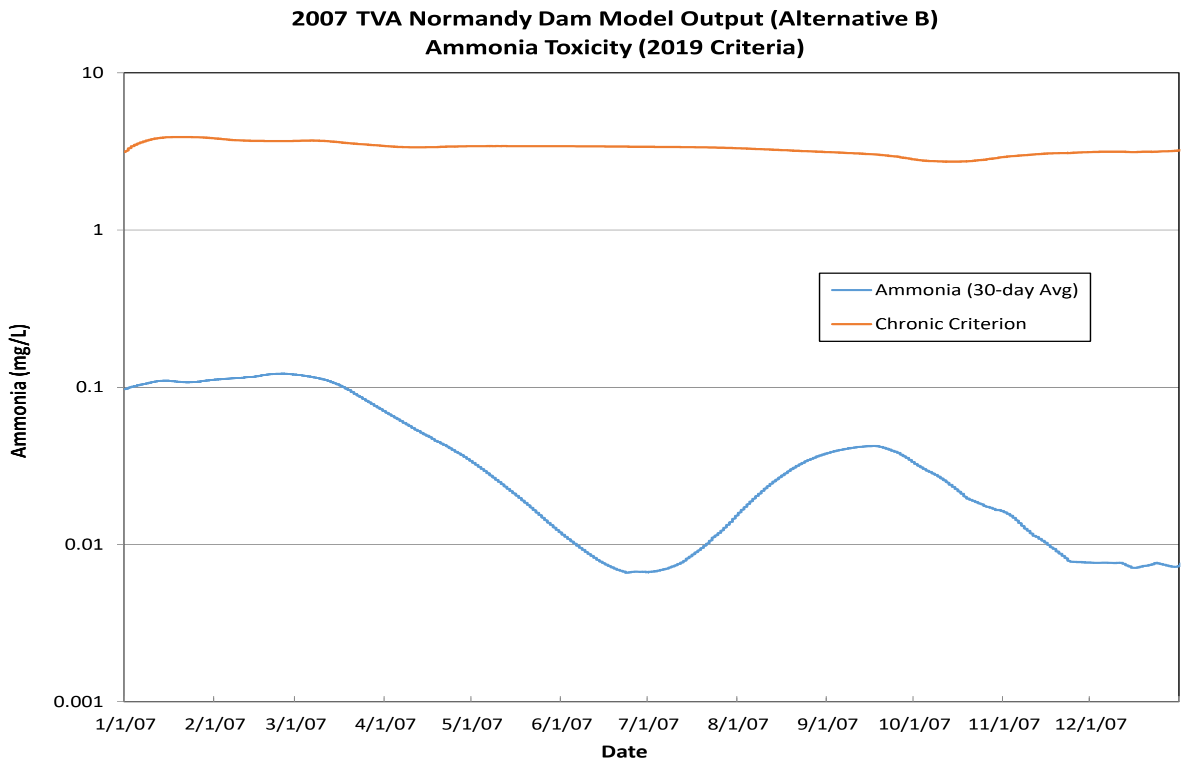


Figure 25. 2007 TVA Normandy Dam Model Output (Alt. B) Ammonia Toxicity – 30-day Chronic Criterion.

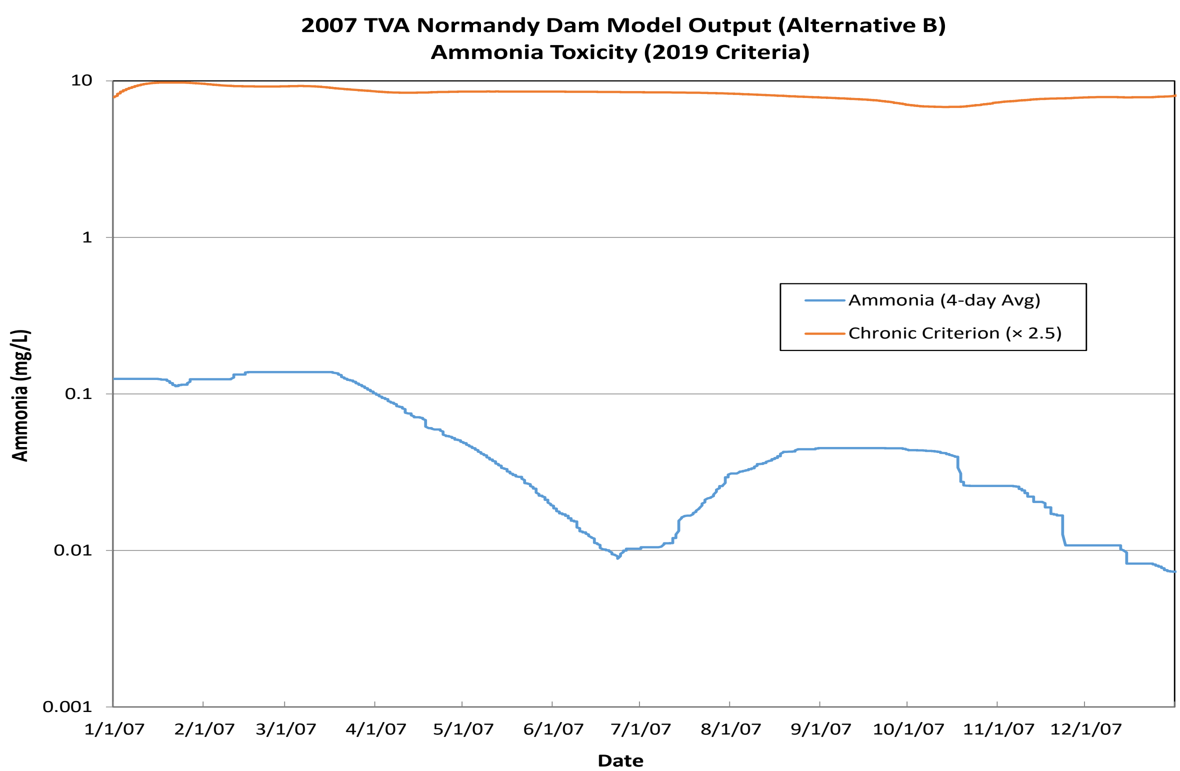


Figure 26. 2007 TVA Normandy Dam Model Output (Alt. B) Ammonia Toxicity – 4-day Chronic Criterion.

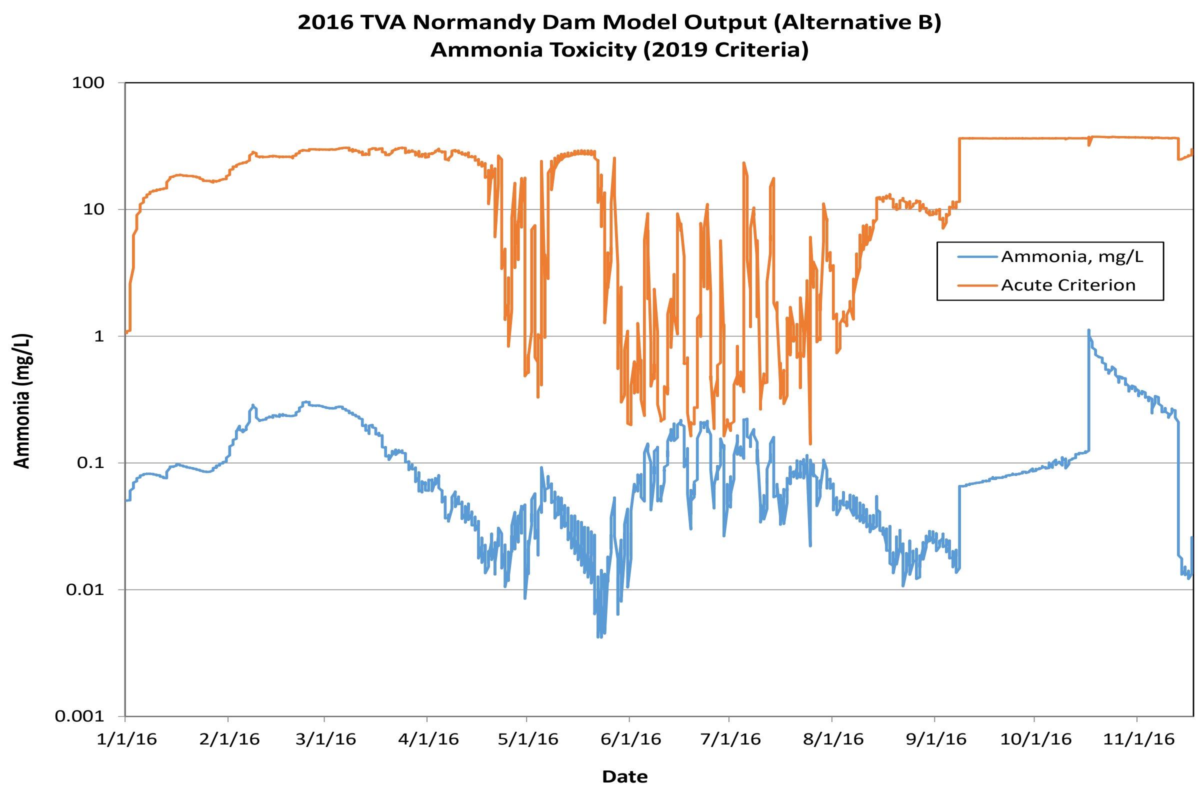


Figure 27. 2016 TVA Normandy Dam Model Output (Alternative B) Ammonia Toxicity - Acute Criterion.

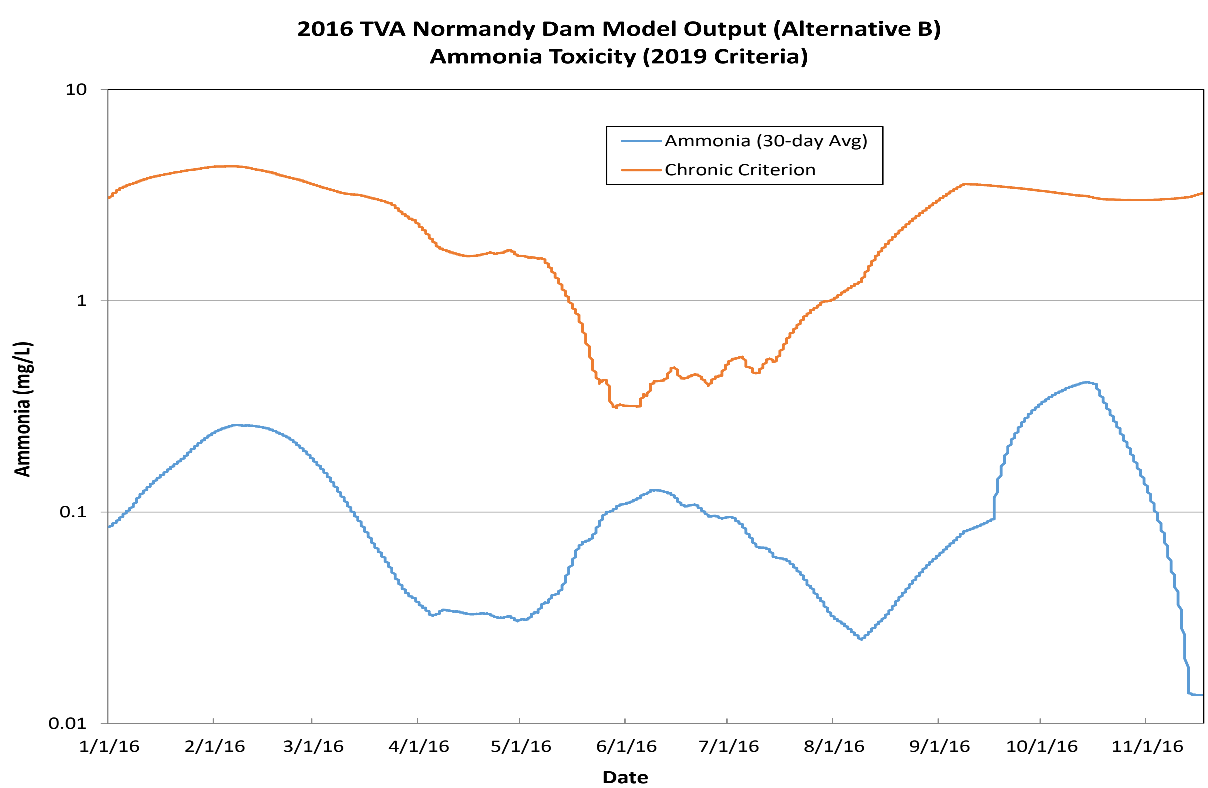


Figure 28. 2016 TVA Normandy Dam Model Output (Alt. B) Ammonia Toxicity – 30-day Chronic Criterion.

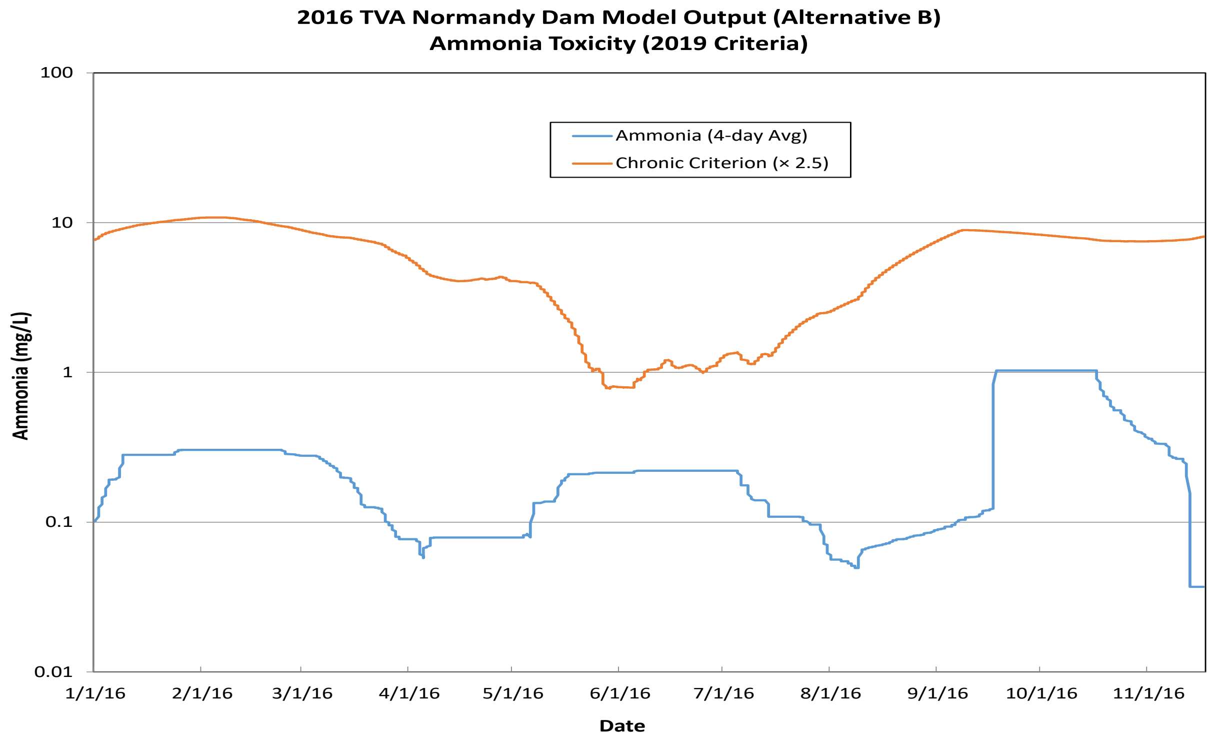


Figure 29. 2016 TVA Normandy Dam Model Output (Alt. B) Ammonia Toxicity – 4-day Chronic Criterion.

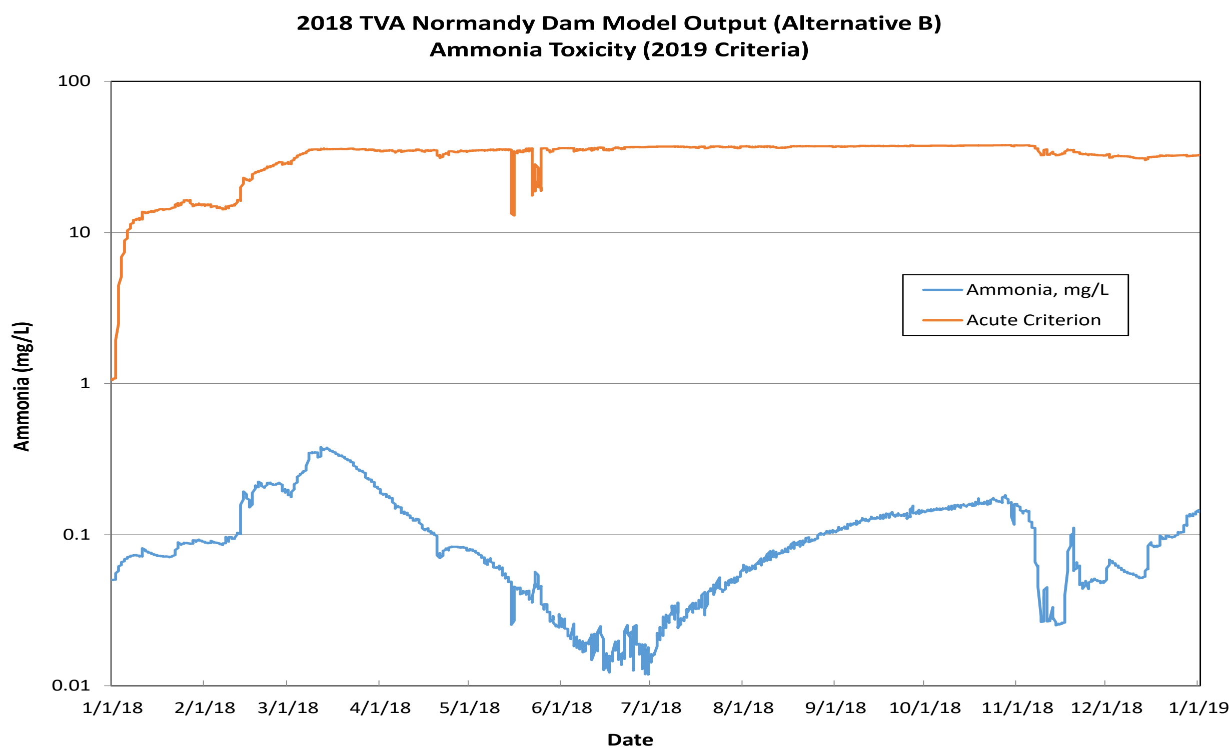


Figure 30. 2018 TVA Normandy Dam Model Output (Alternative B) Ammonia Toxicity - Acute Criterion.

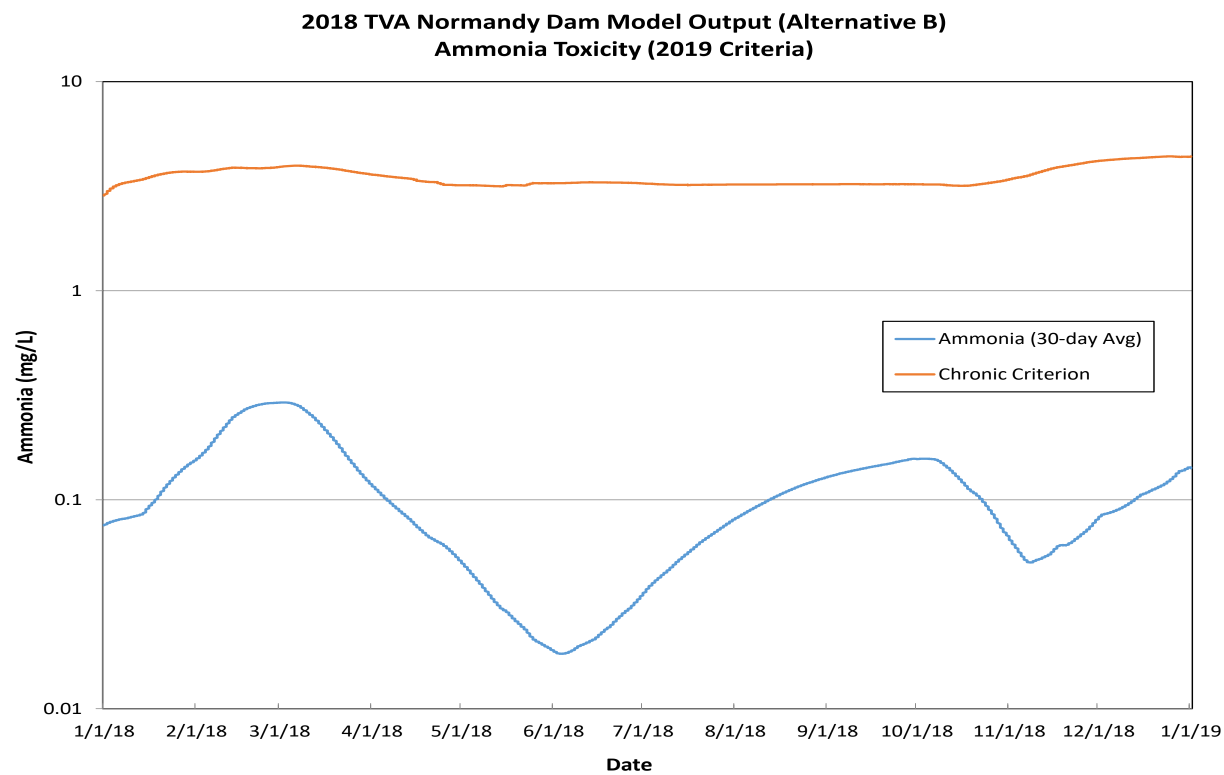


Figure 31. 2018 TVA Normandy Dam Model Output (Alt. B) Ammonia Toxicity – 30-day Chronic Criterion.

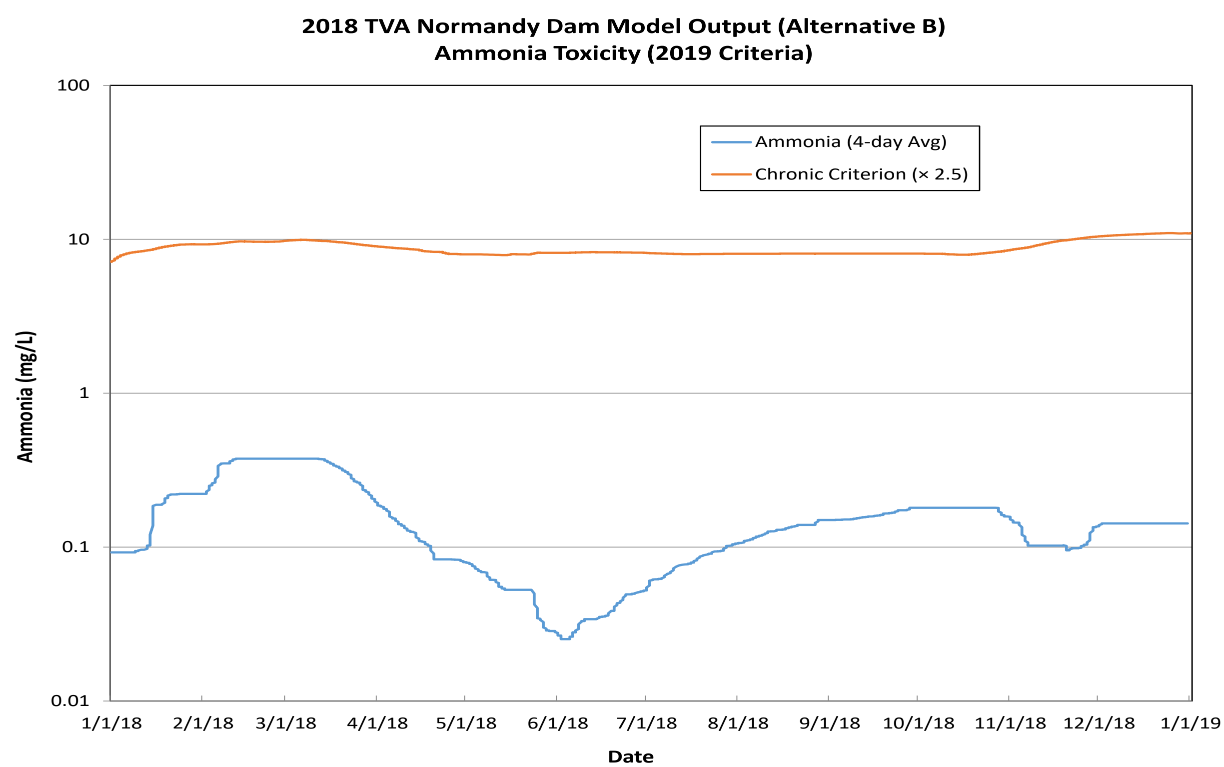


Figure 32. 2018 TVA Normandy Dam Model Output (Alt. B) Ammonia Toxicity – 4-day Chronic Criterion.

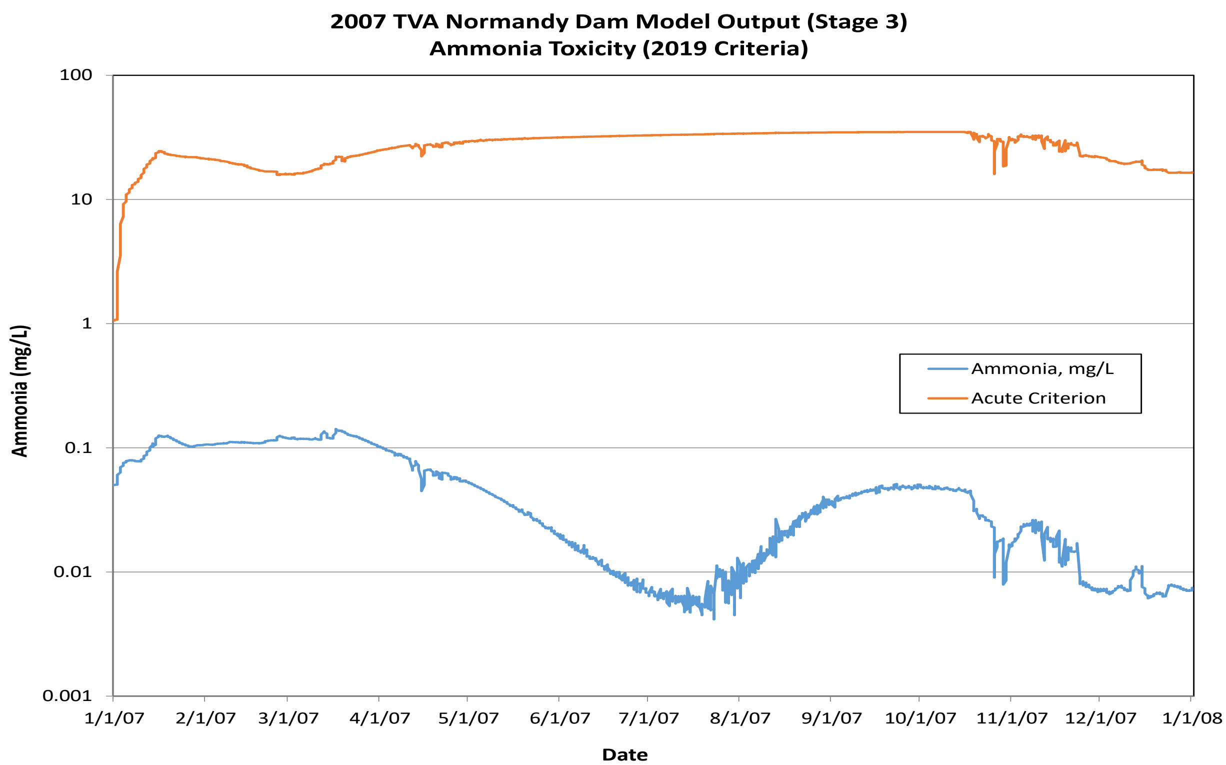


Figure 33. 2007 TVA Normandy Dam Model Output (Stage 3) Ammonia Toxicity - Acute Criterion.

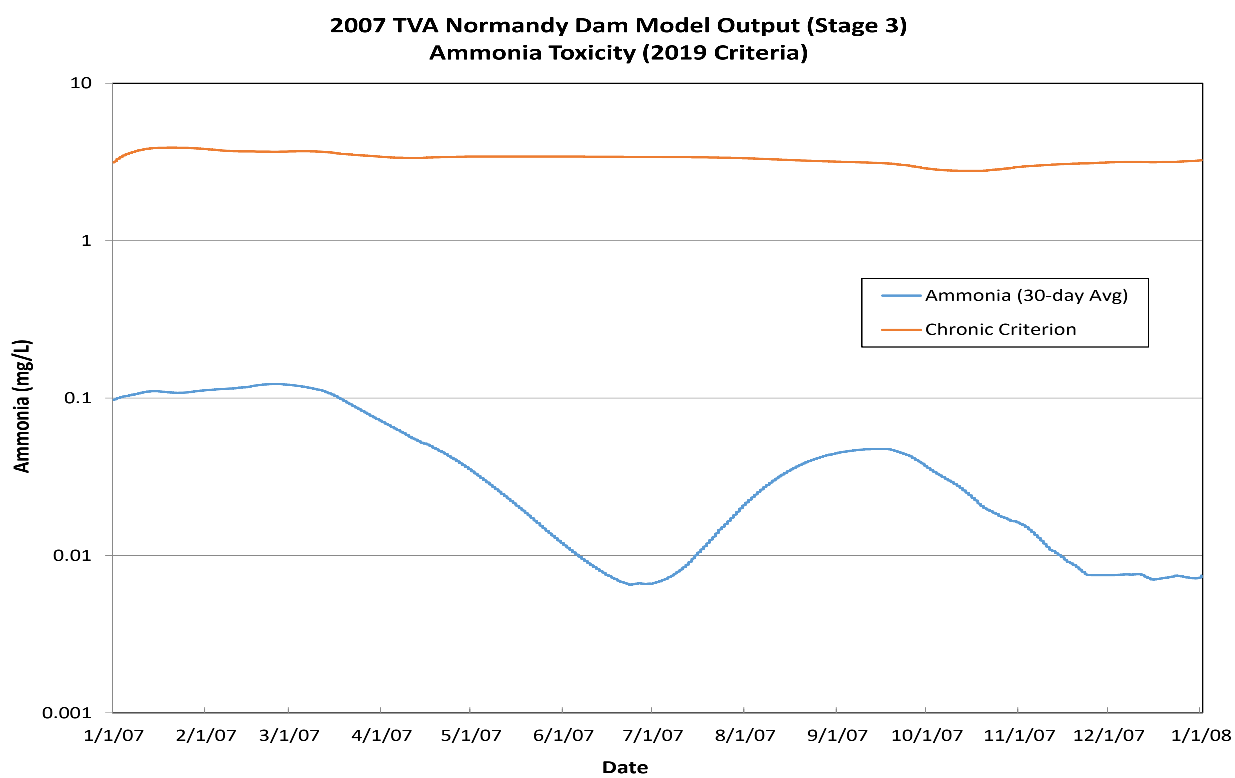


Figure 34. 2007 TVA Normandy Dam Model Output (Stage 3) Ammonia Toxicity – 30-day Chronic Criterion.

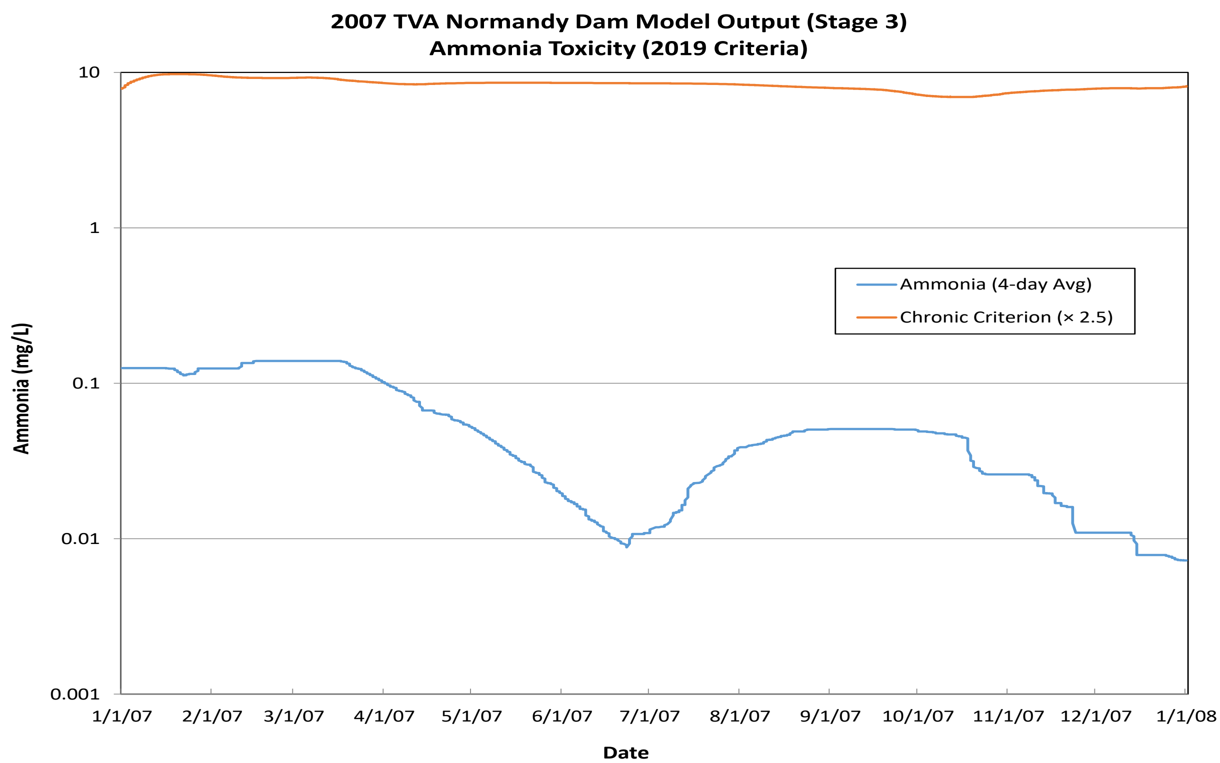


Figure 35. 2007 TVA Normandy Dam Model Output (Stage 3) Ammonia Toxicity – 4-day Chronic Criterion.

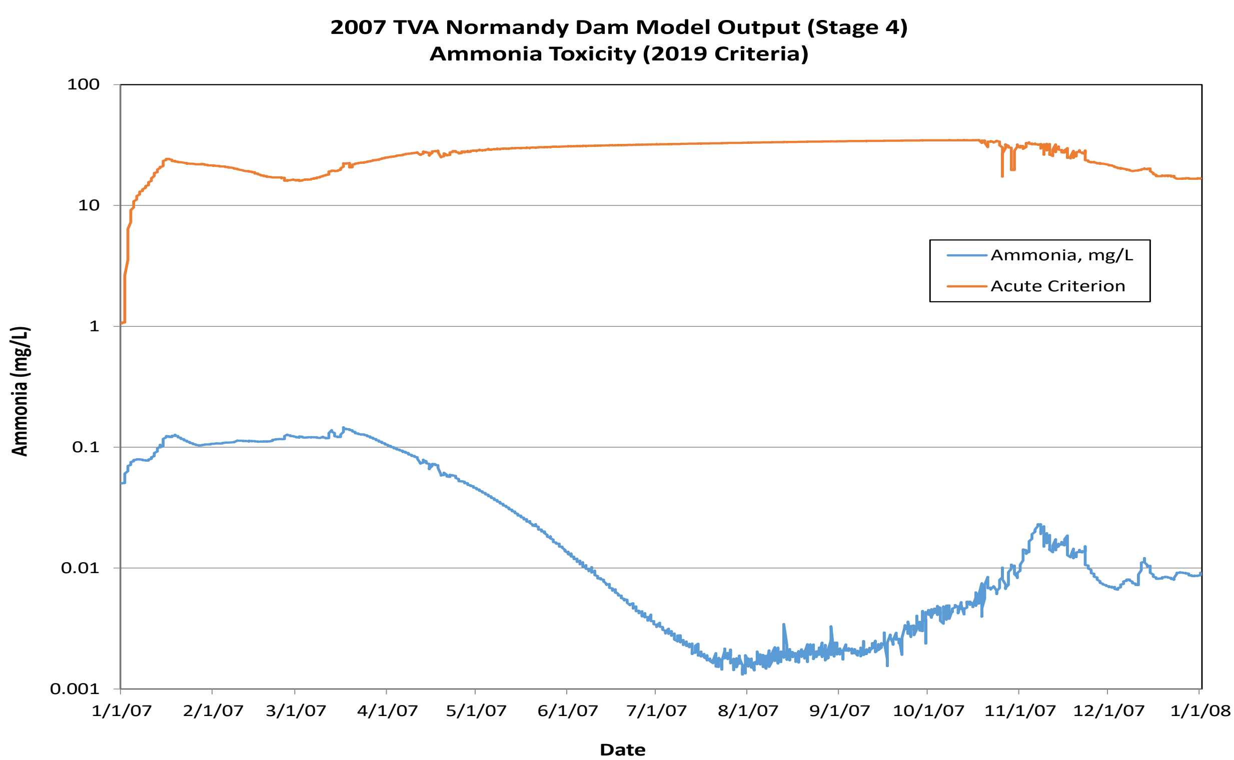


Figure 36. 2007 TVA Normandy Dam Model Output (Stage 4) Ammonia Toxicity - Acute Criterion.

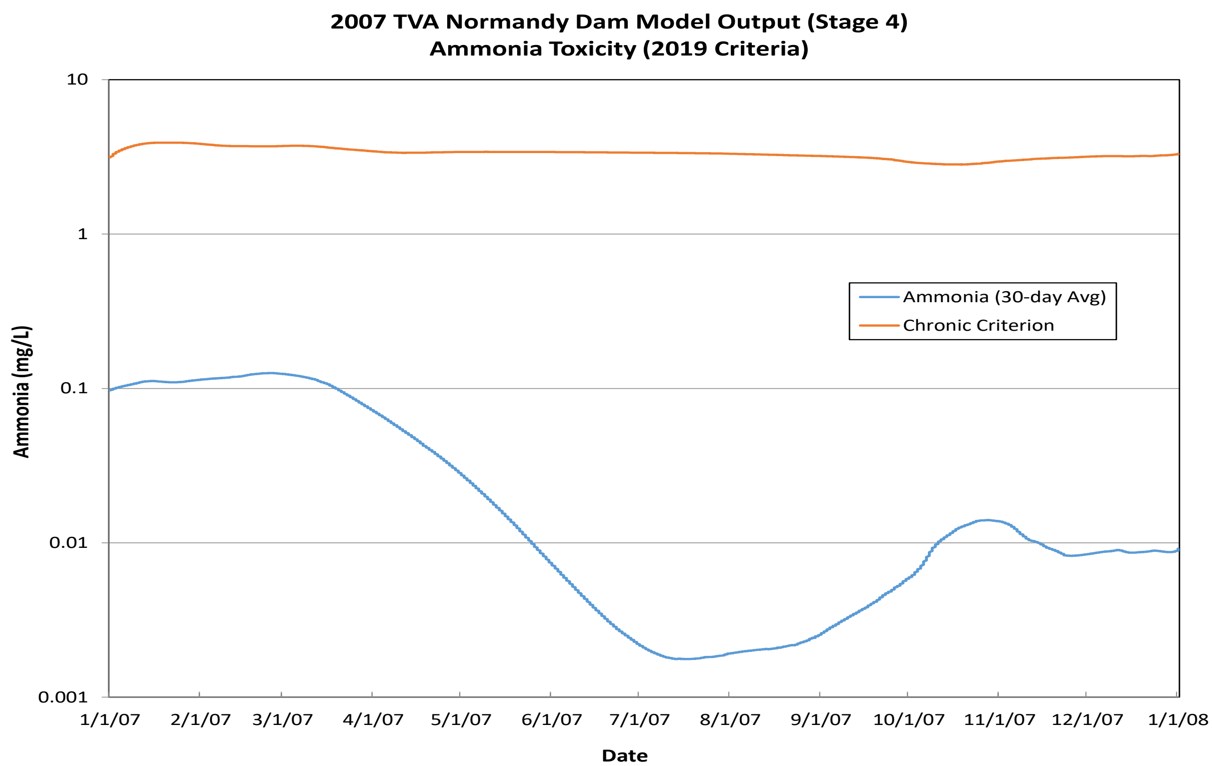


Figure 37. 2007 TVA Normandy Dam Model Output (Stage 4) Ammonia Toxicity – 30-day Chronic Criterion.

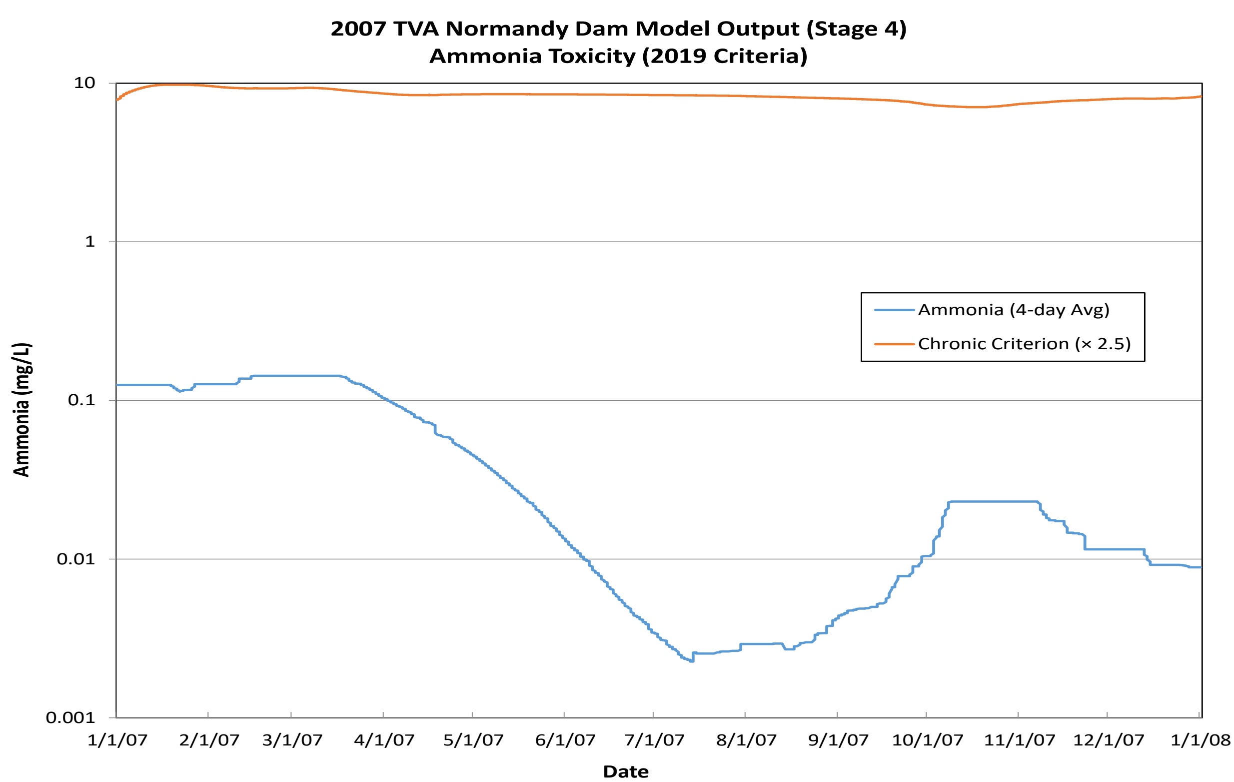


Figure 38. 2007 TVA Normandy Dam Model Output (Stage 4) Ammonia Toxicity – 4-day Chronic Criterion.

Appendix D

QUAL2k Model Set up and Calibration

Model Set up

1. **Model Period**

   September 12, 2016 is used for model development and calibration because BDY (2016) collected the most comprehensive data and the data collected do not have testing errors.

2. **Modeled Area and Hydrogeometry**

   Modeled Area

   The upstream boundary is located downstream from the Shelbyville dam at RM 221.4 where USGS gage 03597860 is located. See Table 3 for boundary inputs for the Duck River QUAL2k model. RM 202.4 is selected as the downstream boundary in order to include the Tarpley Bluff mussel bed monitoring site at RM 205.

   Hydrogeometry

   The river segment from RM 221.4-202.4 is divided into 27 reaches based on Trutta Environmental Solutions' (Trutta, 2018) High Definition Stream Survey (HDSS) conducted between March and August of 2017, and changes in river characteristics.

3. **Point Sources and Tributaries**

   There are two NPDES discharge facilities, Shelbyville STP and Tyson Farms, which discharge at RMs 221.2 and 200.2, respectively. MOR data from Shelbyville STP and DMR data from Tyson Farms are used for model input. The major tributaries, Flat Creek (RM 219) and Sugar Creek (RM 213), are represented as point sources in QUAL2k. No tributary data were collected concurrently with the 2016 BDY field study. TDEC internal data and $1Q_{10}$ flow from USGS StreamStats (USGS, 2017) are used for model input. See Table 4 for point source and tributary inputs for the Duck River QUAL2k model.

4. **Boundary Hydraulics and Water Quality**

   The USGS gage, Duck River at Shelbyville, TN (03597860), at RM 221.4 is used as the upstream boundary and the USGS gage, Duck River near Shelbyville, TN (03598000), at RM 216.4 is used for hydraulics calibration. Average daily flow of 172 cfs from the gage on 9/12/2016 is used for model set-up because it is close to the $1Q_{10}$ flow of 139 cfs. Other target conditions for model calibration (high water and air temperatures, low DO) were also met on 9/12/2016. Water quality data collected by BDY from the same date are used for model set-up and calibration.

Water Quality Constituents	*Units*	*12:00 AM*	*1:00 AM*	*2:00 AM*	*3:00 AM*	*4:00 AM*	*5:00 AM*	*6:00 AM*	*7:00 AM*	*8:00 AM*	*9:00 AM*	*10:00 AM*	*11:00 AM*	*12:00 PM*
Temperature	C	24.75	24.68	24.55	24.45	24.31	24.19	24.05	23.89	23.76	23.75	23.71	23.75	23.76
Conductivity	umhos	161.00	161.00	161.00	161.00	161.00	161.00	161.00	161.00	161.00	161.00	161.00	161.00	161.00
Inorganic Solids	mgD/L	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dissolved Oxygen	mg/L	7.76	7.72	7.76	7.75	7.74	7.75	7.73	7.77	7.78	7.80	7.83	7.85	7.90
CBODslow	mgO2/L	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
CBODfast	mgO2/L	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
Organic Nitrogen	ugN/L	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00
NH4-Nitrogen	ugN/L	196.00	196.00	196.00	196.00	196.00	196.00	196.00	196.00	196.00	196.00	196.00	196.00	196.00
NO3-Nitrogen	ugN/L	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00
Organic Phosphorus	ugP/L	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50
Inorganic Phosphorus (SRP)	ugP/L	92.50	92.50	92.50	92.50	92.50	92.50	92.50	92.50	92.50	92.50	92.50	92.50	92.50
Phytoplankton	ugA/L	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Internal Nitrogen (INP)	ugN/L													
Internal Phosphorus (IPP)	ugP/L													
Detritus (POM)	mgD/L	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10
Pathogen	cfu/100 mL													
Alkalinity	mgCaCO3/L	65.60	65.60	65.60	65.60	65.60	65.60	65.60	65.60	65.60	65.60	65.60	65.60	65.60
Constituent i		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Constituent ii														
Constituent iii														
pH	s.u.	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65

Water Quality Constituents	*Units*	*1:00 PM*	*2:00 PM*	*3:00 PM*	*4:00 PM*	*5:00 PM*	*6:00 PM*	*7:00 PM*	*8:00 PM*	*9:00 PM*	*10:00 PM*	*11:00 PM*
Temperature	C	23.90	24.09	24.19	24.22	23.97	23.93	23.92	23.94	23.92	23.88	23.89
Conductivity	umhos	161.00	161.00	161.00	161.00	161.00	161.00	161.00	161.00	161.00	161.00	161.00
Inorganic Solids	mgD/L	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dissolved Oxygen	mg/L	7.92	7.91	7.92	7.89	7.83	7.79	7.79	7.80	7.82	7.80	7.83
CBODslow	mgO2/L	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
CBODfast	mgO2/L	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
Organic Nitrogen	ugN/L	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00
NH4-Nitrogen	ugN/L	196.00	196.00	196.00	196.00	196.00	196.00	196.00	196.00	196.00	196.00	196.00
NO3-Nitrogen	ugN/L	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00	1360.00
Organic Phosphorus	ugP/L	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50
Inorganic Phosphorus (SRP)	ugP/L	92.50	92.50	92.50	92.50	92.50	92.50	92.50	92.50	92.50	92.50	92.50
Phytoplankton	ugA/L	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Internal Nitrogen (INP)	ugN/L											
Internal Phosphorus (IPP)	ugP/L											
Detritus (POM)	mgD/L	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10
Pathogen	cfu/100 mL											
Alkalinity	mgCaCO3/L	65.60	65.60	65.60	65.60	65.60	65.60	65.60	65.60	65.60	65.60	65.60
Constituent i		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Constituent ii												
Constituent iii												
pH	s.u.	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65

Table 3. Boundary Inputs for the Duck River QUAL2k model.

Constituents	Units	Shelbyville STP	Tyson Farms	Flat Creek	Sugar Creek
River Mile	miles	221.1	220.2	219.2	213.8
Flow	m^3/s	0.0973	0.0603	0.0107	0.0037
Temperature	°C	26	27	22.3	21.9
Spec. Cond.	µmhos	161	161	250	288
DO	mg/L	7.89	5.8	7.85	5.33
Slow CBOD	mg/L	0.44	0.57	2.2	2.2
Fast CBOD	mg/L	7.39	13.41	2.2	2.2
Organic N	µg N/L	190	323	156	313
Ammonia N	µg N/L	40	250	91	100
Nitrate + Nitrite N	µg N/L	50800	10750	223	187
Organic P	µg P/L	202	320	9.5	9.5
Inorganic P	µg P/L	1820	4900	22	158
Phytoplankton	µg A/L	0	0	0.6	0.6
Alkalinity	mg $CACO_3$/L	78.1	100	100	100
pH	unitless	7.6	7.5	7.38	6.94

Table 4: Point Source and Tributary Inputs for the Duck River QUAL2k model.

Calibration

1. Hydarulics Calibration

Two USGS gages are located in the section of the Duck River near Shelbyville, TN: USGS gage 03597860 at RM 221.4 and USGS gage 03598000 at RM 216. Flow data from these two gages are used for hydraulics calibration. During the 2017 HDSS conducted by Trutta, channel width data were collected. Although these data were collected from a different year than other calibration data, at around one to two miles scale, they have the most hydraulics information of the Duck River section under study. The channel widths, along with water depths from USGS gages, are used in the hydraulics calibration. The hydraulics calibration plots are presented in Figures 39-41.

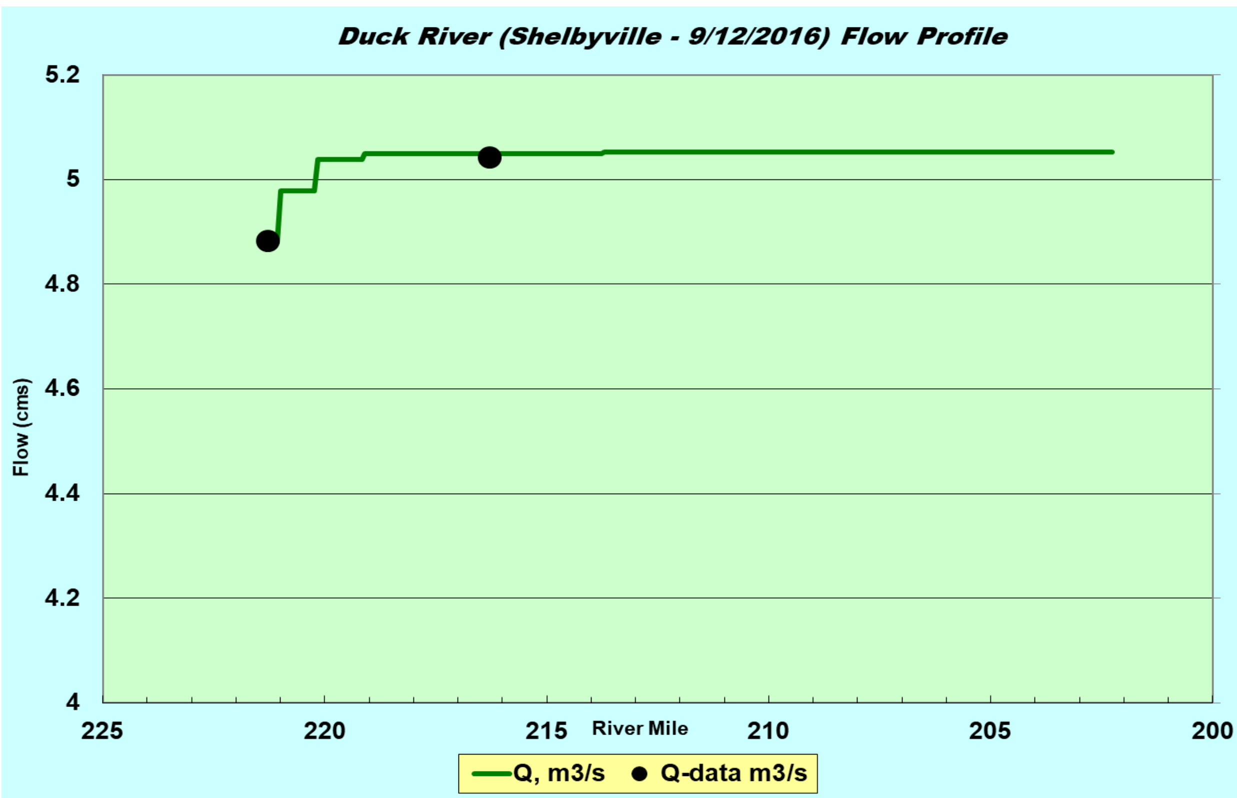


Figure 39: Flow Profile and Calibration for Duck River RMs 221.4 – 202.

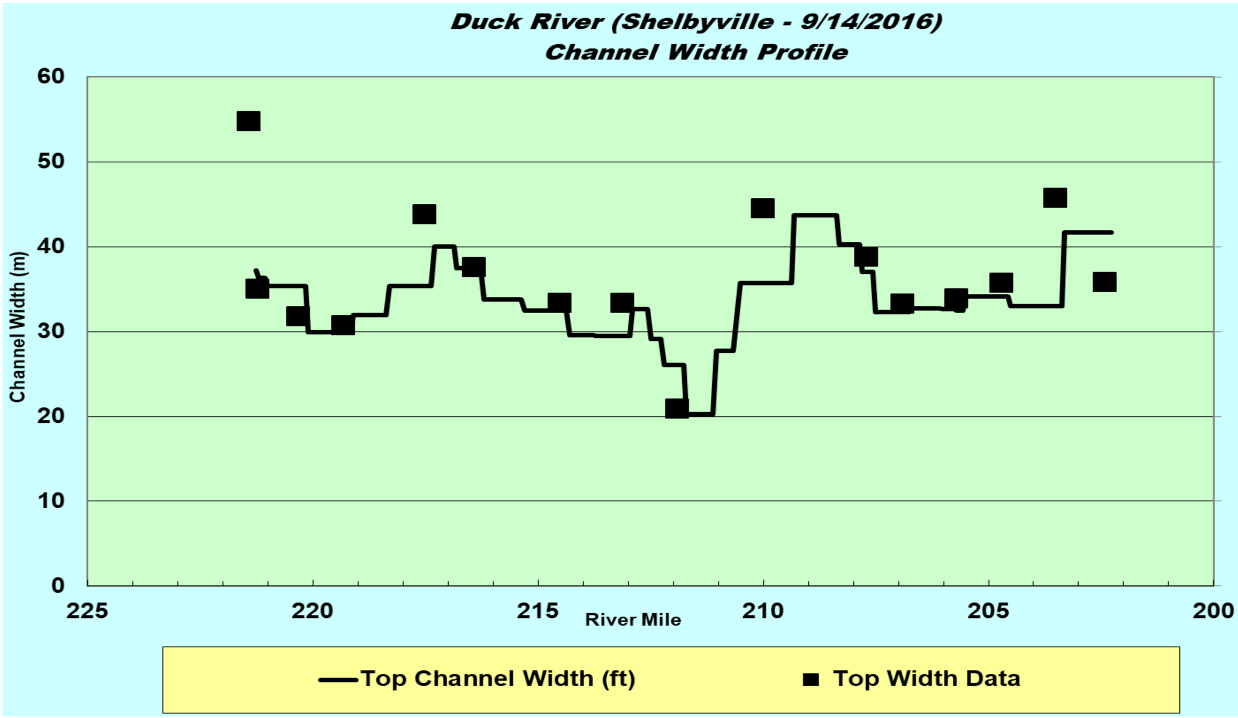


Figure 40: Water Depth Profile and Calibration for Duck River RMs 221.4 – 202.

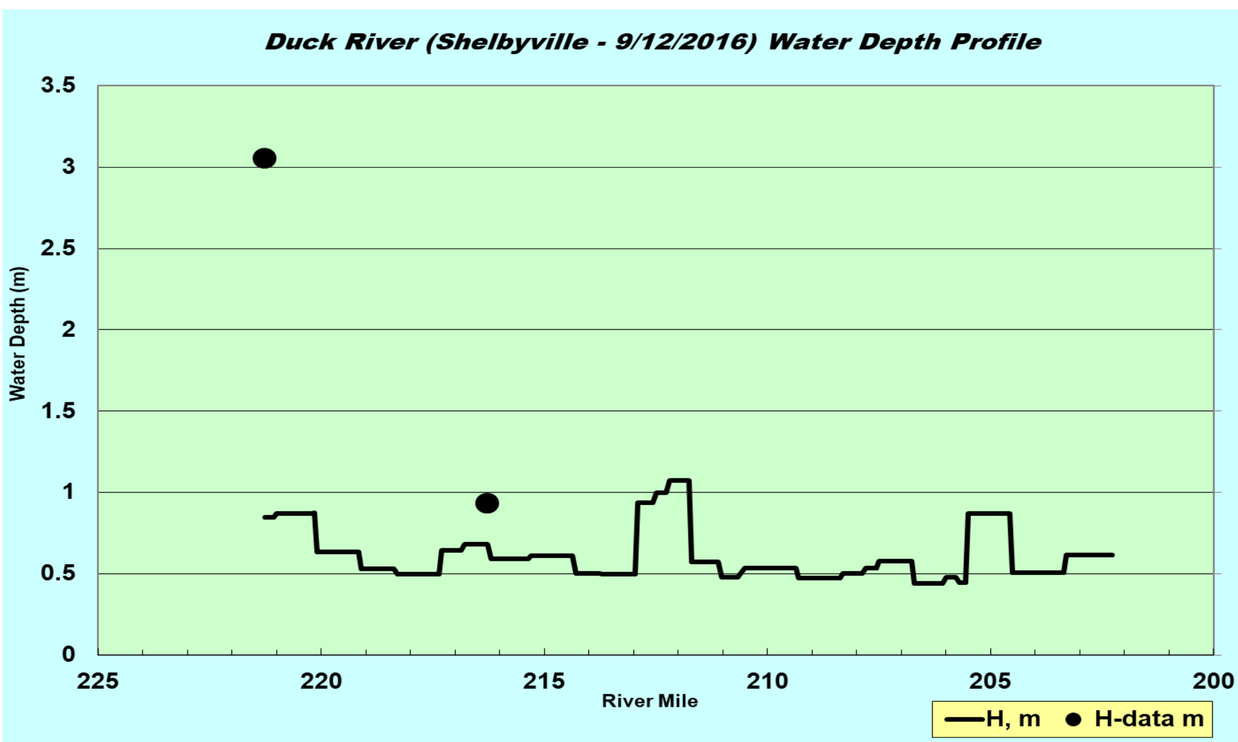


Figure 41: Water Depth Profile and Calibration for Duck River RMs 221.4 – 202.

2. Water Quality Calibration

Water quality samples collected by BDY on 9/12/2016 were used for model set-up and calibration. Constituents that are calibrated include water temperature, pH, dissolved oxygen, total ammonia, nitrate, inorganic phosphorus, total nitrogen, total kjeldahl nitrogen, and total phosphorus. The calibration results and water quality profiles are presented in Figures 42-50.

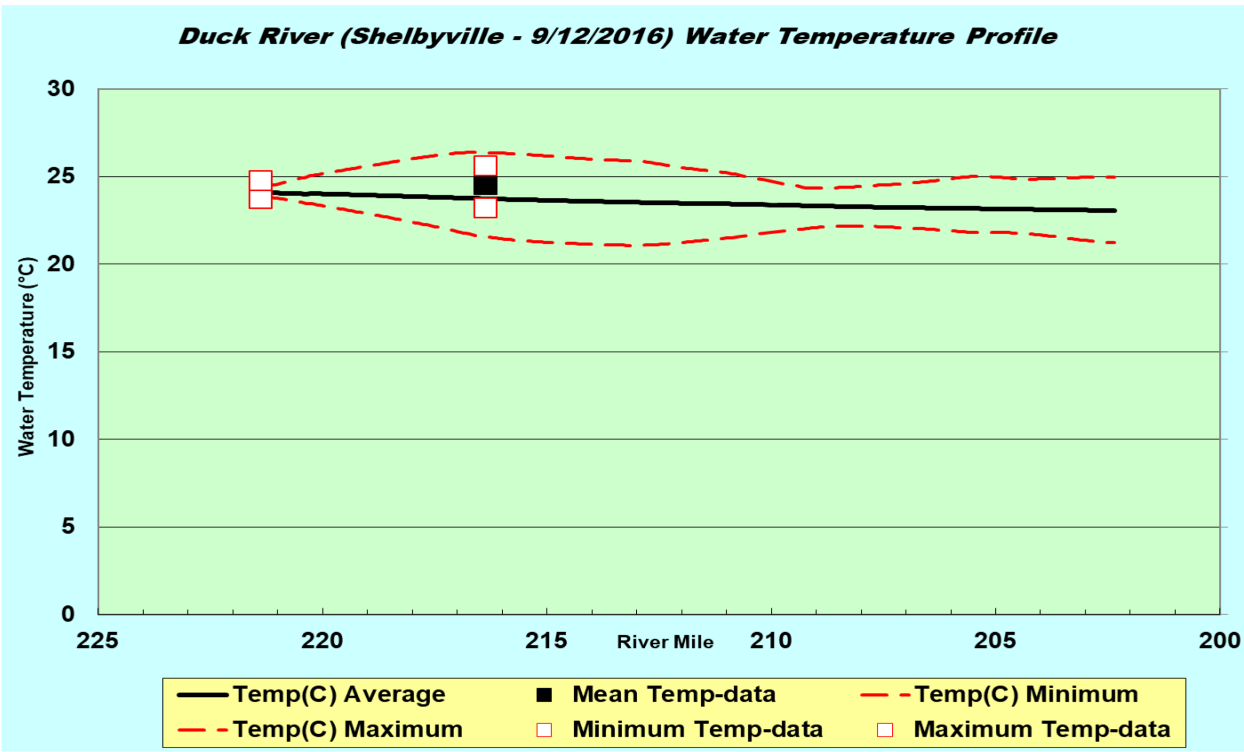


Figure 42. Water Temperature Profile and Calibration for Duck River RMs 221.4 – 202.

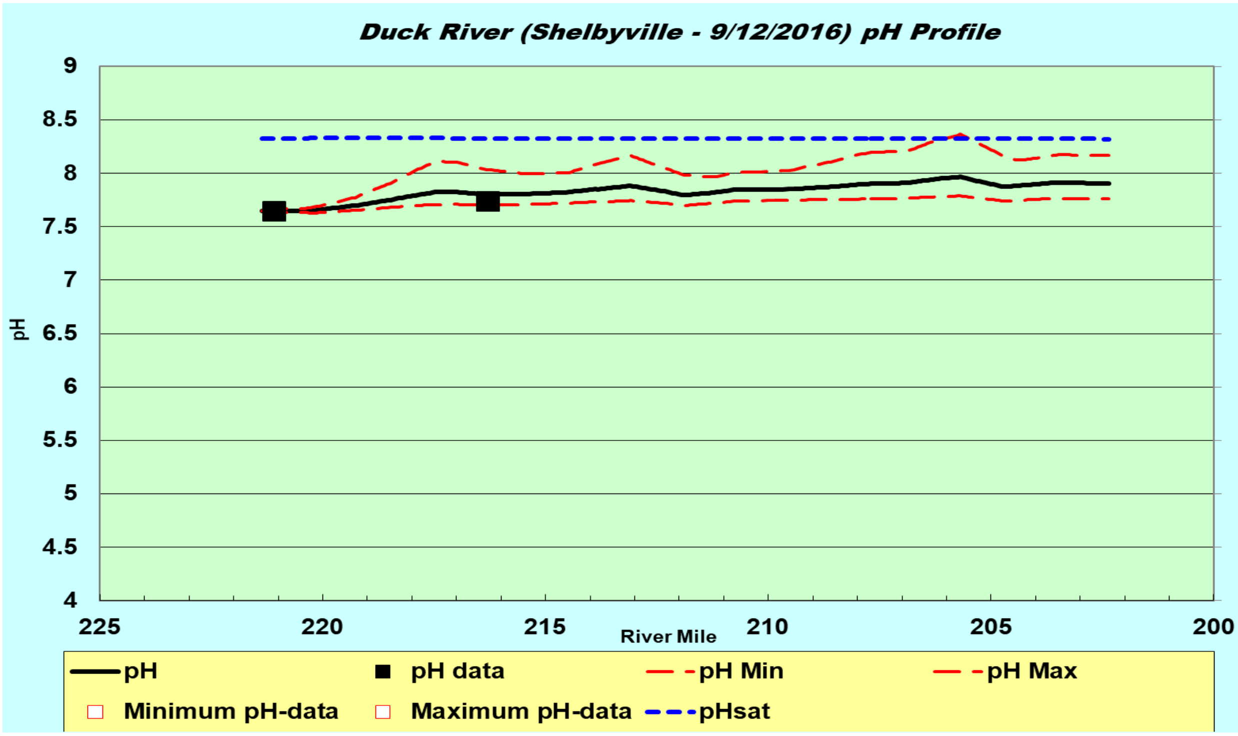


Figure 43. pH Profile and Calibration for Duck River RMs 221.4 – 202.

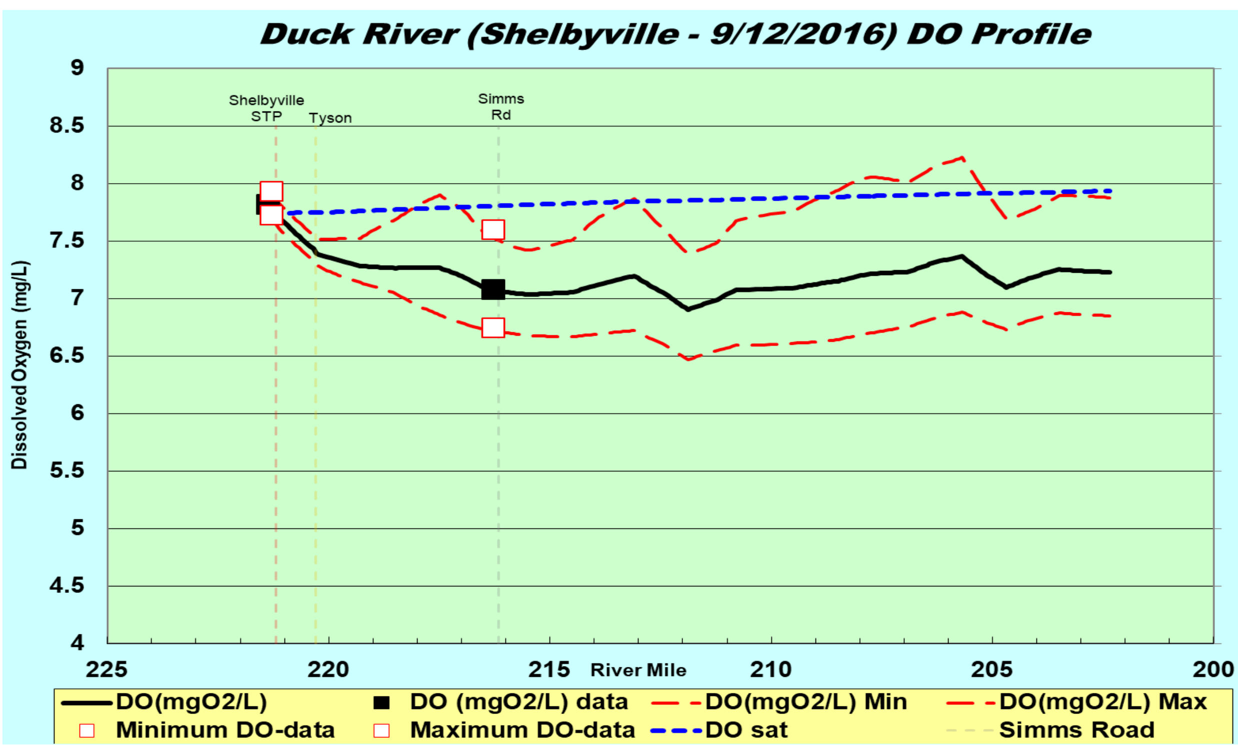


Figure 44. Dissolved Oxygen Profile and Calibration for Duck River RMs 221.4 – 202.

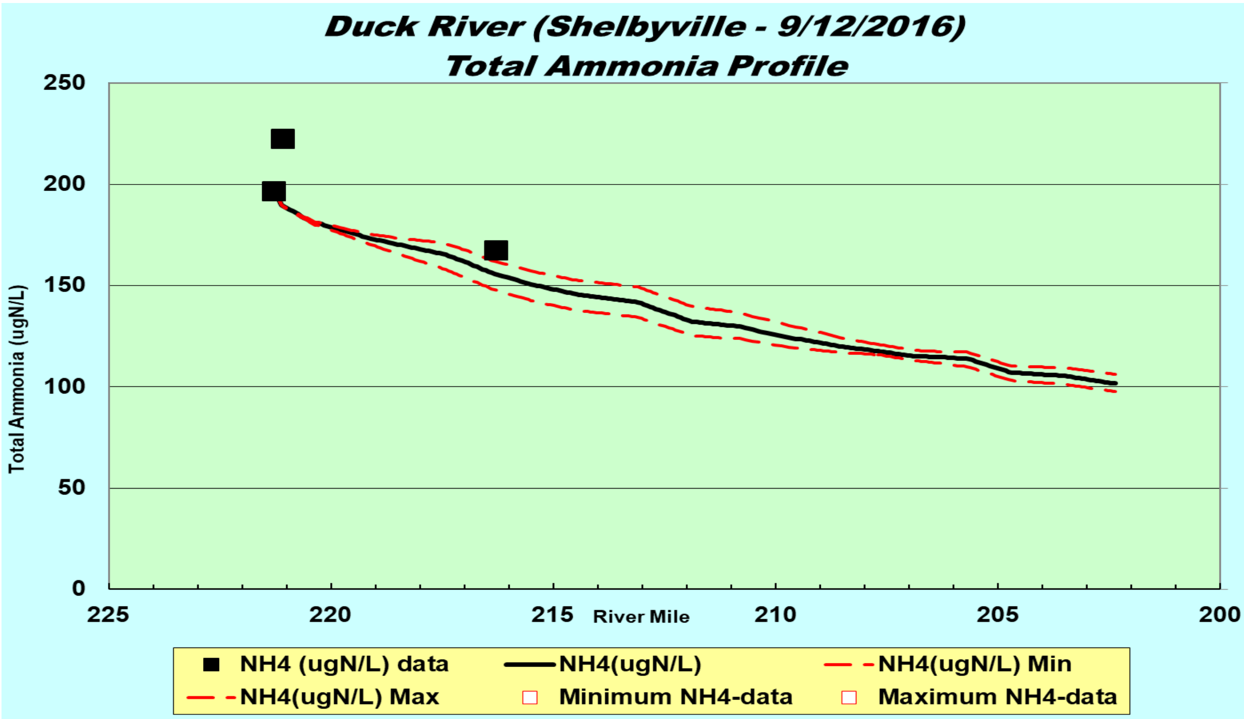


Figure 45. Total Ammonia Profile and Calibration for Duck River RMs 221.4 – 202.

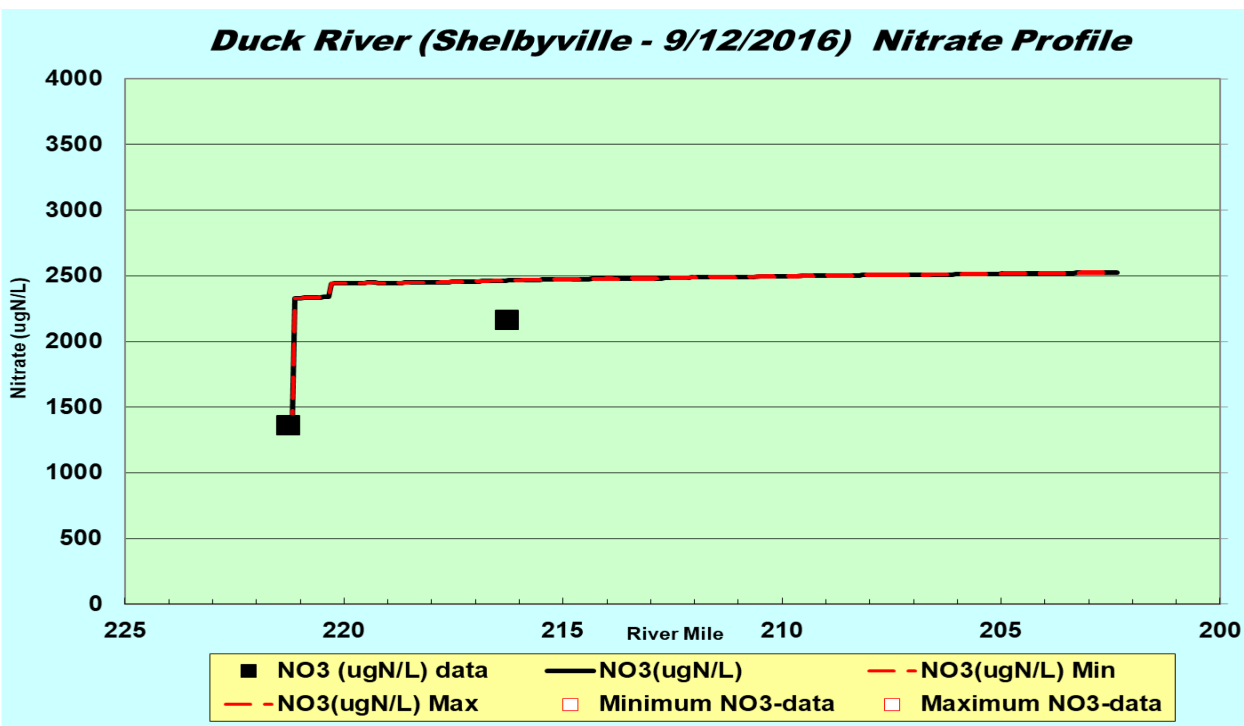


Figure 46. Nitrate Profile and Calibration for Duck River RMs 221.4 – 202.

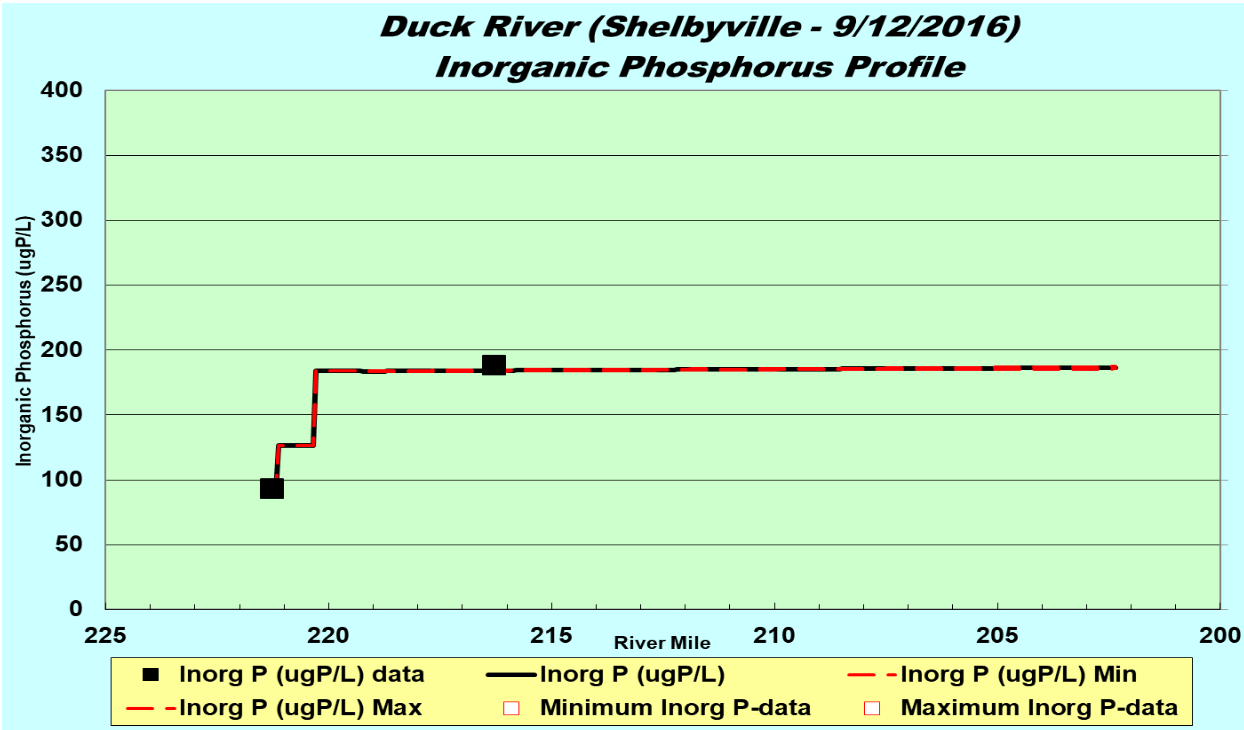


Figure 47. Inorganic Phosphorus Profile and Calibration for Duck River RMs 221.4 – 202.

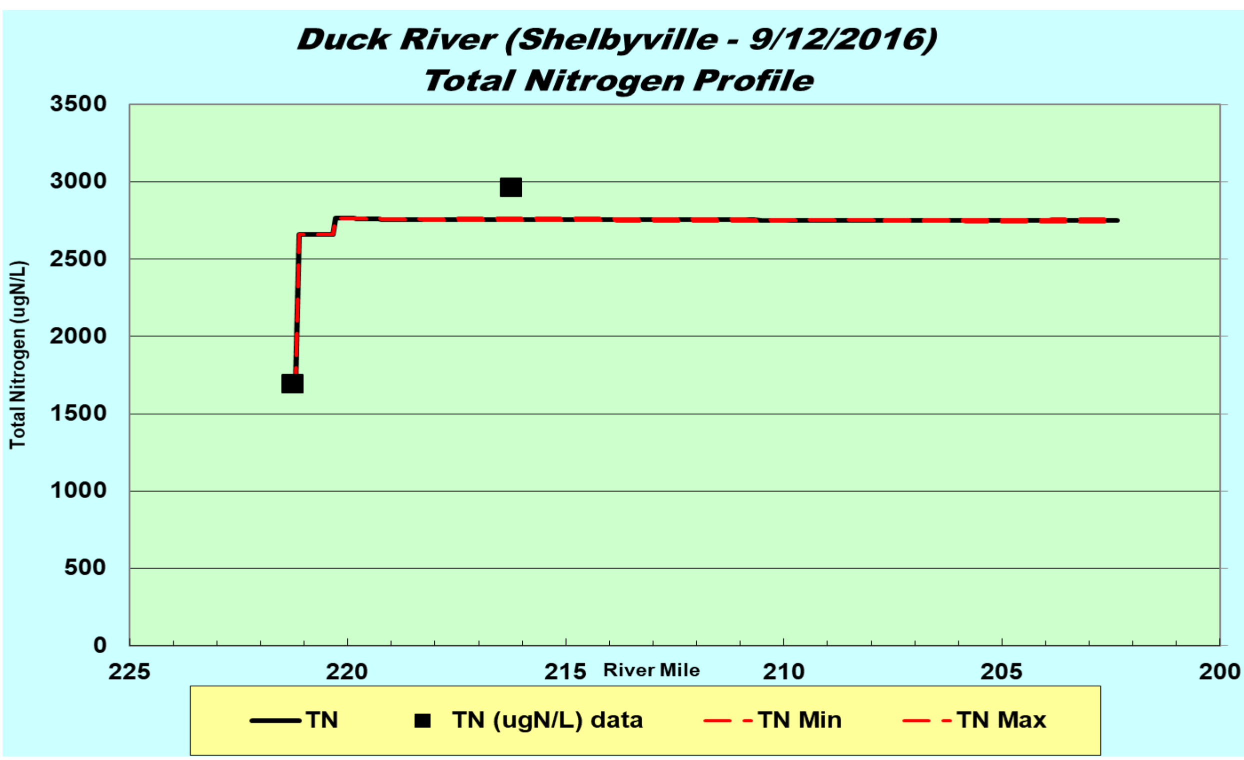


Figure 48. Total Nitrogen Profile and Calibration for Duck River RMs 221.4 – 202.

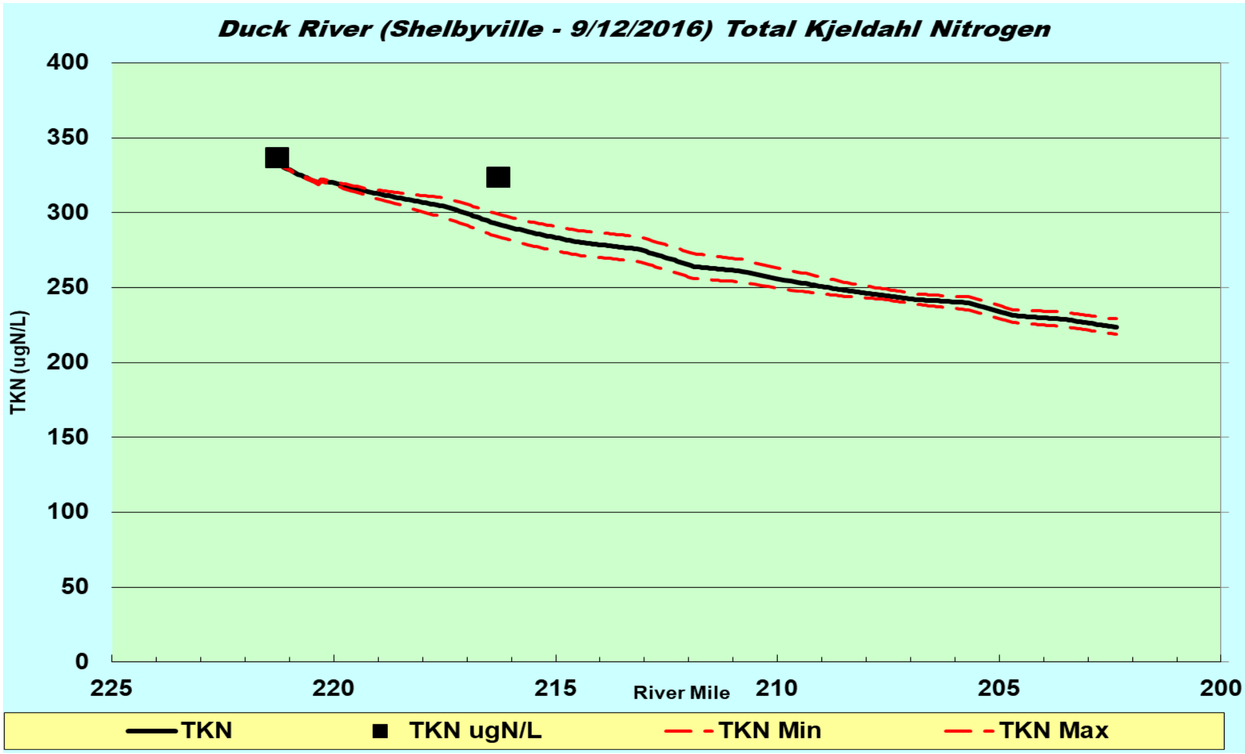


Figure 49. Total Kjeldahl Nitrogen Profile and Calibration for Duck River RMs 221.4 – 202.

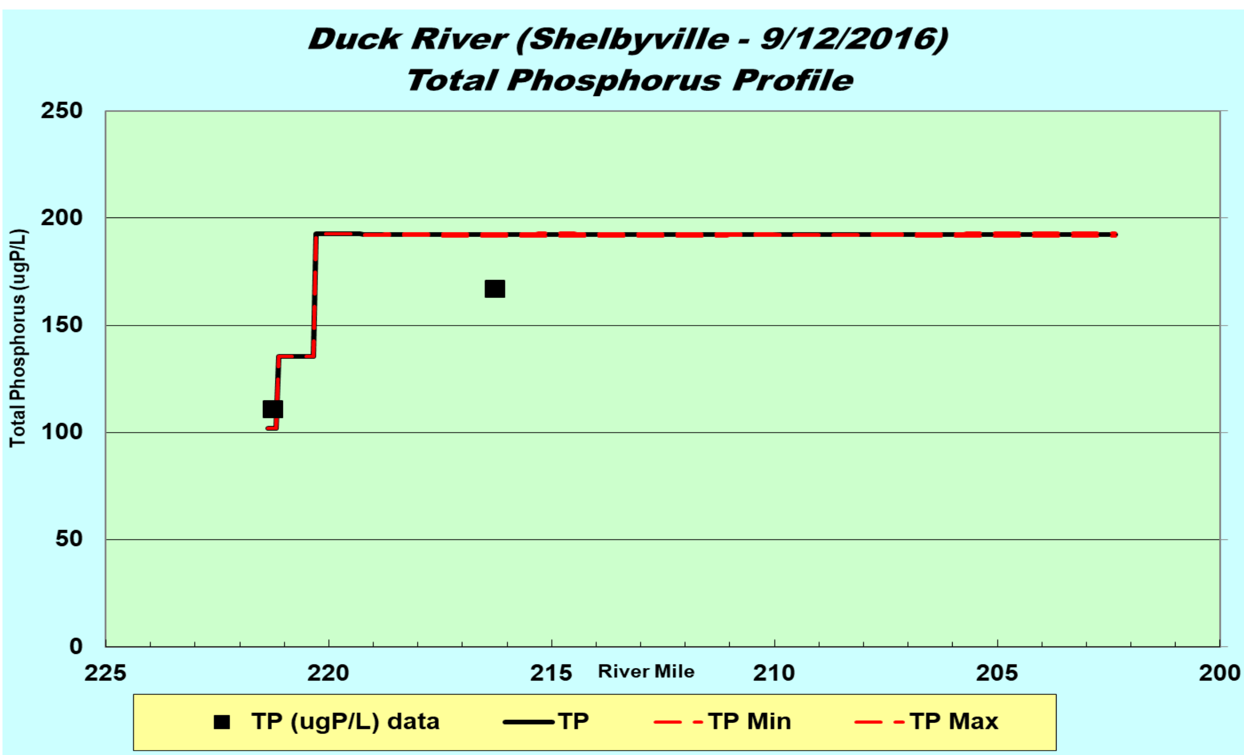


Figure 50. Total Phosphorus Profile and Calibration for Duck River RMs 221.4 – 202.

Appendix E

Permitted Facility Effluent Ammonia Toxicity Analyses

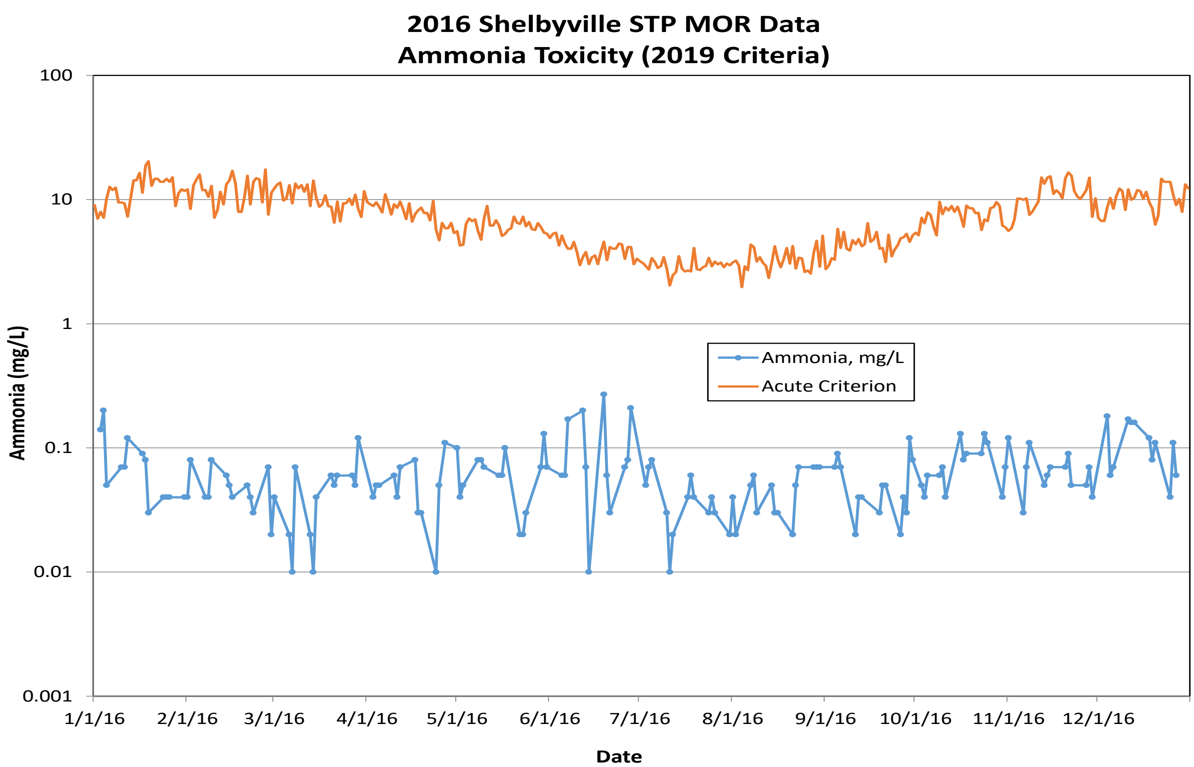


Figure 51. 2016 Shelbyville STP Effluent Ammonia Toxicity Analysis – Acute Criterion.

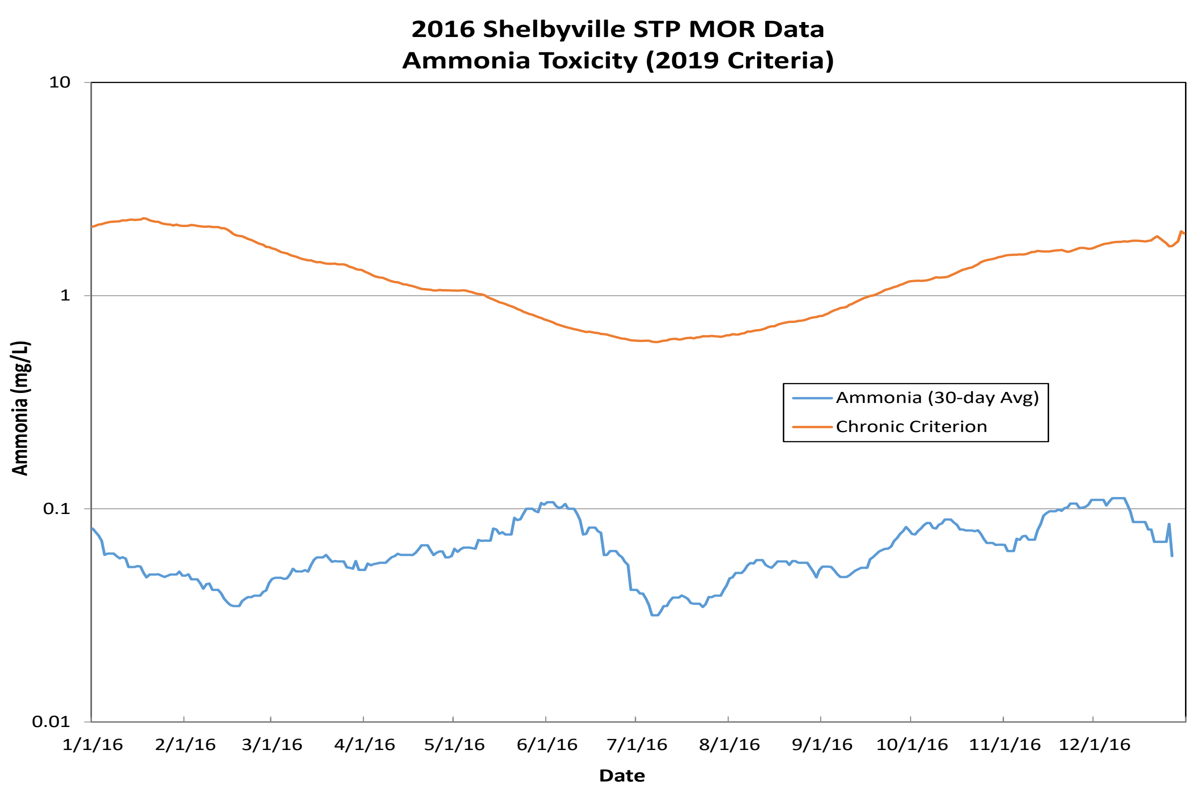


Figure 52. 2016 Shelbyville STP Effluent Ammonia Toxicity Analysis – 30-day Chronic Criterion.

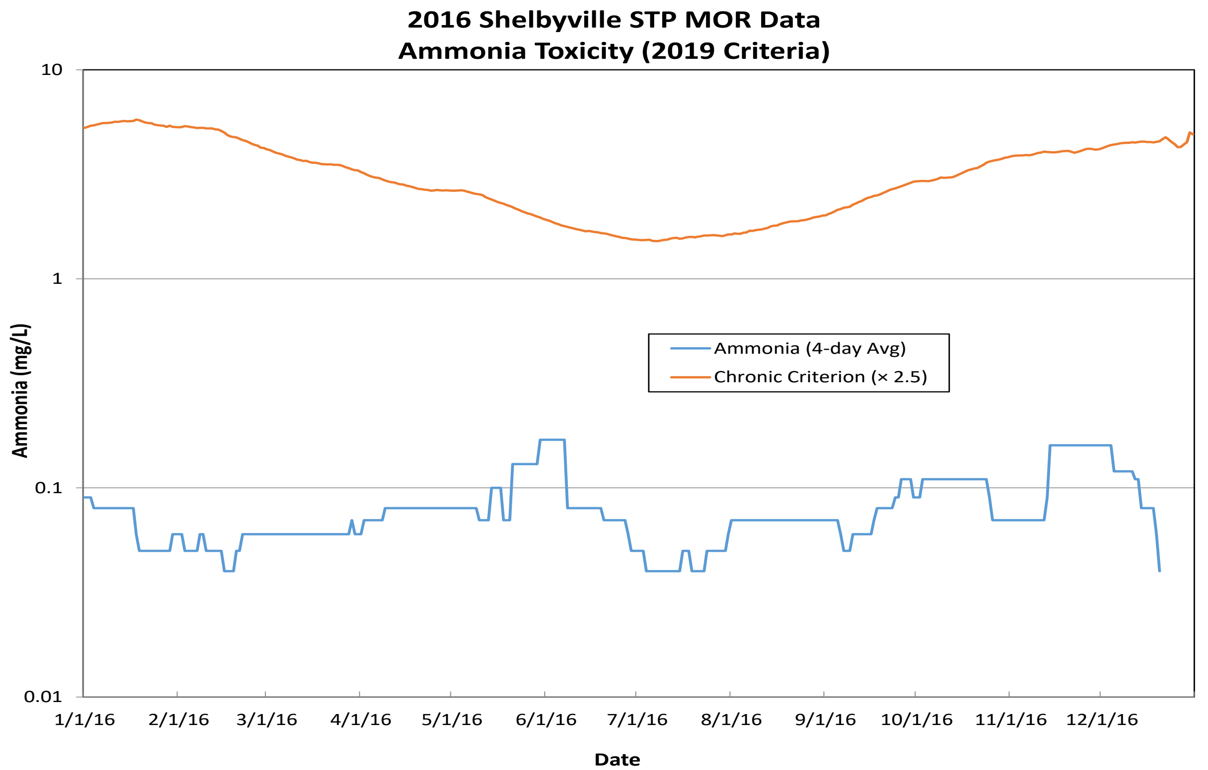


Figure 53. 2016 Shelbyville STP Effluent Ammonia Toxicity Analysis – 4-day Chronic Criterion.

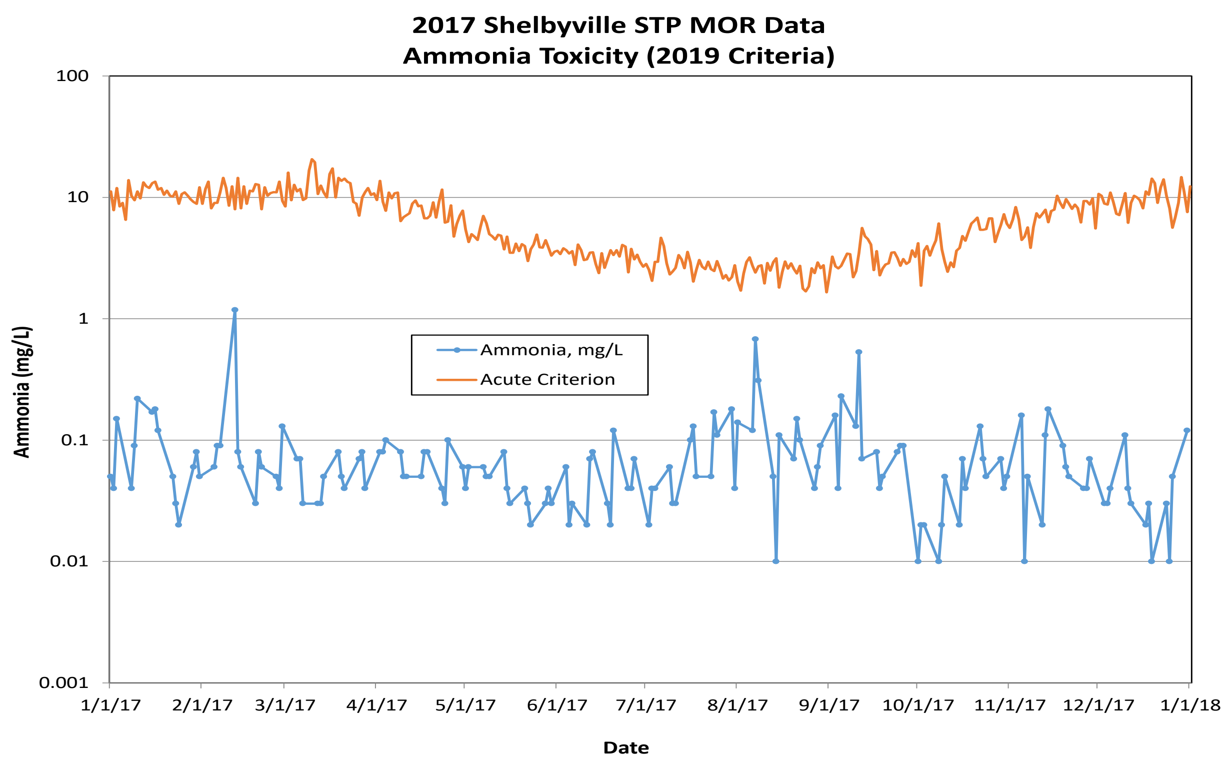


Figure 54. 2017 Shelbyville STP Effluent Ammonia Toxicity Analysis – Acute Criterion.

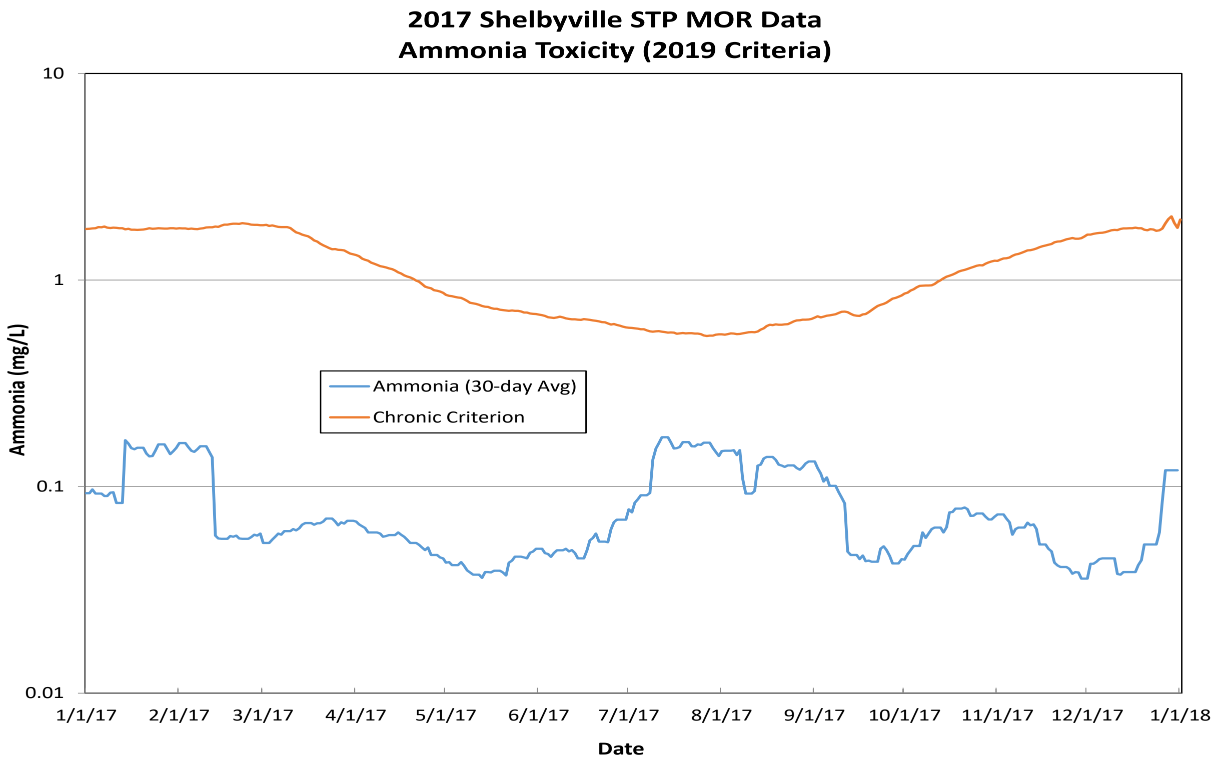


Figure 55. 2017 Shelbyville STP Effluent Ammonia Toxicity Analysis – 30-day Chronic Criterion.

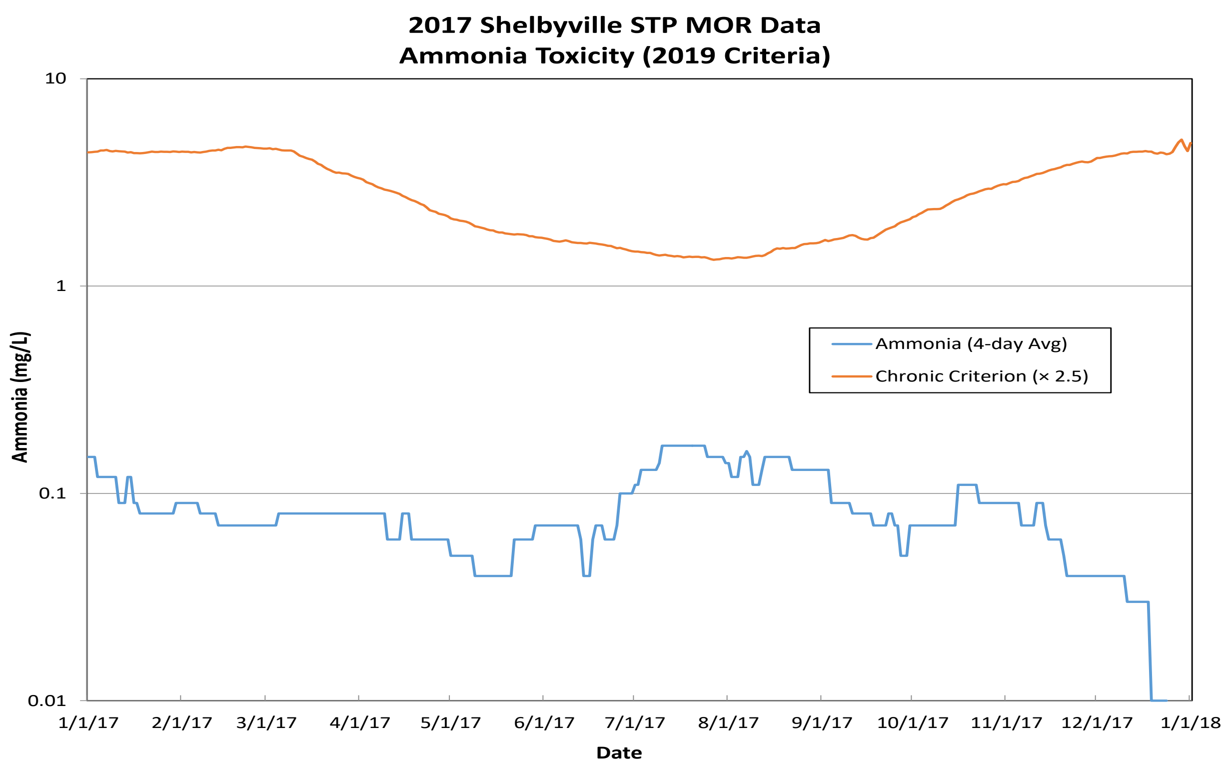


Figure 56. 2017 Shelbyville STP Effluent Ammonia Toxicity Analysis – 4-day Chronic Criterion.

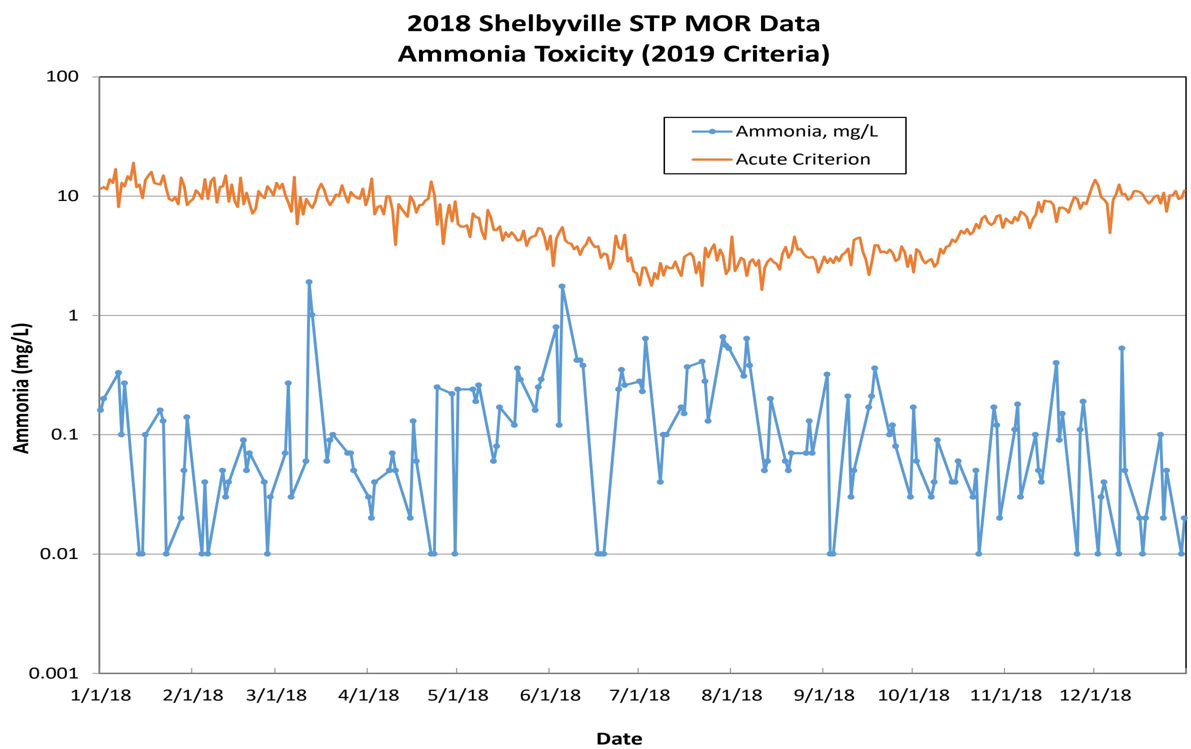


Figure 57. 2018 Shelbyville STP Effluent Ammonia Toxicity Analysis – Acute Criterion.

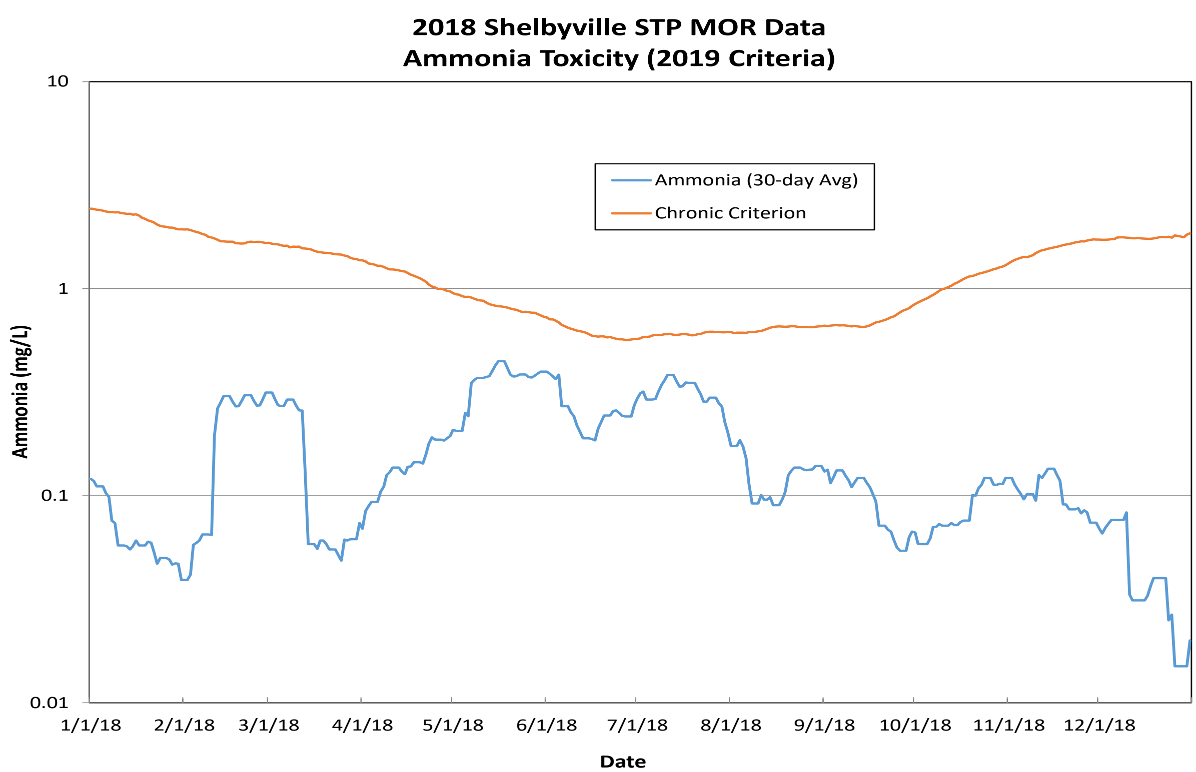


Figure 58. 2018 Shelbyville STP Effluent Ammonia Toxicity Analysis – 30-day Chronic Criterion.

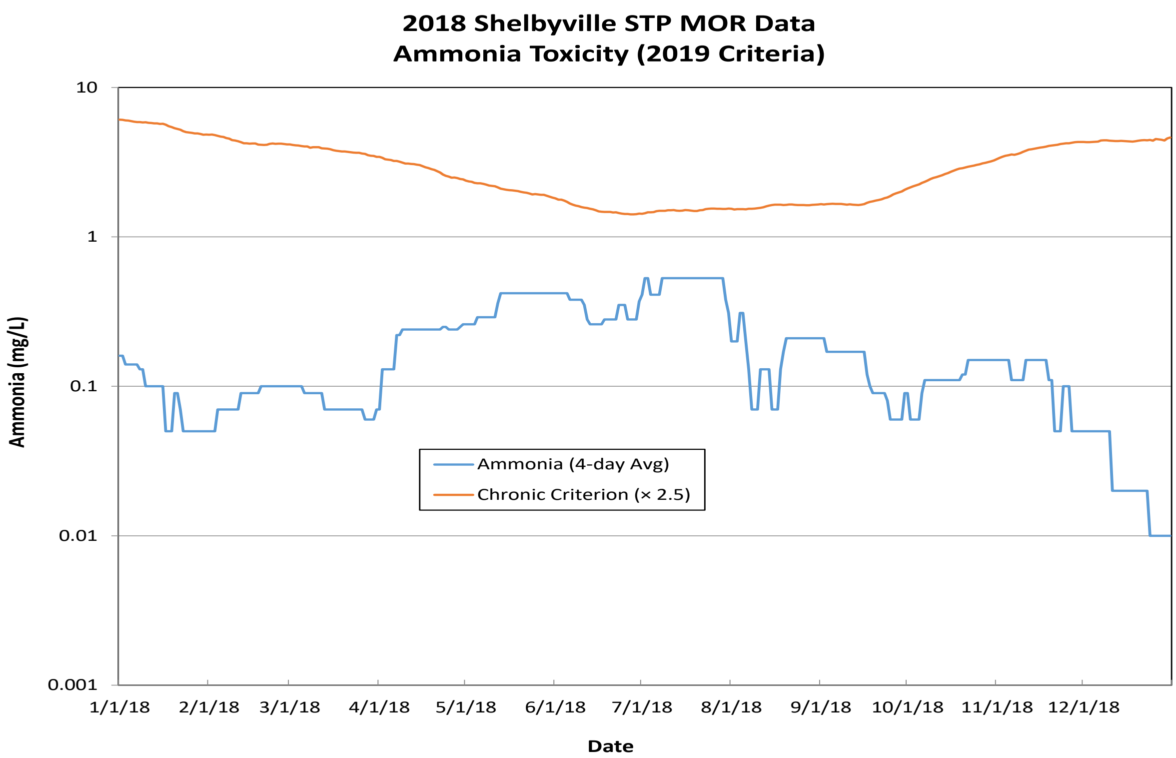


Figure 59. 2018 Shelbyville STP Effluent Ammonia Toxicity Analysis – 4-day Chronic Criterion.

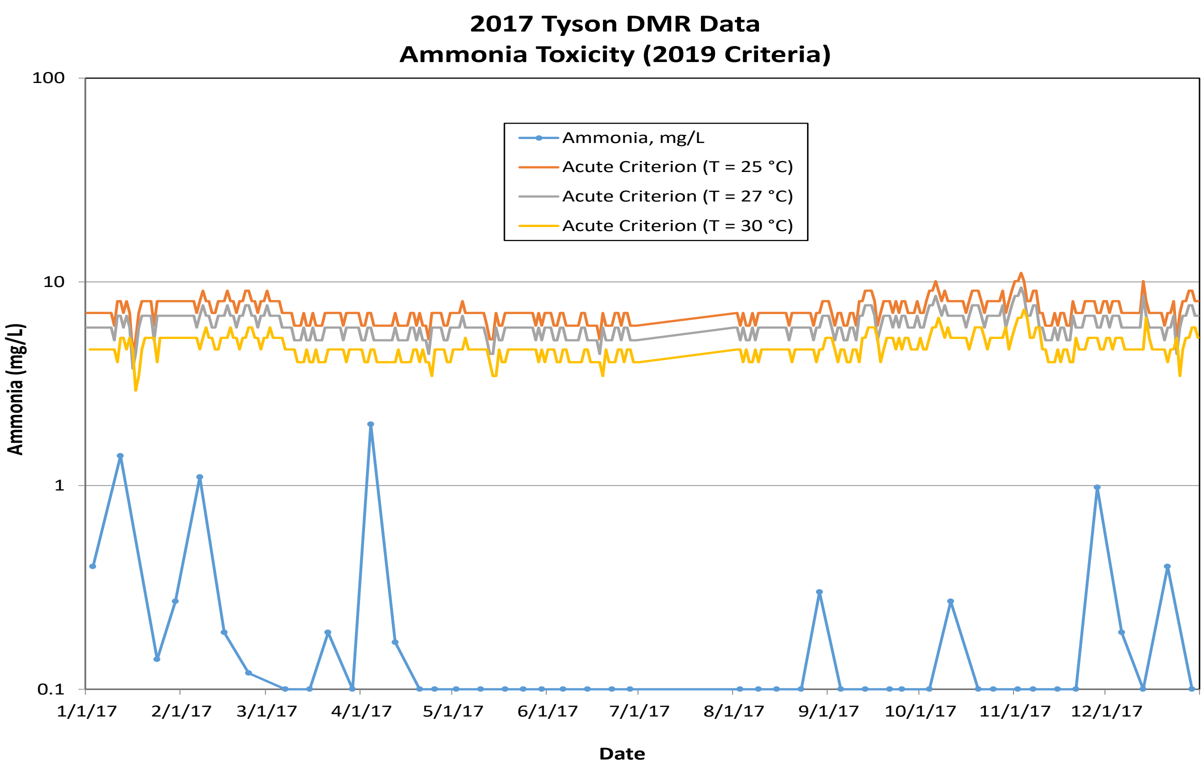


Figure 60. 2017 Tyson Farms Effluent Ammonia Toxicity Analysis – Acute Criterion.

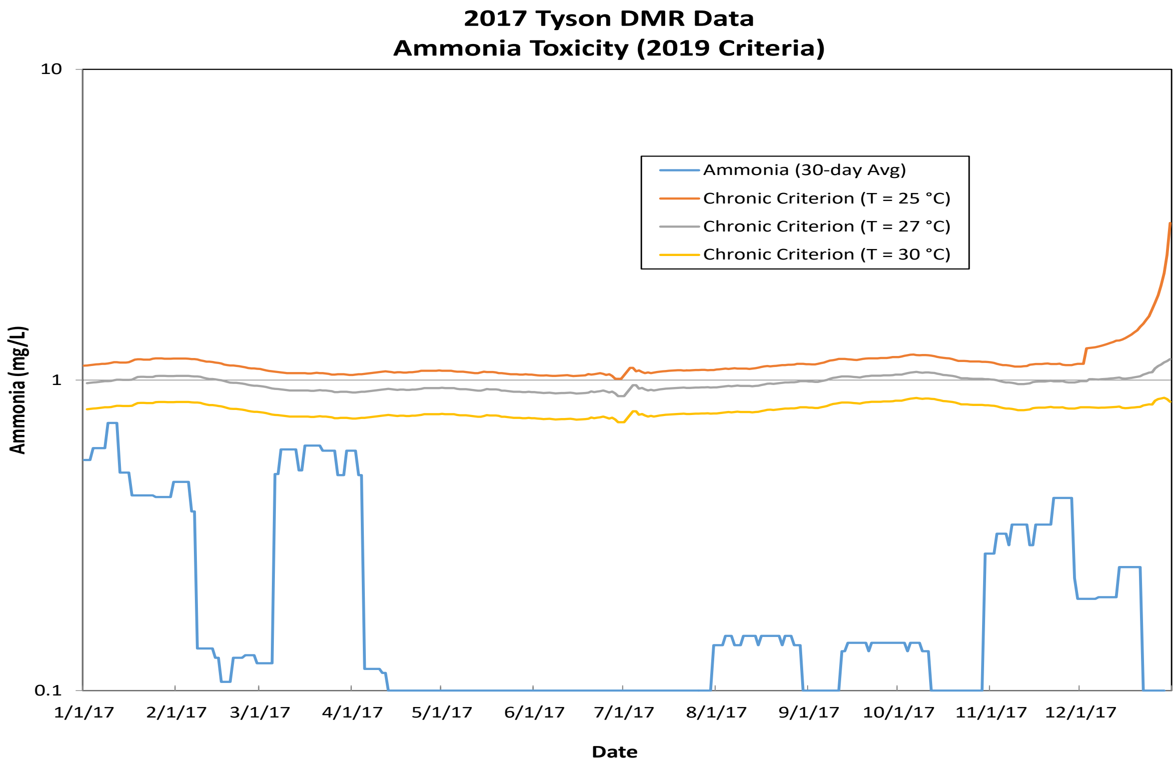


Figure 61. 2017 Tyson Farms Effluent Ammonia Toxicity Analysis – 30-day Chronic Criterion.

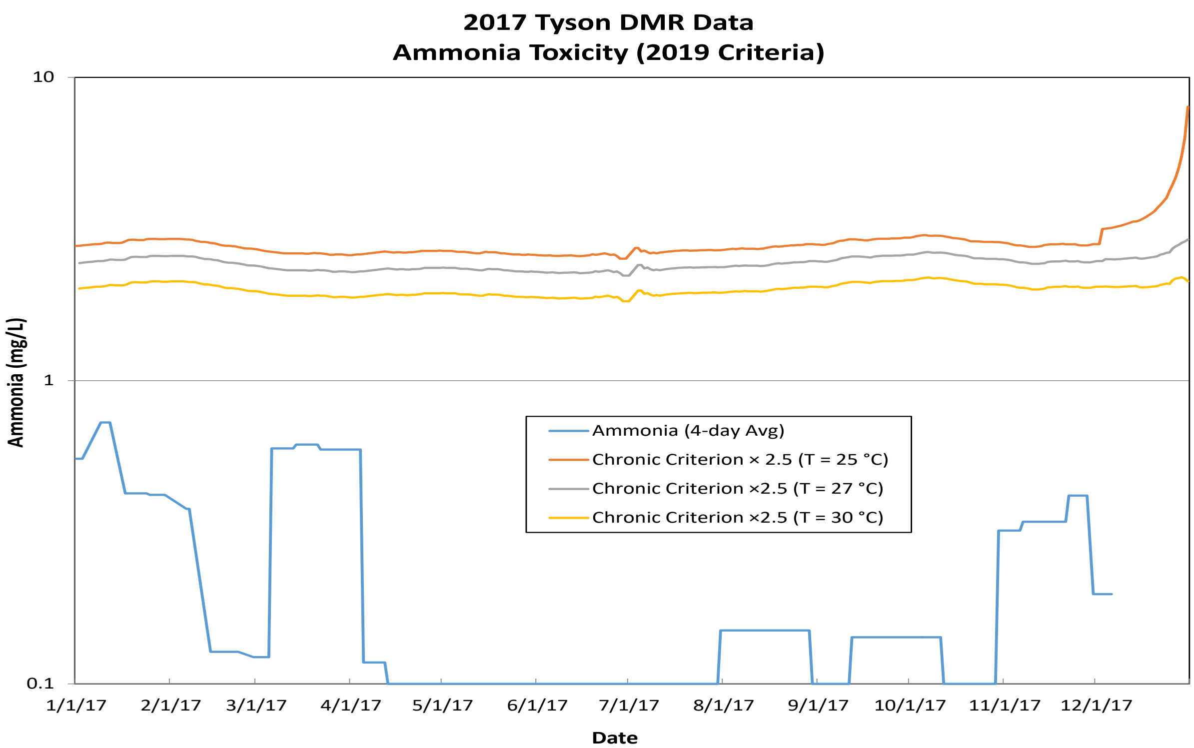


Figure 62. 2017 Tyson Farms Effluent Ammonia Toxicity Analysis – 4-day Chronic Criterion.

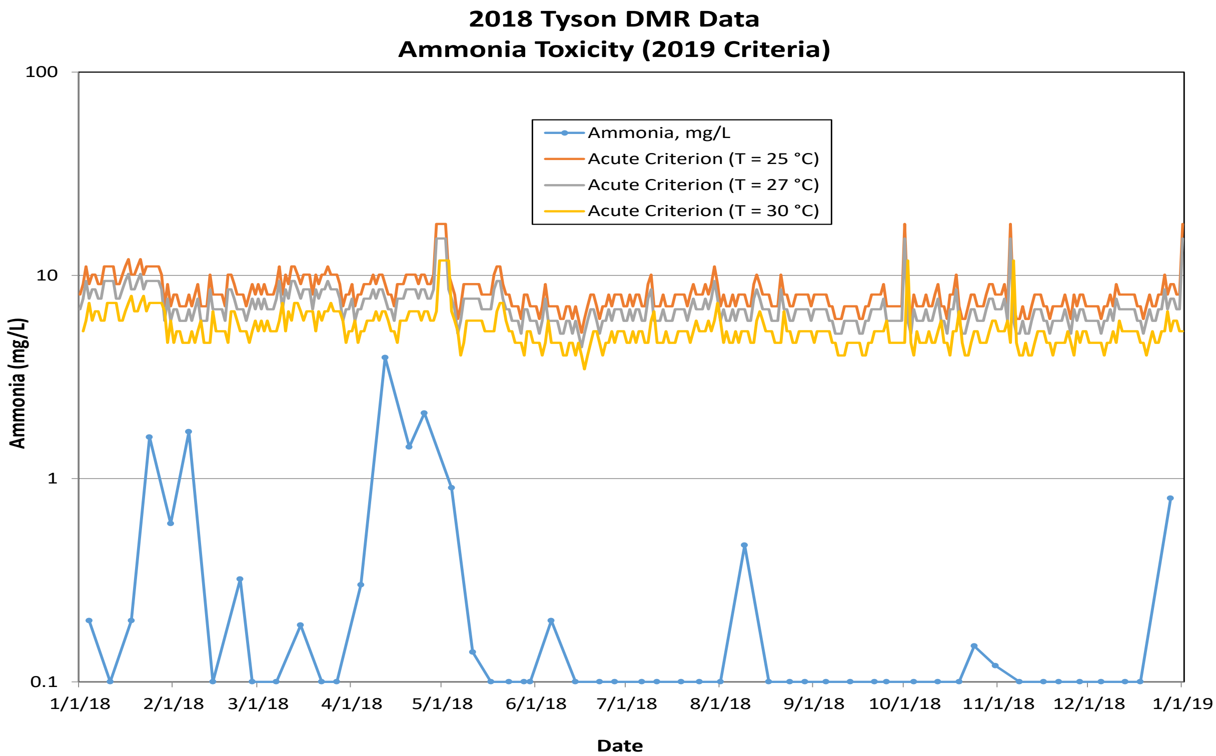


Figure 63. 2018 Tyson Farms Effluent Ammonia Toxicity Analysis – Acute Criterion.

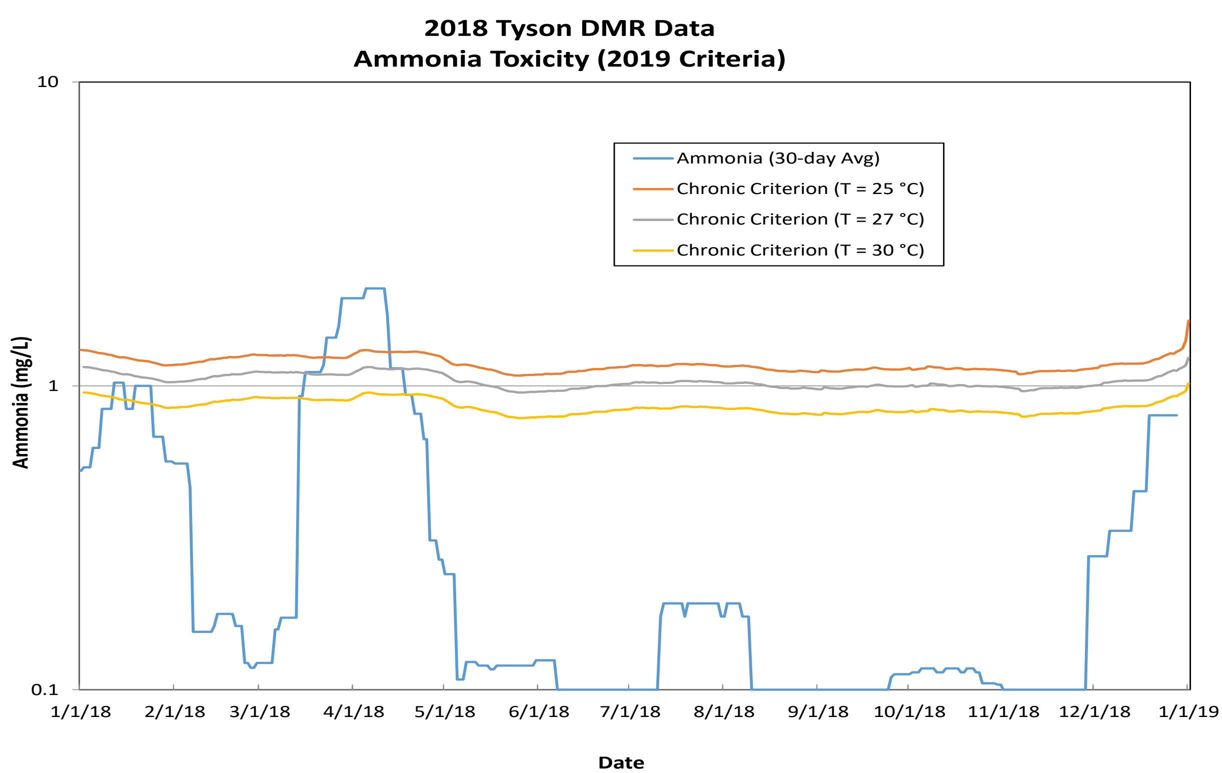


Figure 64. 2018 Tyson Farms Effluent Ammonia Toxicity Analysis – 30-day Chronic Criterion.

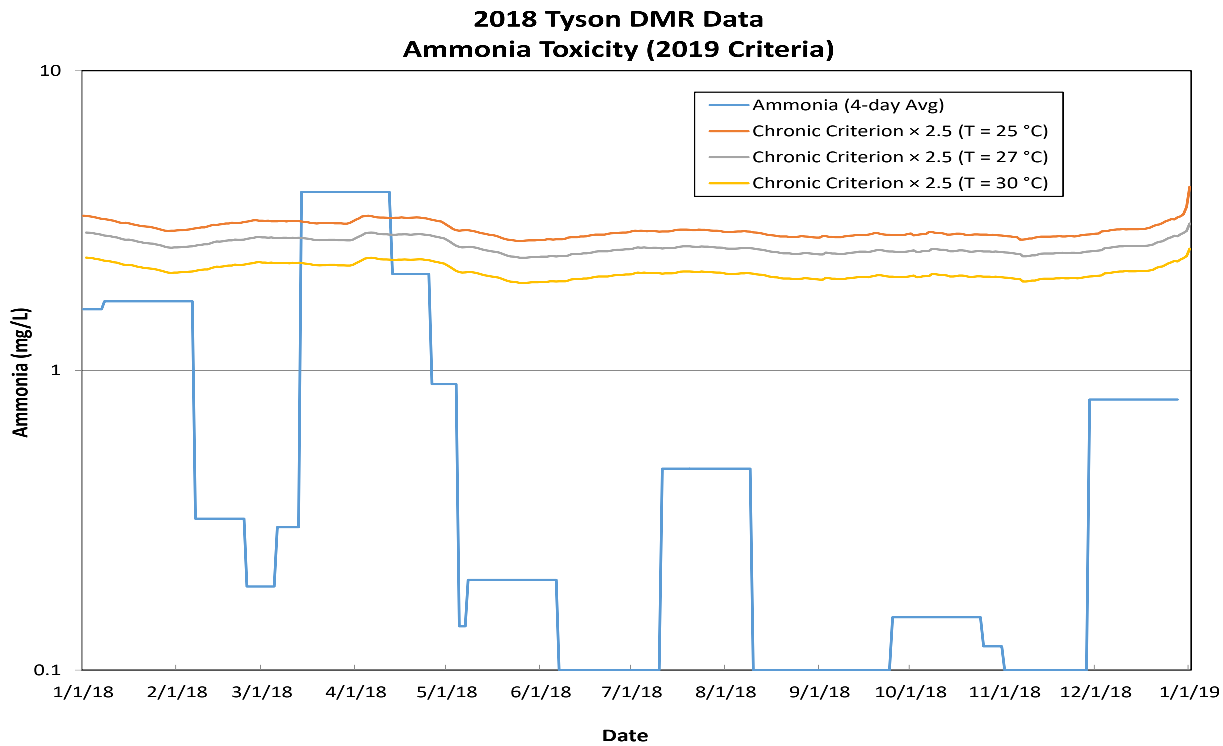


Figure 65. 2018 Tyson Farms Effluent Ammonia Toxicity Analysis – 4-day Chronic Criterion.

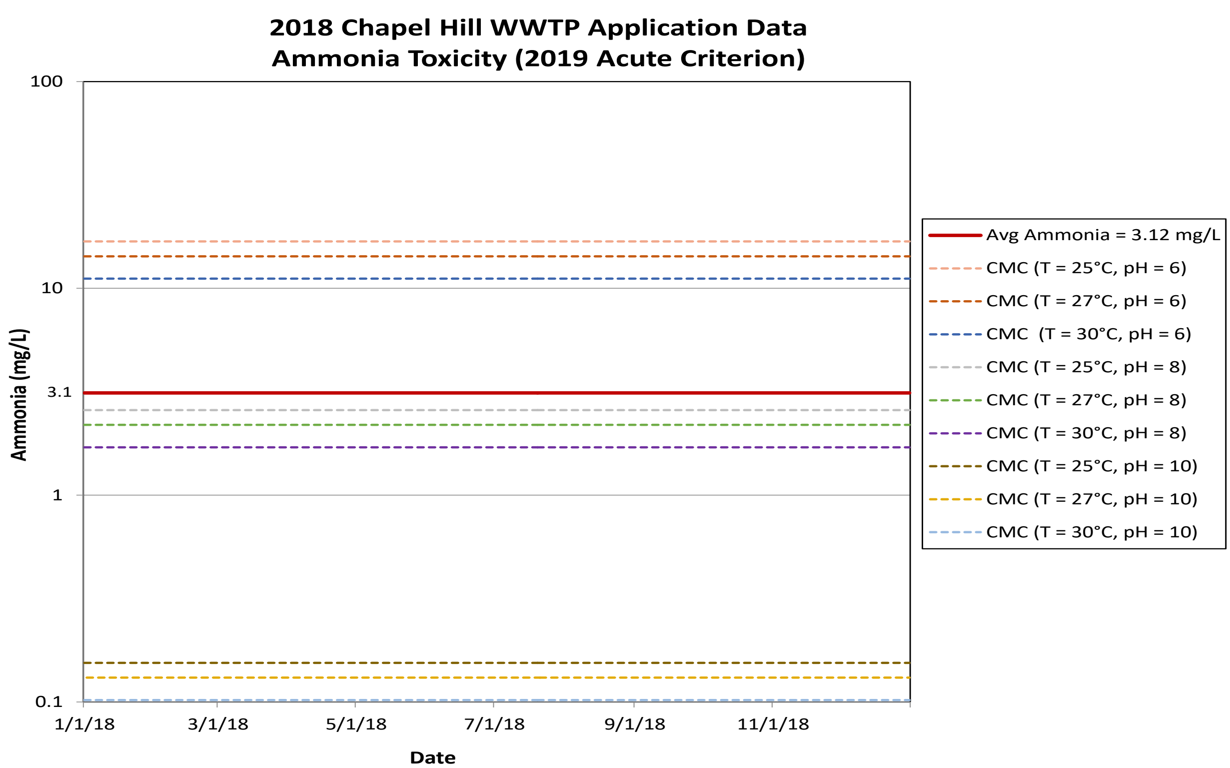


Figure 66. 2018 Chapel Hill WWTP Effluent Ammonia Toxicity Analysis – Acute Criterion.

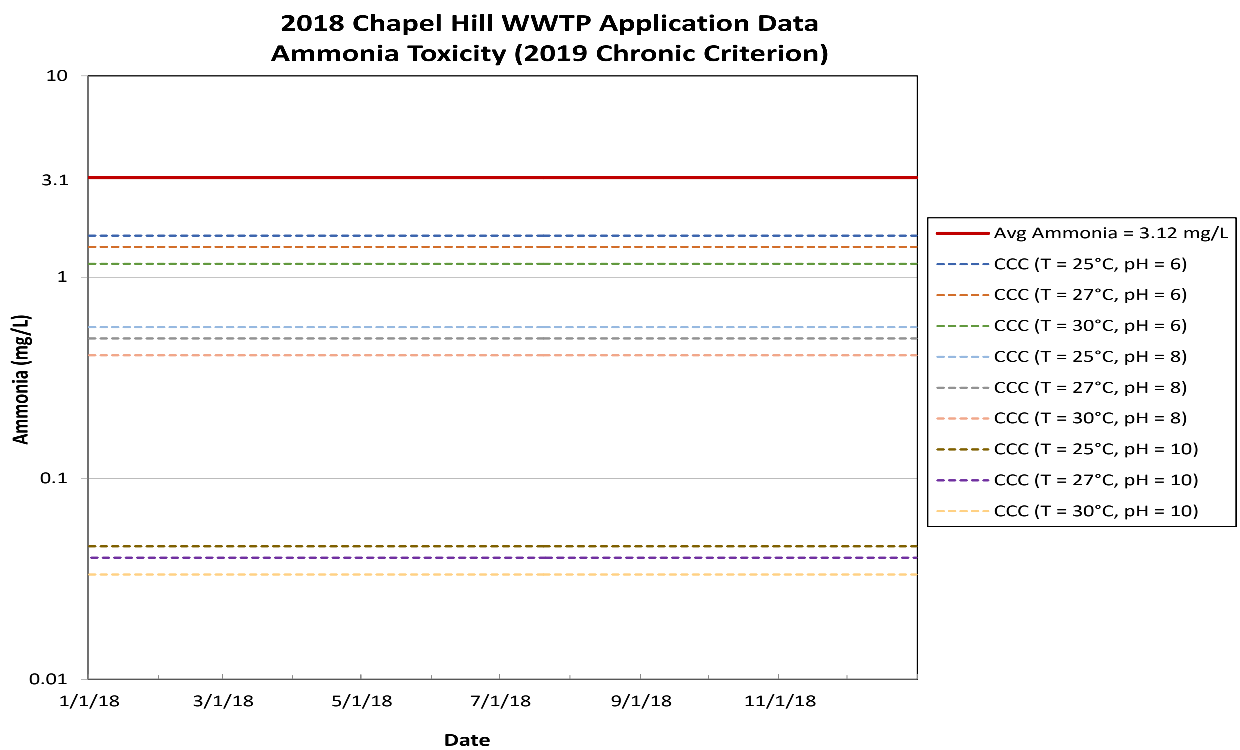


Figure 67. 2018 Chapel Hill WWTP Effluent Ammonia Toxicity Analysis – Chronic Criterion.

Ammonia Toxicity Tables for Chapel Hill WWTP:

Table 5. Acute Criterion (CMC).

NH_3 Conc. (Avg) = 3.1 mg/L	CMC (New Criteria)	CMC (New Criteria)	CMC (New Criteria)
Temp. \ PH	6	8	10
25 °C	16.87	2.58	0.15
27 °C	14.29	2.19	0.13
30 °C	11.15	1.70	0.10

Table 6. Chronic Criterion (CCC).

NH_3 Conc. (Avg) = 3.1 mg/L	CCC (New Criteria)	CCC (New Criteria)	CCC (New Criteria)
Temp. \ PH	6	8	10
25 °C	1.61	0.56	0.05
27 °C	1.41	0.49	0.04
30 °C	1.16	0.41	0.03

Appendix F

Duck River EA QUAL2k Model Critical Conditions Water Quality Parameters

Critical Boundary Conditions

From State of Tennessee – EPA Region 4 Agreement (1991):

- Critical Flow = Proposed minimum flow (155, 139, 135, 120, and 80 cfs)
- Water Temperature = 27°C
- DO = 6 mg/L (State-EPA Agreement) and 7.1 mg/L (minimum field data, BDY 2016)
- pH = 7.65 (BDY grab sample 9/12/16)
- Specific Conductivity = 161 µS/cm (BDY grab sample 9/12/16)
- $CBOD_5$ = 1.5 mg/L
- Assumed f-ratio = 1.5 for background flow of Duck River, upstream of the Shelbyville STP. Applying this ratio to a background $CBOD_5$ = 1.5 mg/L, results in $CBOD_{Ultimate}$ = 2.25 mg/L.
- NO_3 = (BDY grab sample 9/12/16)
- NH_3 = Highest of value from State-EPA Agreement or field measurement

  0.231 mg/L (State-EPA Agreement with NBOD:NH_3 ratio of 4.33), or

  0.196 mg/L (2016 highest concentration of field measurement)

  NH_3 (final) = 0.231 mg/L as N

- Organic N = 1.318 mg/L as N (highest concentration of 2016 BDY field measurements)

Facilities Discharge

Shelbyville STP (TN0024180) Permit Limits

- Design Flow = 6.5 MGD = 0.285 m^3/s
- Temperature = 29°C (High MOR effluent temperature 2016-2018)
- DO = 6.68 mg/L (Minimum DO from MOR 2016-2018)
- pH = 9 (Highest pH limit)
- Specific Conductivity = 161 µS/cm (Assume to be the same as Duck River concentration)
- $CBOD_5$ = 25 mg/L (Effluent Limit)

  $CBOD_{Ultimate}$ = 80 mg/L

  Used f-ratio = 3.2 for activated sludge treatment plant (ref.:*Technical Guidance Manual For Developing Total Maximum Daily Loads, Book 2: Streams And Rivers, Part 1: Biochemical Oxygen Demand/Dissolved Oxygen And Nutrients/Eutrophication*, EPA 823-B-97-002, March 1997) for the Shelbyville STP effluent. Applying this ratio to an effluent $CBOD_5$ = 25 mg/l, results in $CBOD_{Ultimate}$ = 80 mg/l.

- NH_3 (Monthly Average) = 2.3 mg/L (Monthly Effluent Limit, No TN limit)
- NO_3 = Based on 9/16/2016 calibration data.
- Organic N = 0.190 mg/L (2016 BDY highest field measurement downstream from STP)

- Organic P = 0.202 mg/L
- Ortho P = 1.82 mg/L (2016 BDY field measurement, and 90% Ortho P & 10% Organic P based on downstream measurement)

Tyson Farms (TN0002135) Permit Limits

- Design Flow = 1.168 MGD = 0.0331 m^3/s
- Temperature = 27°C (No reported temperature available. Assume same as the river's critical condition temperature.)
- DO = 5.6 mg/L (Minimum DO from 2016-2018 DMR)
- pH = 9 (Maximum permit pH)
- Specific Conductivity = 161 µS/cm (Assume to be the same as Duck River concentration)
- $CBOD_5$ = 16 mg/L (Permit Monthly Average)

  CBODu = 16*4.47 = 71.52 mg/L

  Used f-ratio= 4.47 (based on long term BOD test) for Tyson effluent. Applying this ratio to an effluent $CBOD_5$ = 16 mg/L, results in $CBOD_{Ultimate}$ = 71.5 mg/L.

- TN = 103 mg/L (Permit Monthly Average)
- NH_3 = 4 mg/L (Permit Monthly Average)
- Organic N = 1.44 mg/L (2016 BDY highest field measurement Organic N at Simms Rd.)
- NO_3 = 98 mg/L (2016 BDY field measurement)
- TP = 20 mg/L (Max TP from 2016-18 DMR)
- Ortho P = 19.68 mg/L (based on TP and ratio below)
- Organic P = 0.32 mg/L (based on TP and ratio below)

  Based on information from Tyson Farms Processing plant at North Fork Obion, 98.4% of the TP is Ortho-Phosphorus, and 1.6% is Organic Phosphorus.

Appendix G

QUAL2k Model Longitudinal Ammonia Toxicity Profiles for Duck River below Shelbyville

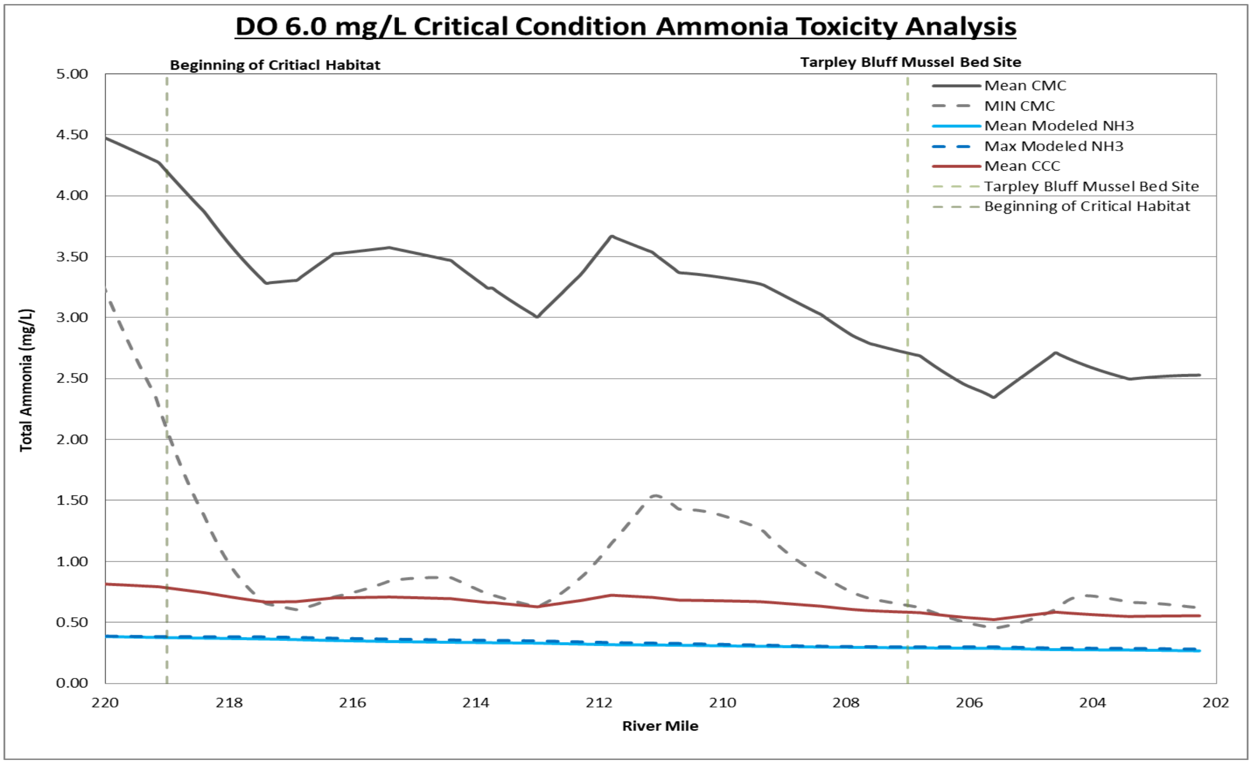


Figure 68. QUAL2k Model Ammonia Toxicity Profile (Alternative A) – 155 cfs/Boundary DO = 6.0 mg/L.

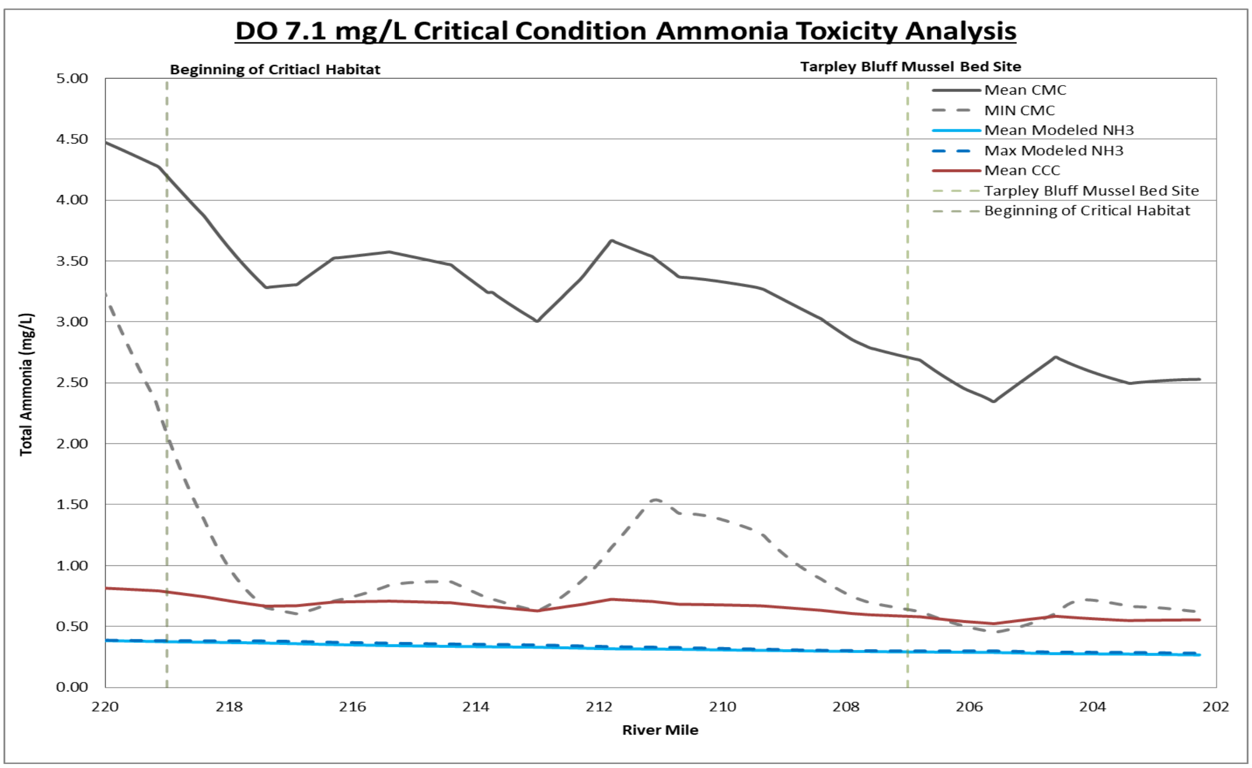


Figure 69. QUAL2k Model Ammonia Toxicity Profile (Alternative A) – 155 cfs/Boundary DO = 7.1 mg/L.

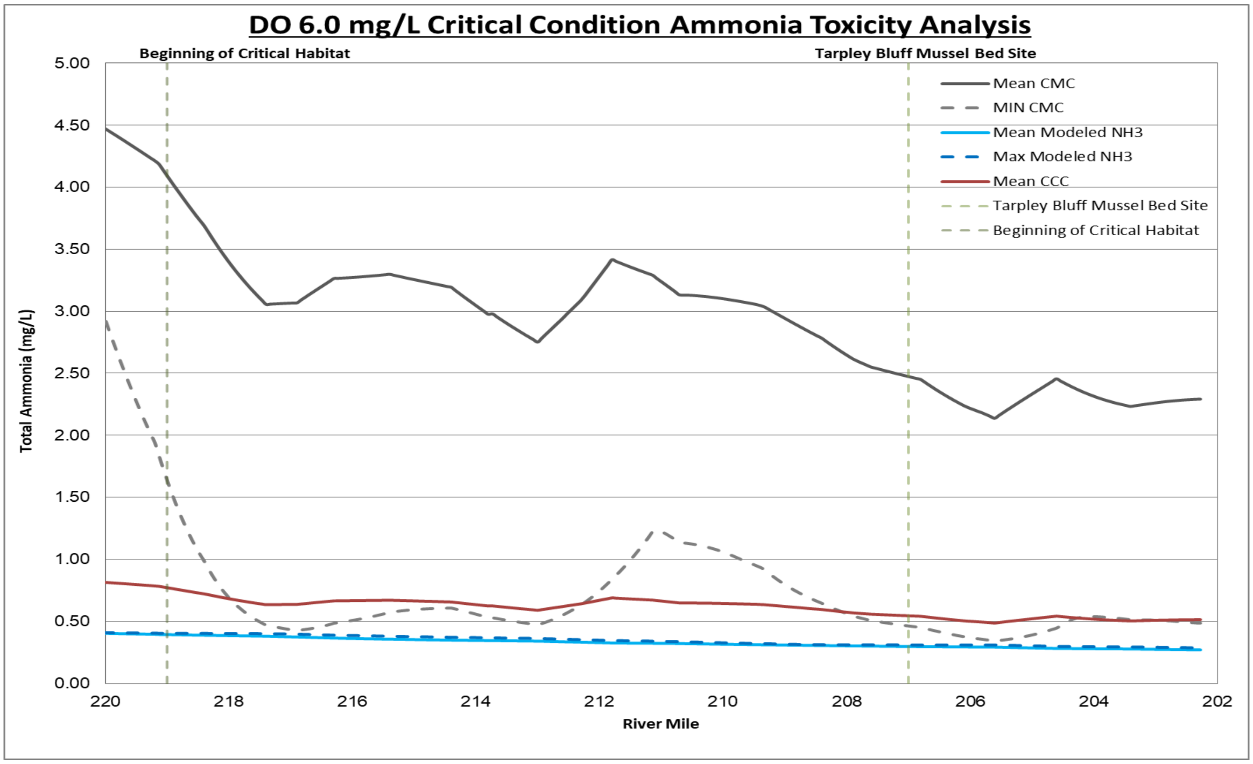


Figure 70. QUAL2k Model Ammonia Toxicity Profile (Alternative B) – 135 cfs/Boundary DO = 6.0 mg/L.

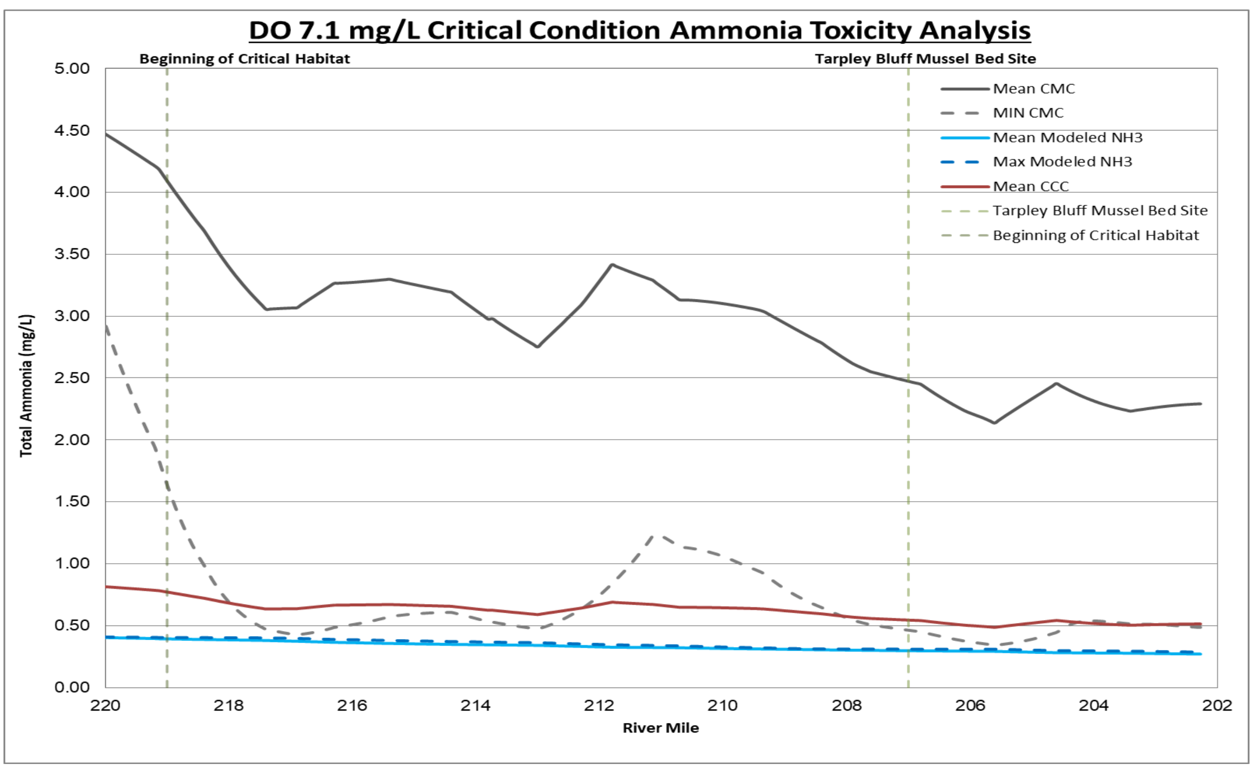


Figure 71. QUAL2k Model Ammonia Toxicity Profile (Alternative B) – 135 cfs/Boundary DO = 7.1 mg/L.

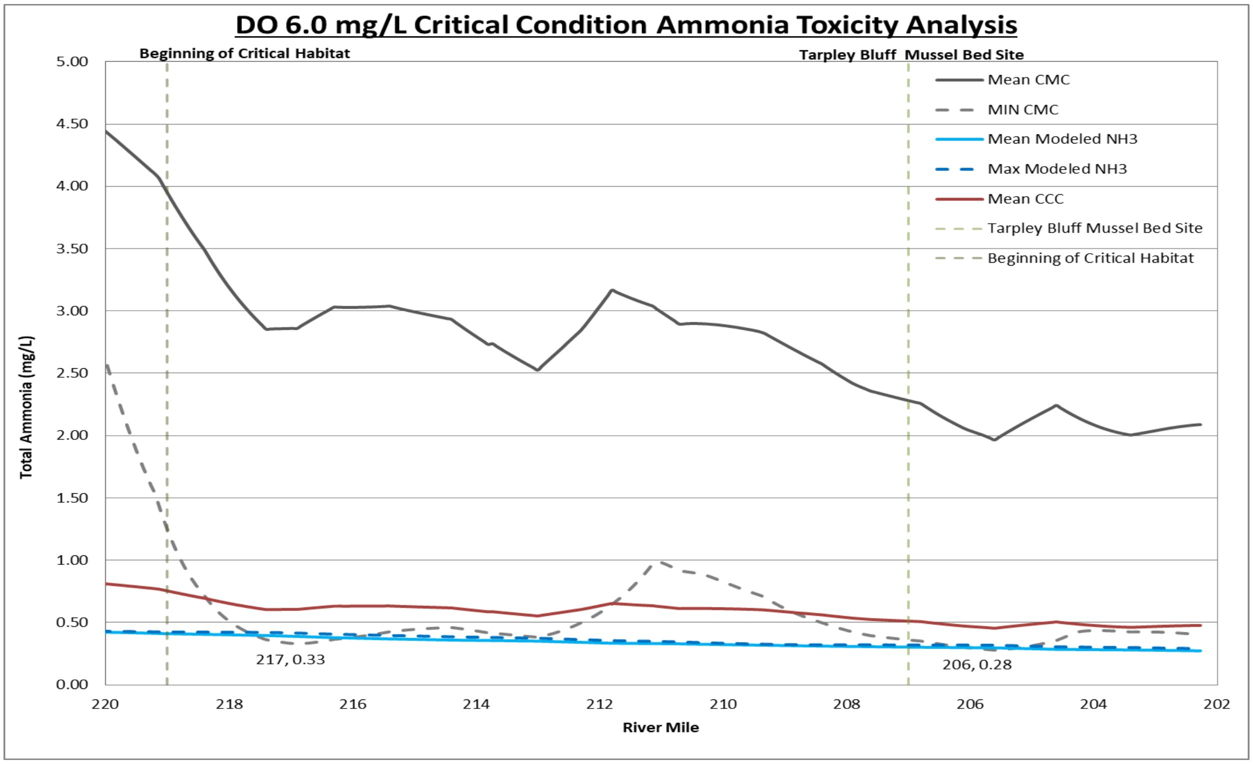


Figure 72. QUAL2k Model Ammonia Toxicity Profile (Stage 3) – 120 cfs/Boundary DO = 6.0 mg/L.

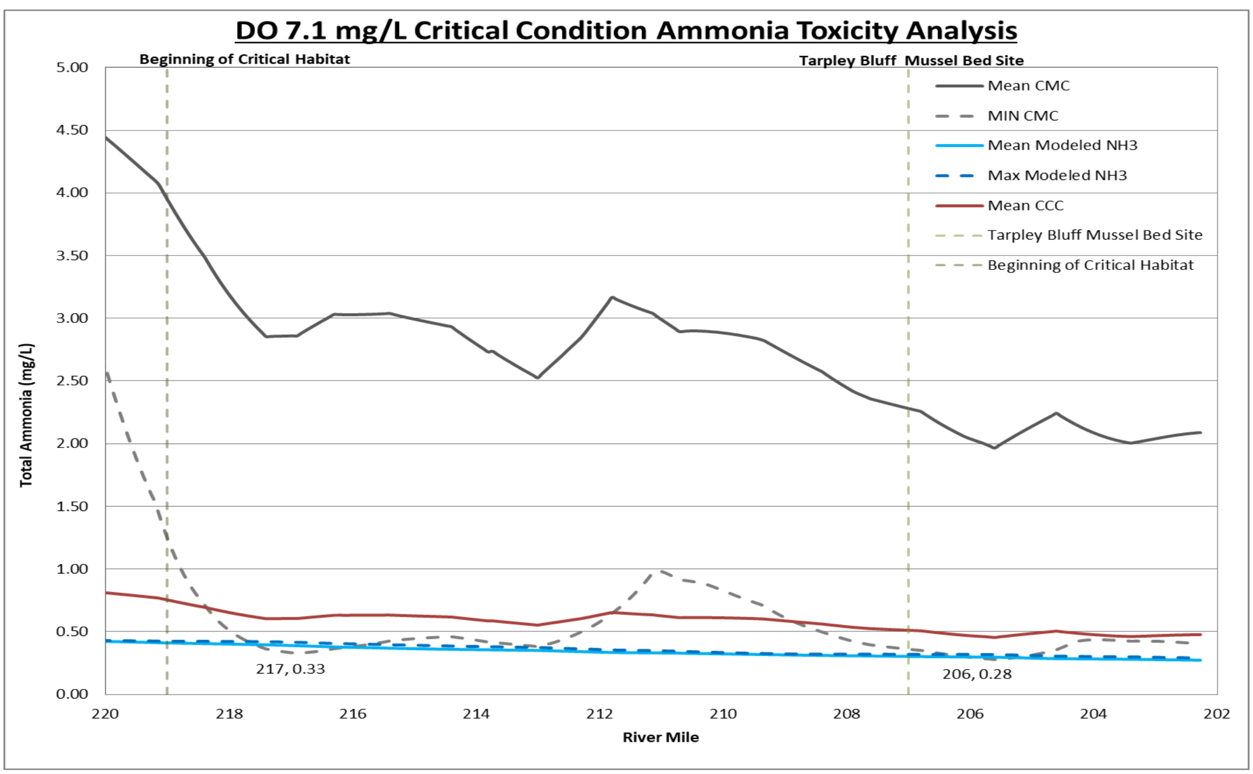


Figure 73. QUAL2k Model Ammonia Toxicity Profile (Stage 3) – 120 cfs/Boundary DO = 7.1 mg/L.

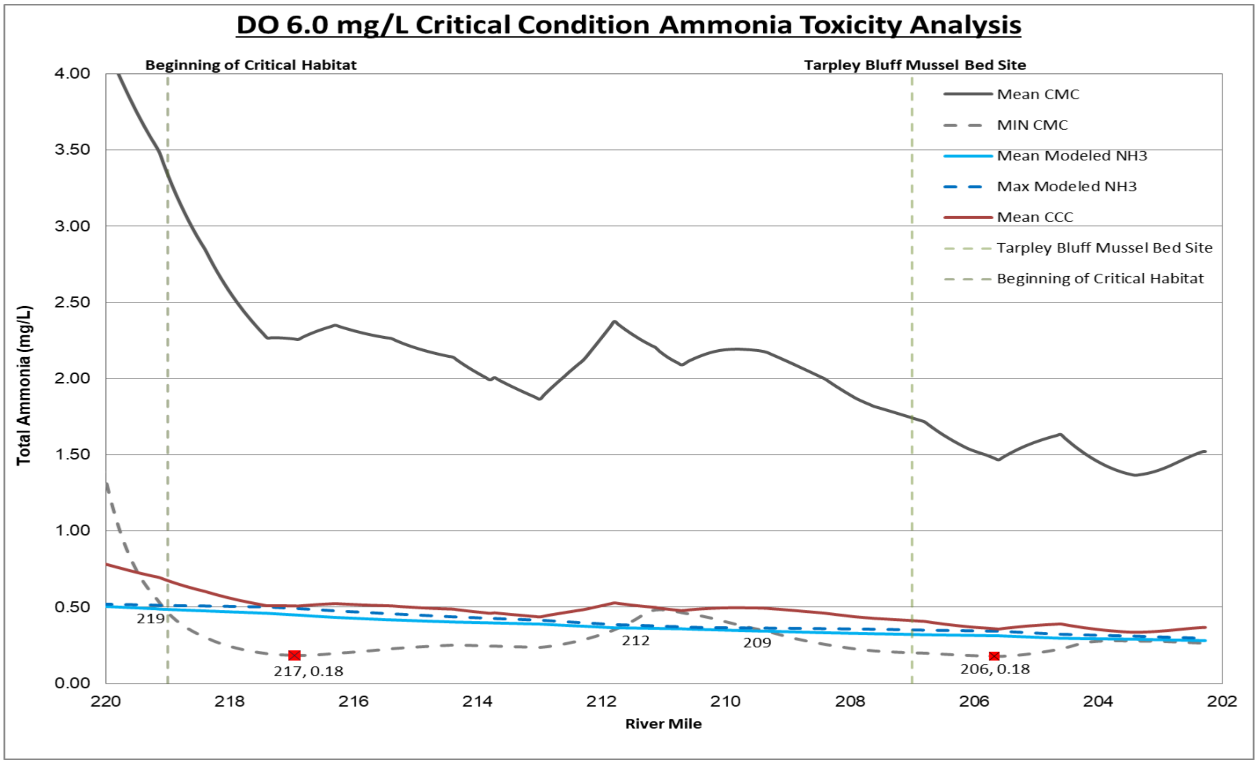


Figure 74. QUAL2k Model Ammonia Toxicity Profile (Stage 4) – 80 cfs/Boundary DO = 6.0 mg/L.

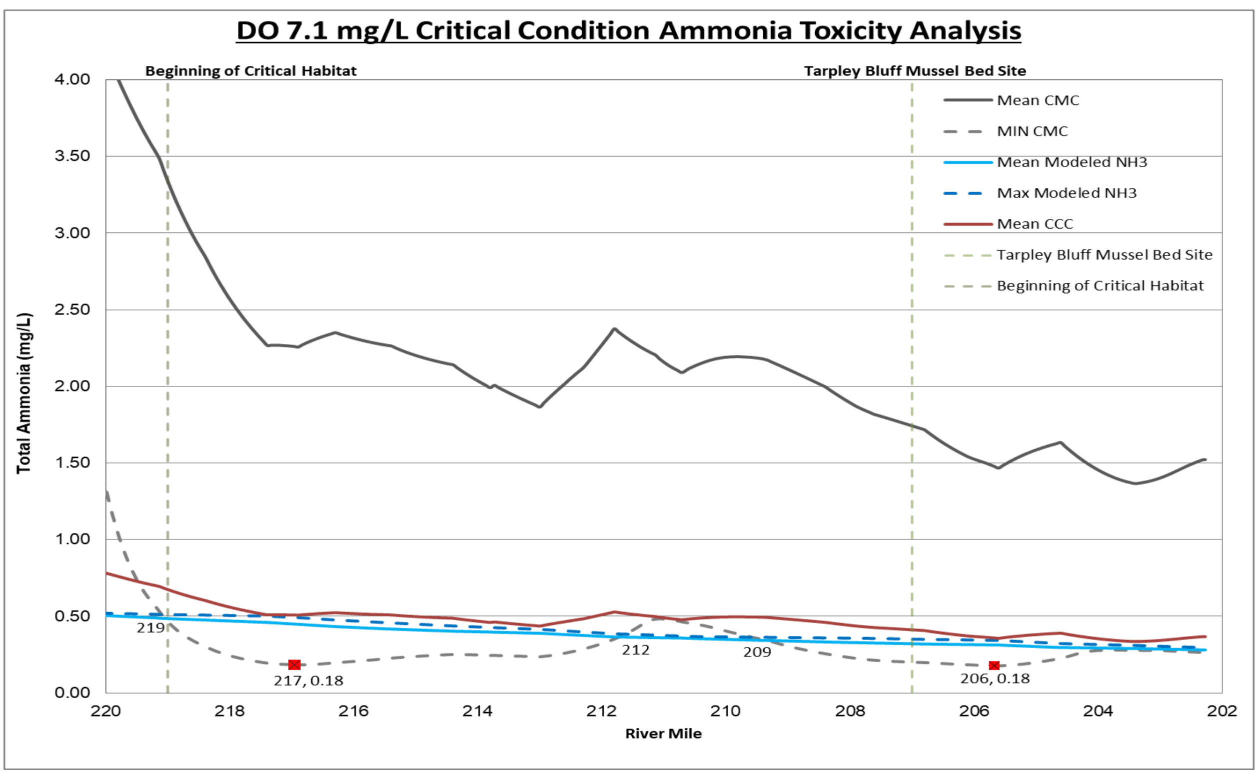


Figure 75. QUAL2k Model Ammonia Toxicity Profile (Stage 4) – 80 cfs/Boundary DO = 7.1 mg/L.

Appendix H

QUAL2k Model Longitudinal DO Profiles for Duck River below Shelbyville

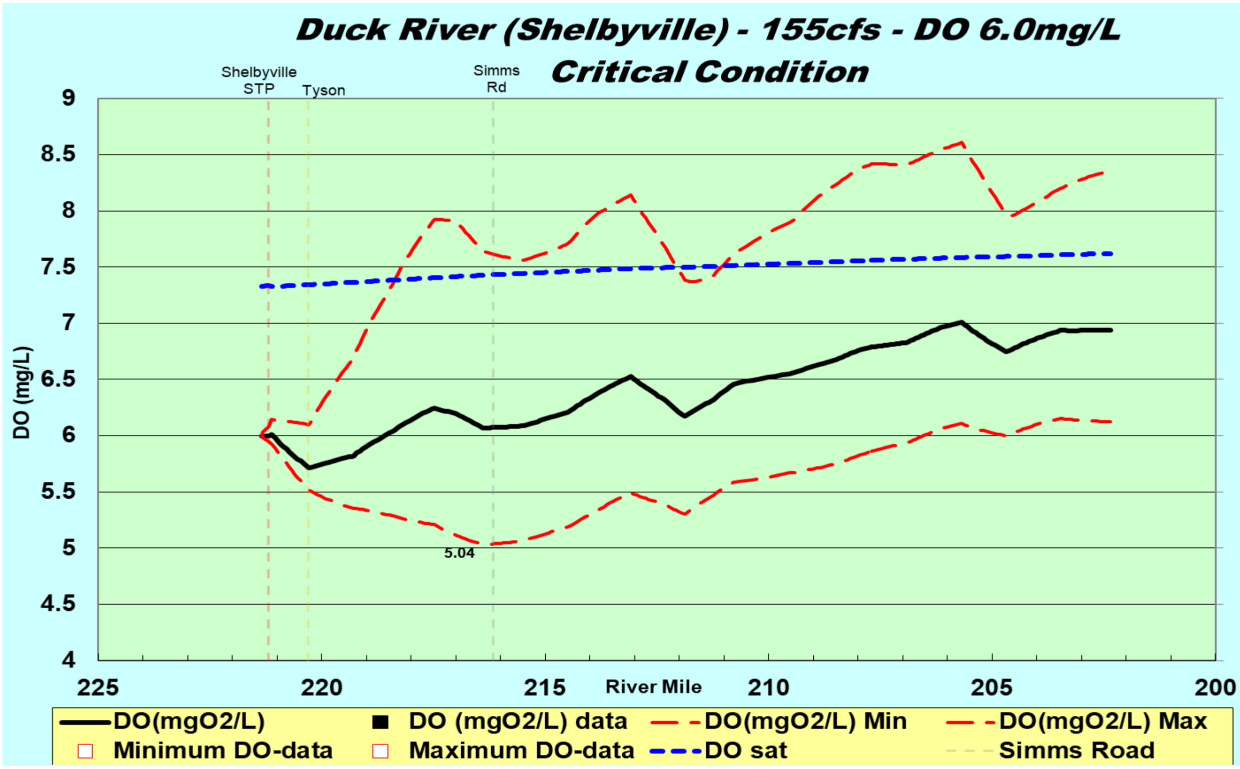


Figure 76. QUAL2k Assimilative Capacity Model (Alternative A) – 155 cfs/Boundary DO = 6.0 mg/L.

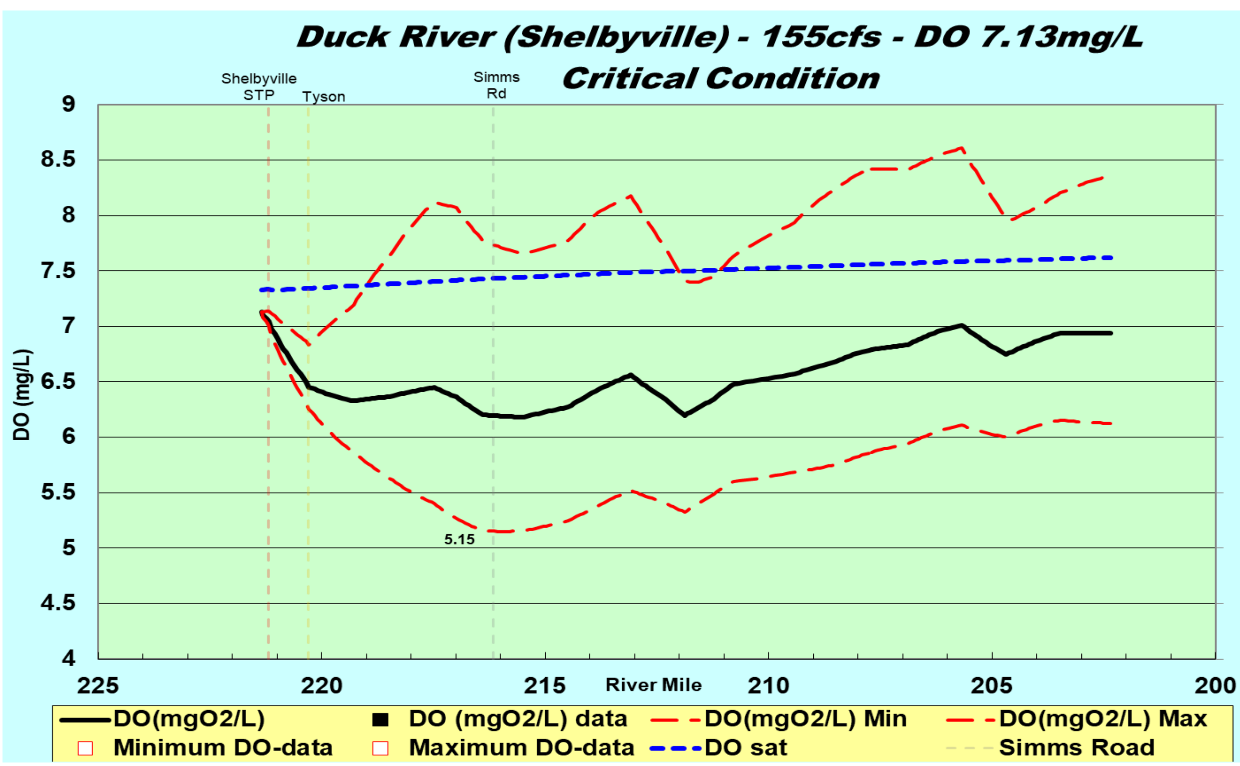


Figure 77. QUAL2k Assimilative Capacity Model (Alternative A) – 155 cfs/Boundary DO = 7.1 mg/L.

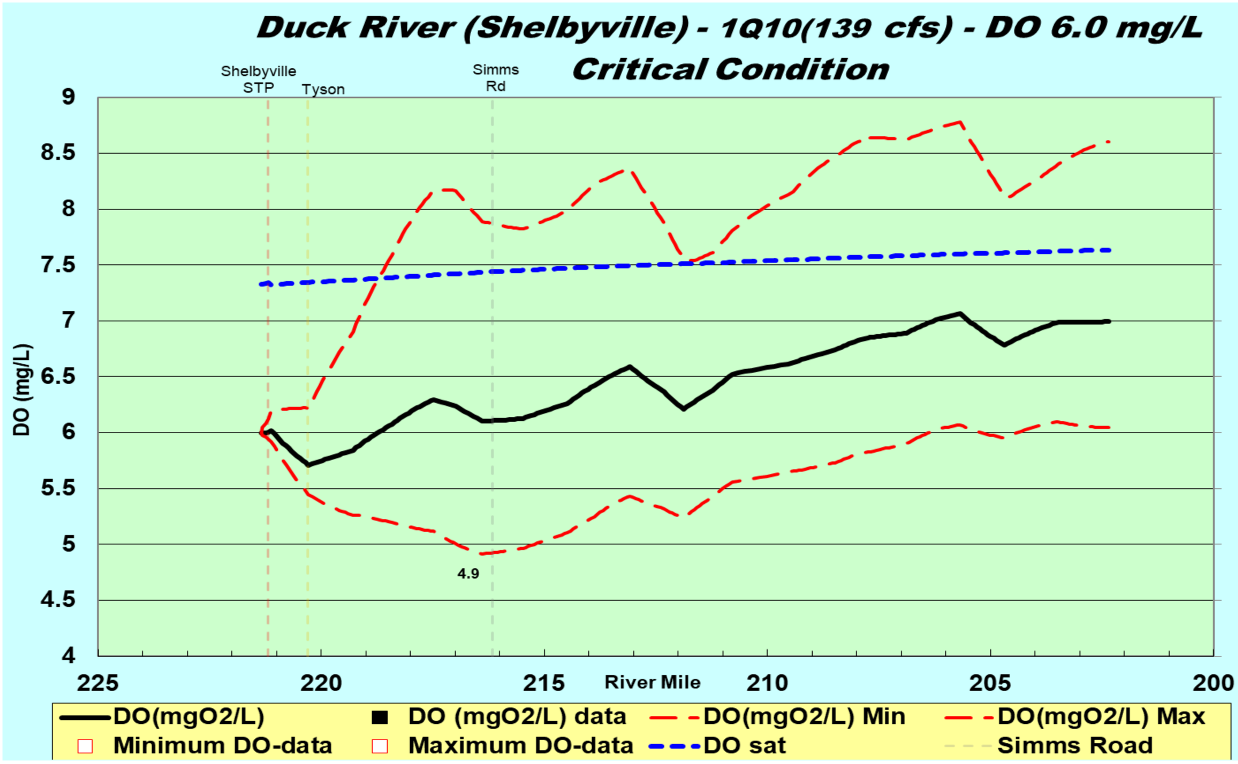


Figure 78. QUAL2k Assimilative Capacity Model ($1Q_{10}$) – 139 cfs/Boundary DO = 6.0 mg/L.

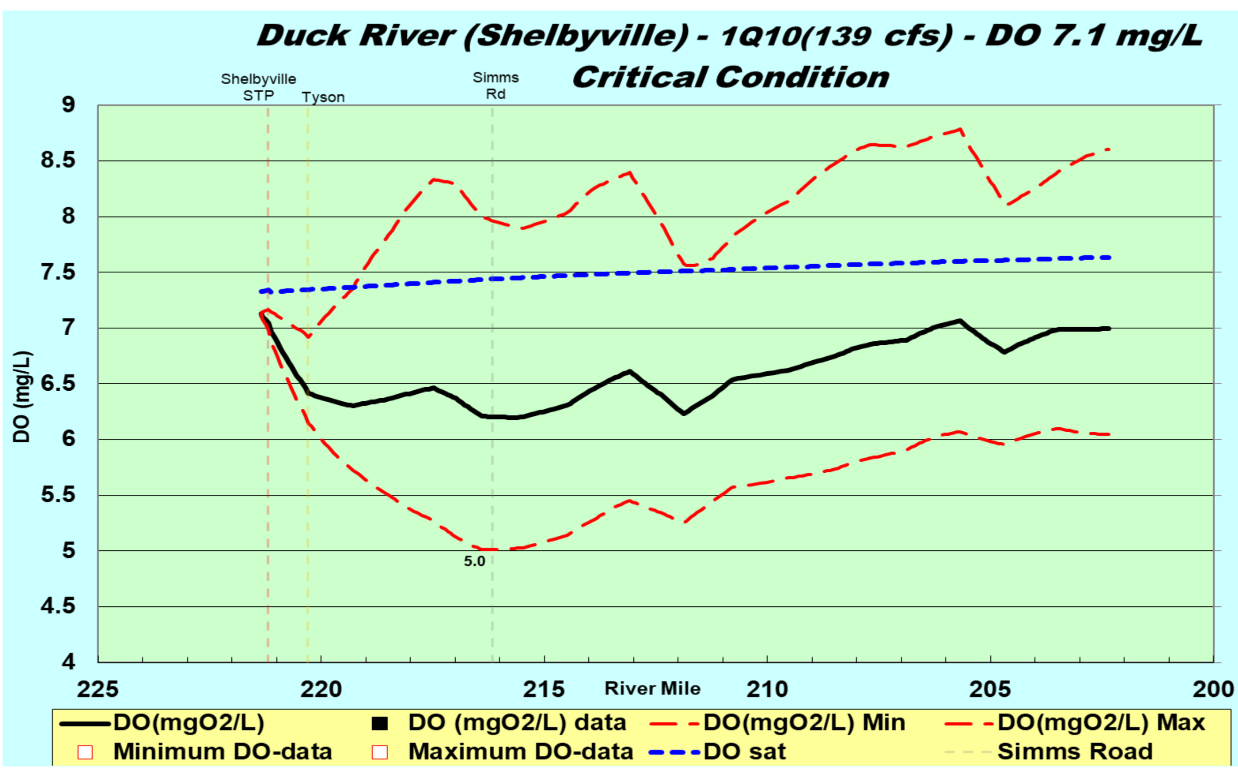


Figure 79. QUAL2k Assimilative Capacity Model ($1Q_{10}$) – 139 cfs/Boundary DO = 7.1 mg/L.

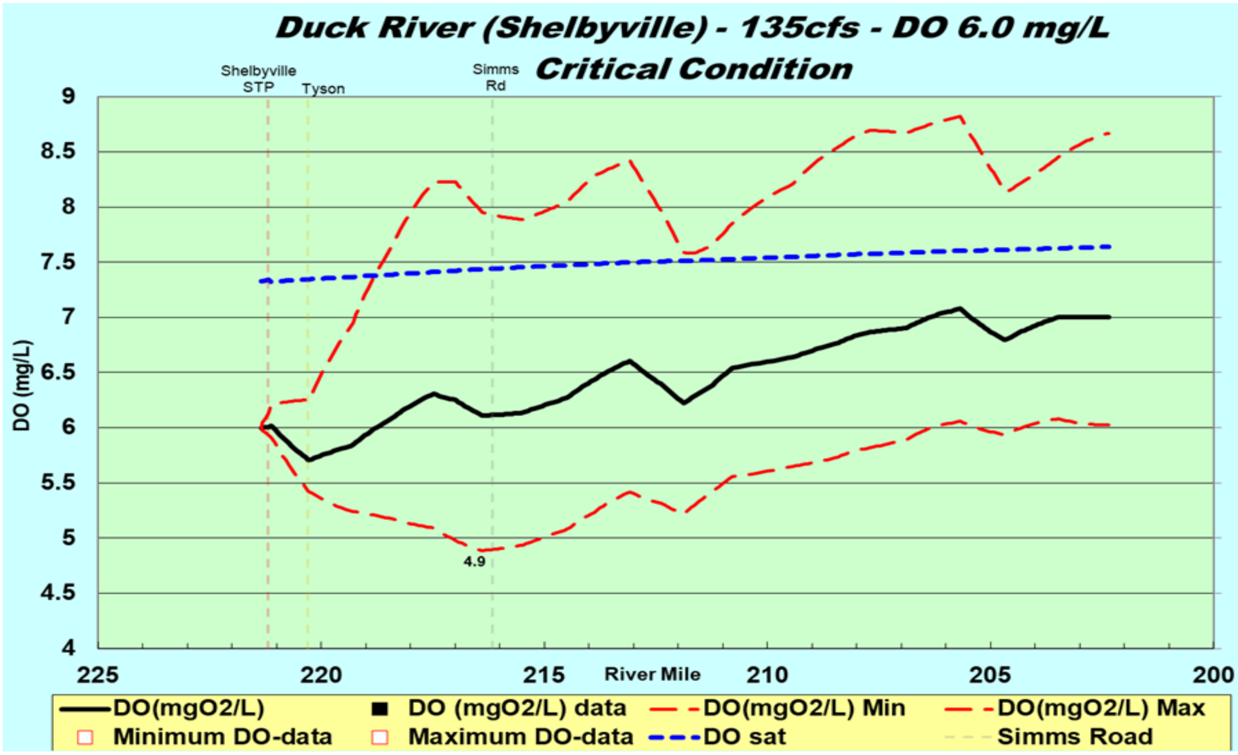


Figure 80. QUAL2k Assimilative Capacity Model (Alternative B) – 135 cfs/Boundary DO = 6.0 mg/L.

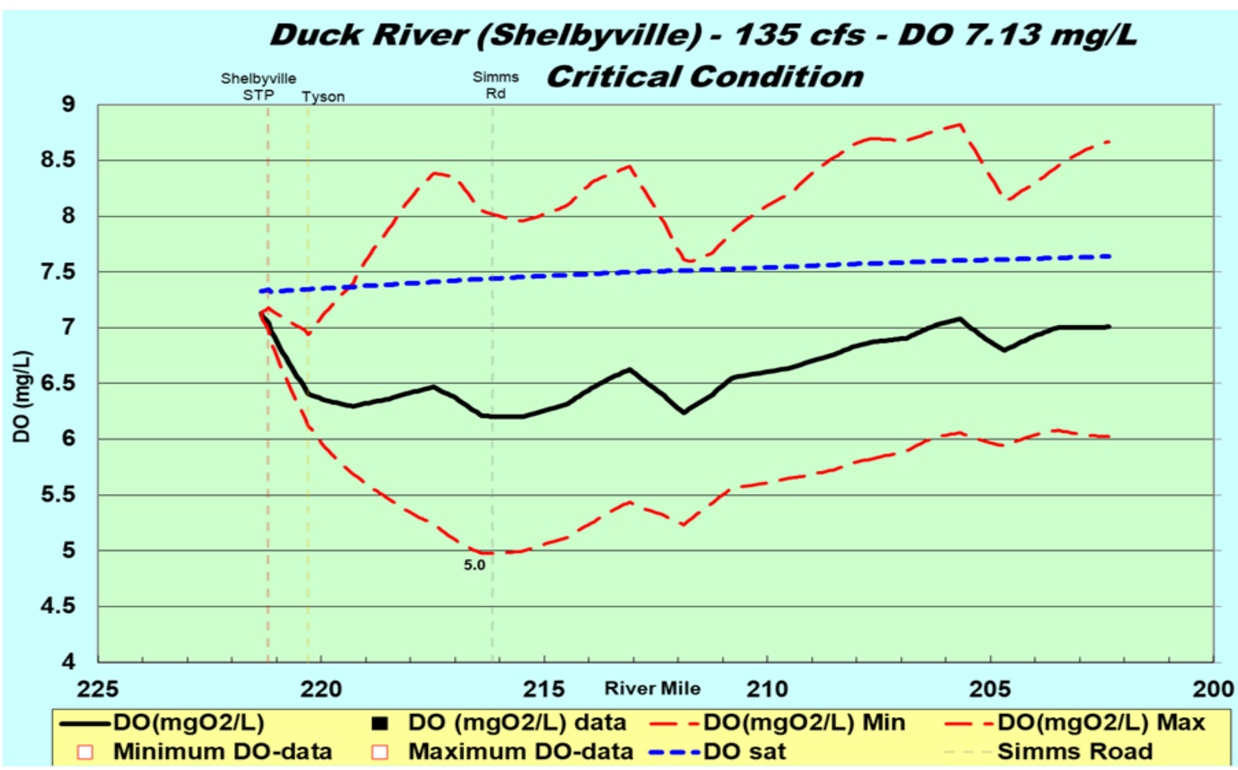


Figure 81. QUAL2k Assimilative Capacity Model (Alternative B) – 135 cfs/Boundary DO = 7.1 mg/L.

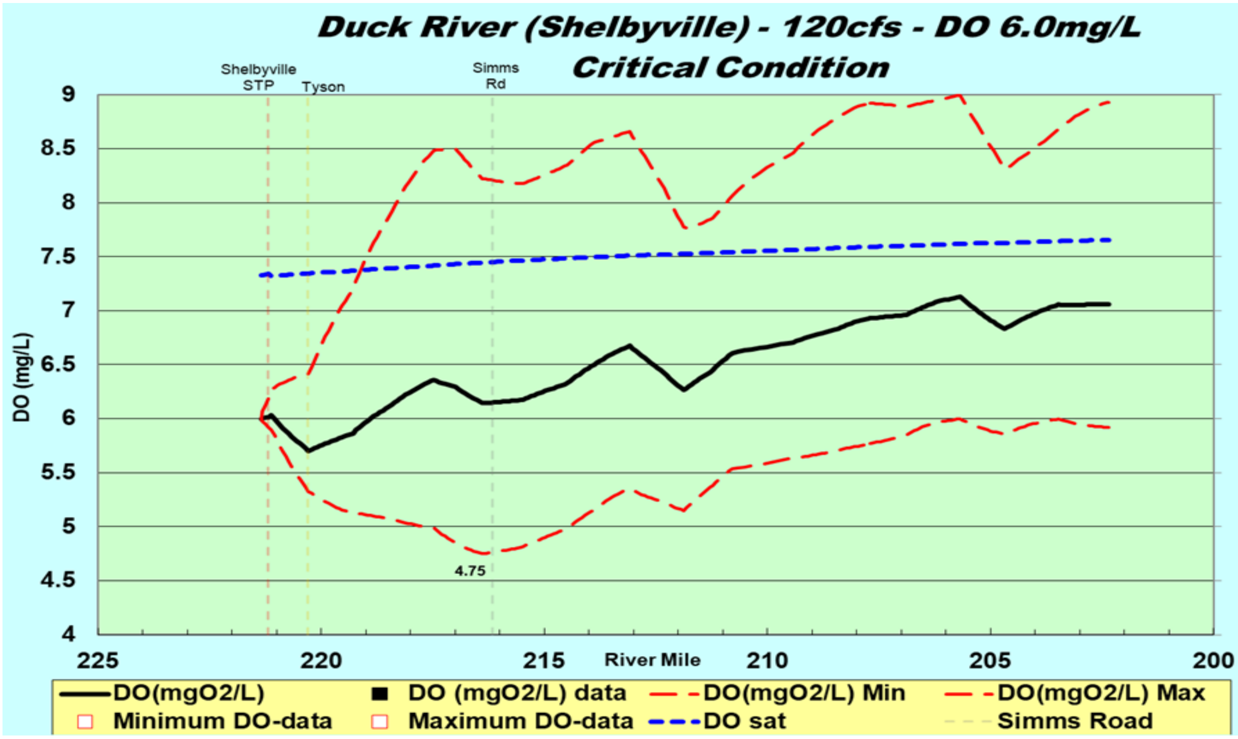


Figure 82. QUAL2k Assimilative Capacity Model (Stage 3) – 120 cfs/Boundary DO = 6.0 mg/L.

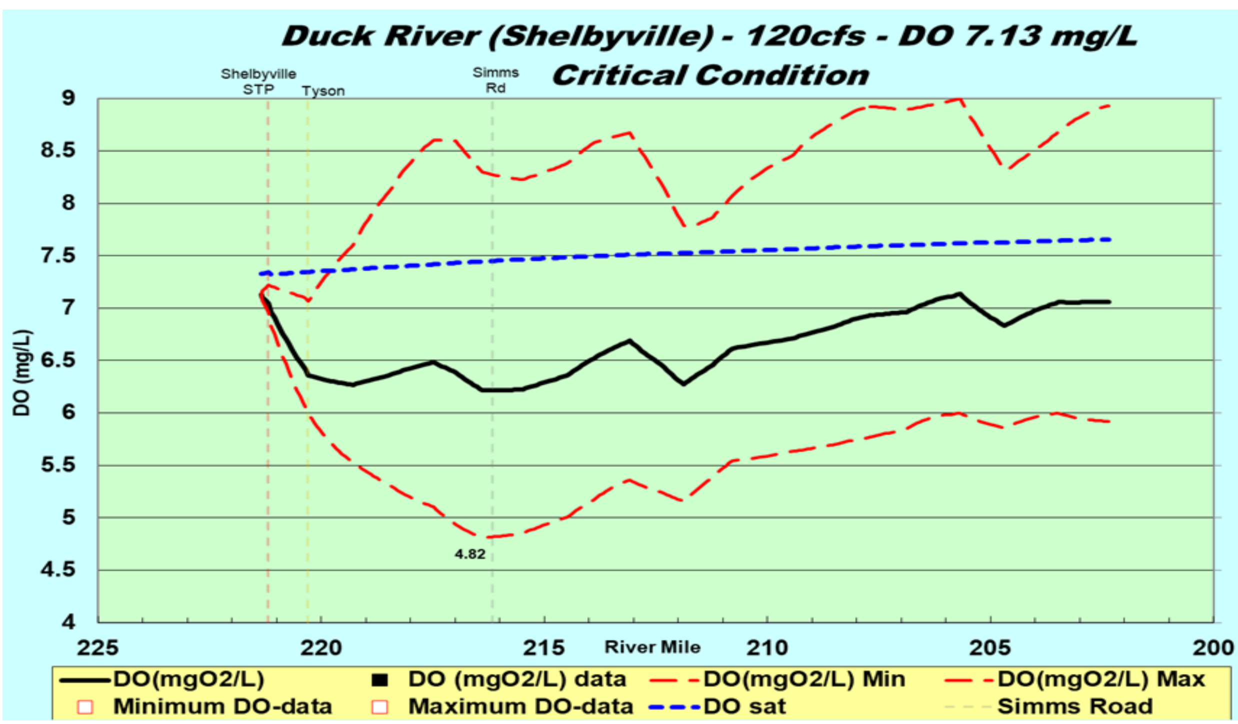


Figure 83. QUAL2k Assimilative Capacity Model (Stage 3) – 120 cfs/Boundary DO = 7.1 mg/L.

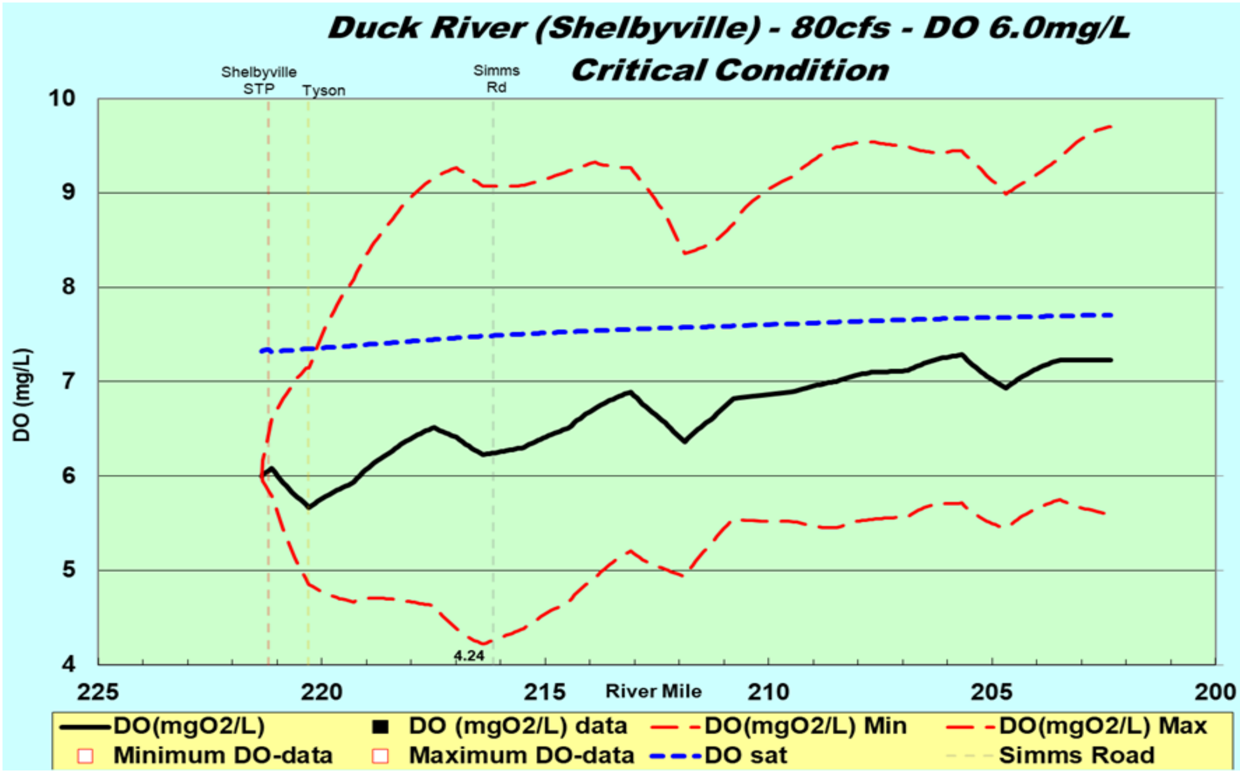


Figure 84. QUAL2k Assimilative Capacity Model (Stage 4) – 80 cfs/Boundary DO = 6.0 mg/L.

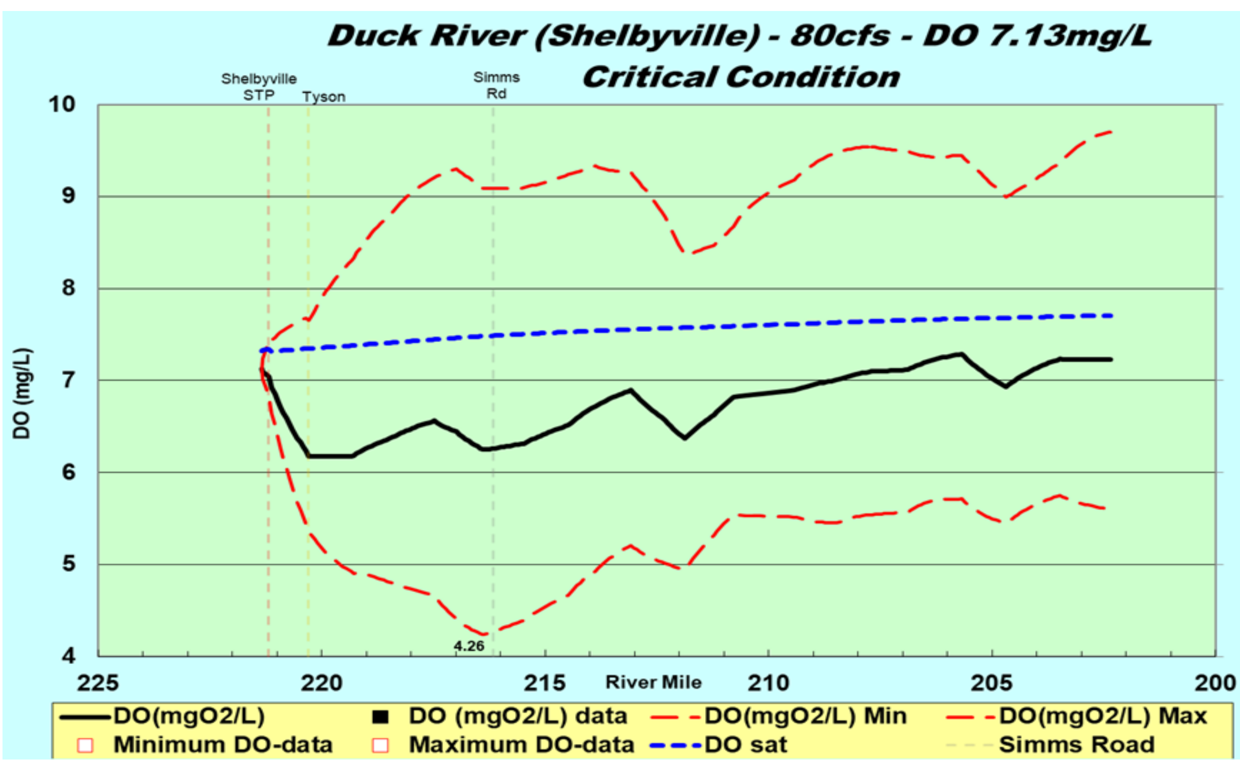


Figure 85. QUAL2k Assimilative Capacity Model (Stage 4) – 80 cfs/Boundary DO = 7.1 mg/L.

APPENDIX D – WETTED PERIMETER FIGURES

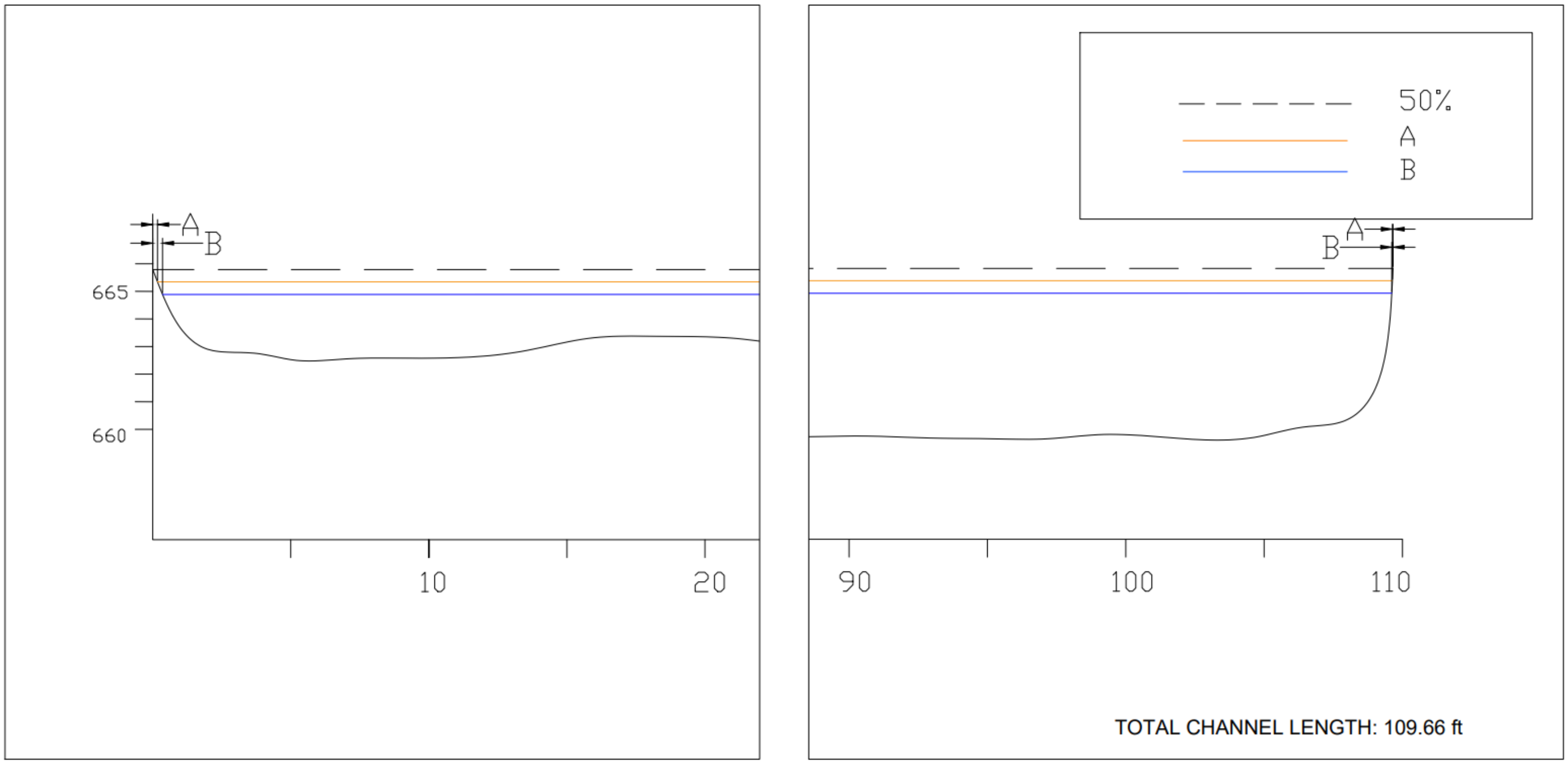


Figure D-1. Bank view of the lowest wetted perimeter predicted by the OASIS model at Tarpley Bluff with recent water demands during the summer period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

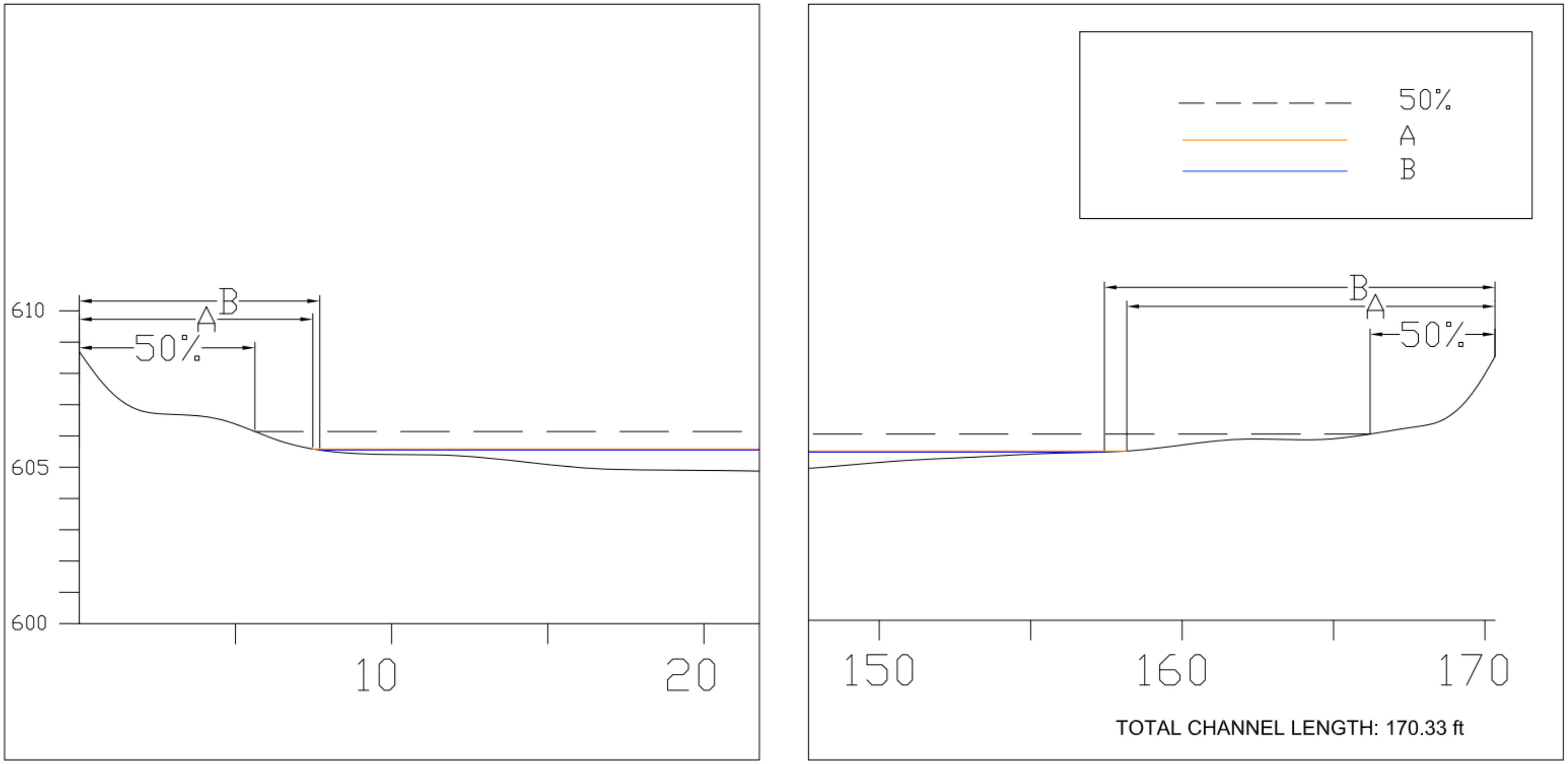


Figure D-2. Bank view of the lowest wetted perimeter predicted by the OASIS model at Lillard Mill with recent water demands during the summer period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line. Note that both the A and B lines are depicted, but they are so close that they are hard to distinguish on the graph.

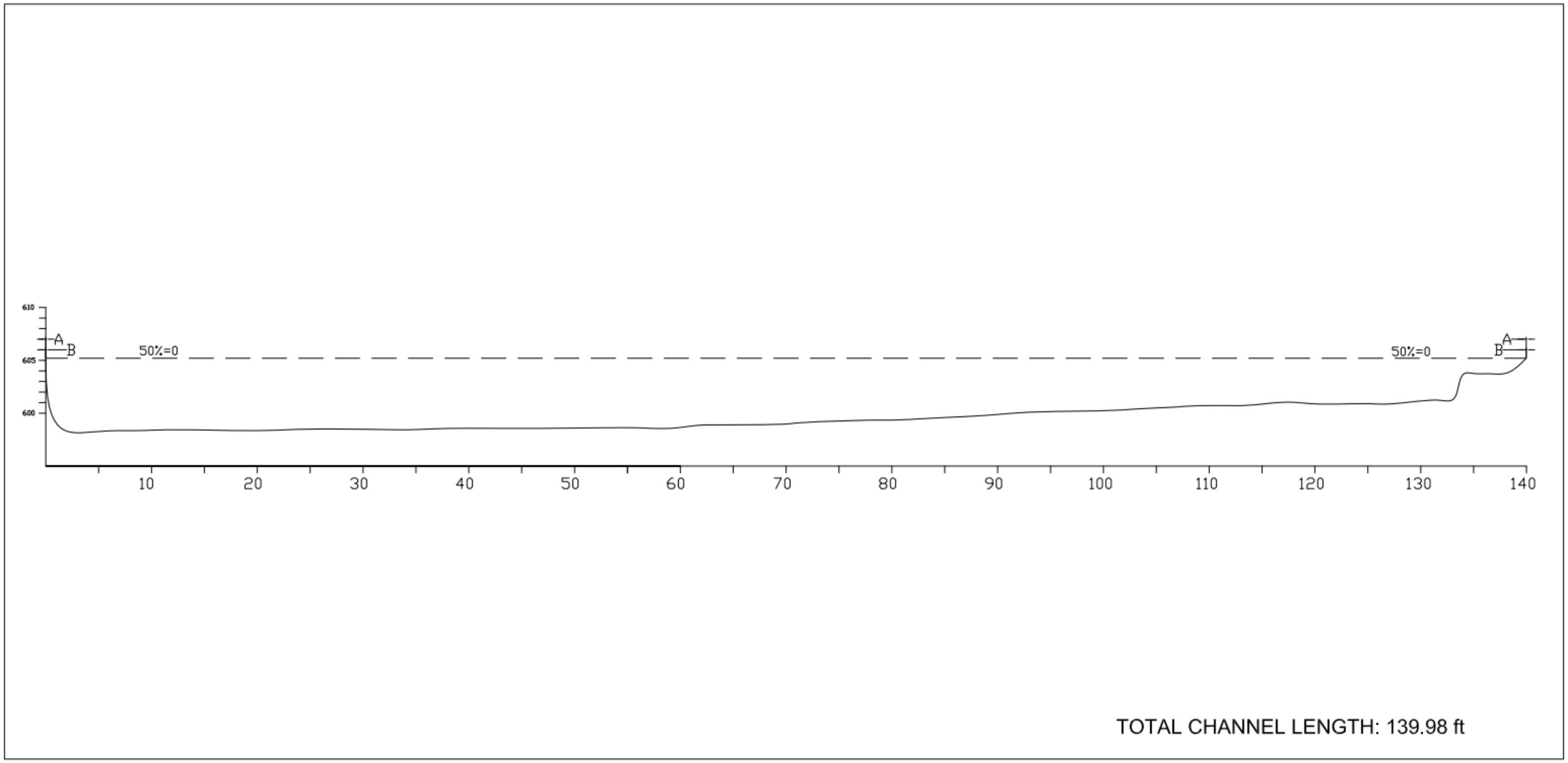


Figure D-3. Bank view of the lowest wetted perimeter predicted by the OASIS model at Venable Spring with recent water demands during the summer period for Alternatives A and B. Note that the wetted perimeters for both alternatives exceed the maximum perimeter of the channel. The 50th percentile wetted perimeter value is depicted by the hashed line.

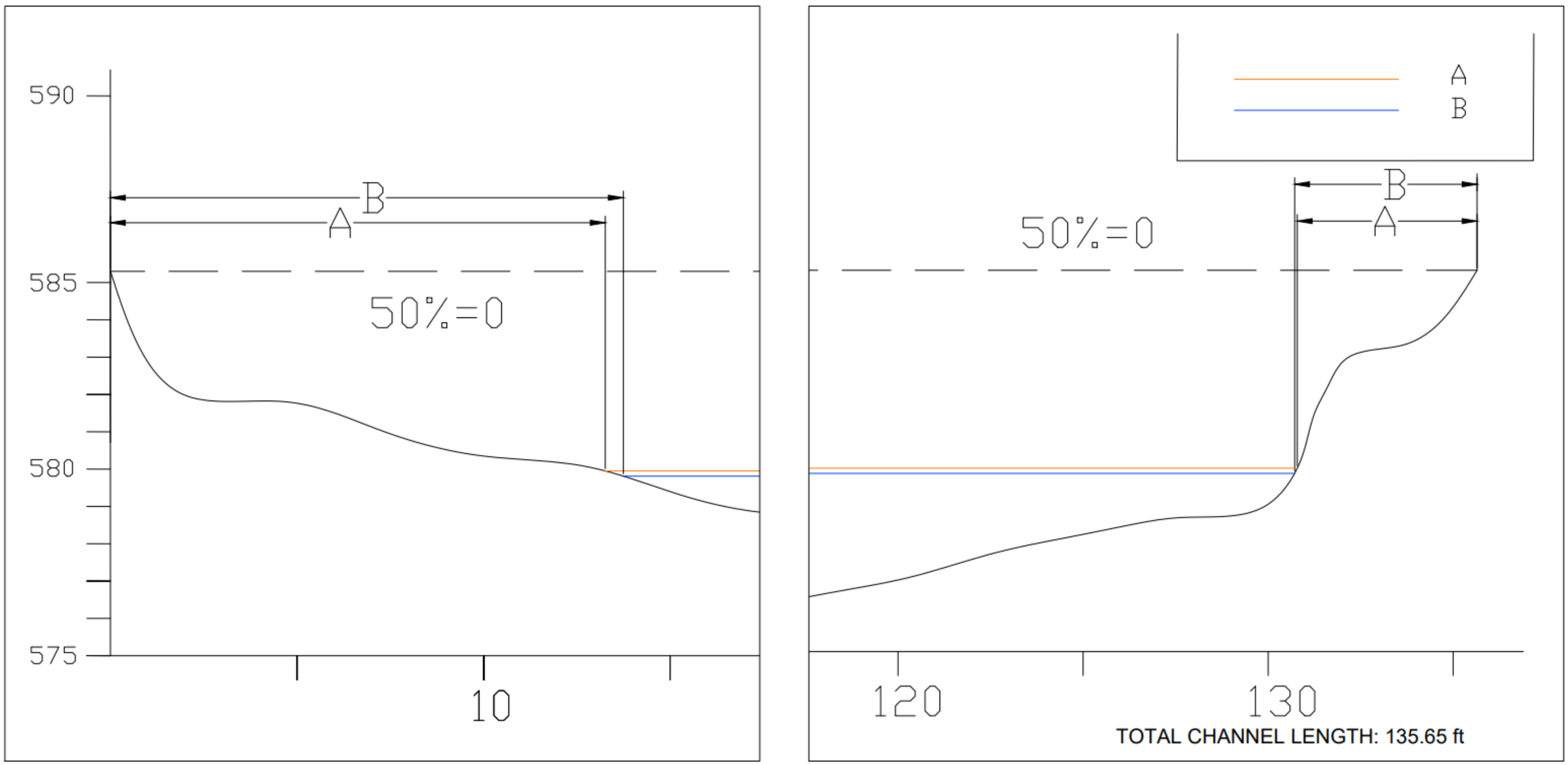


Figure D-4. Bank view of the lowest wetted perimeter predicted by the OASIS model at Hooper Island with recent water demands during the summer period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

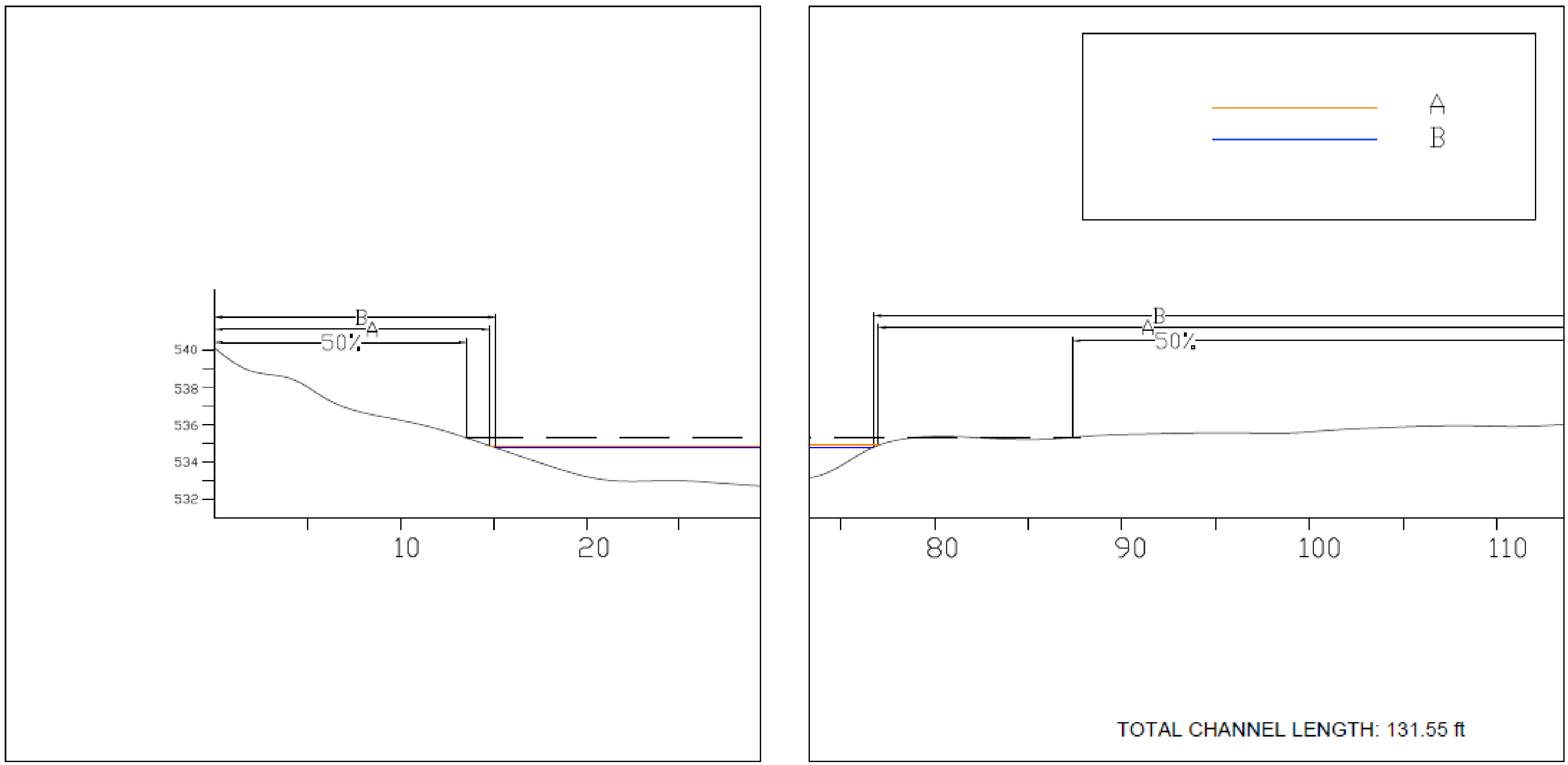


Figure D-5. Bank view of the lowest wetted perimeter predicted by OASIS model at Riverside Park with recent water demands during the summer period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

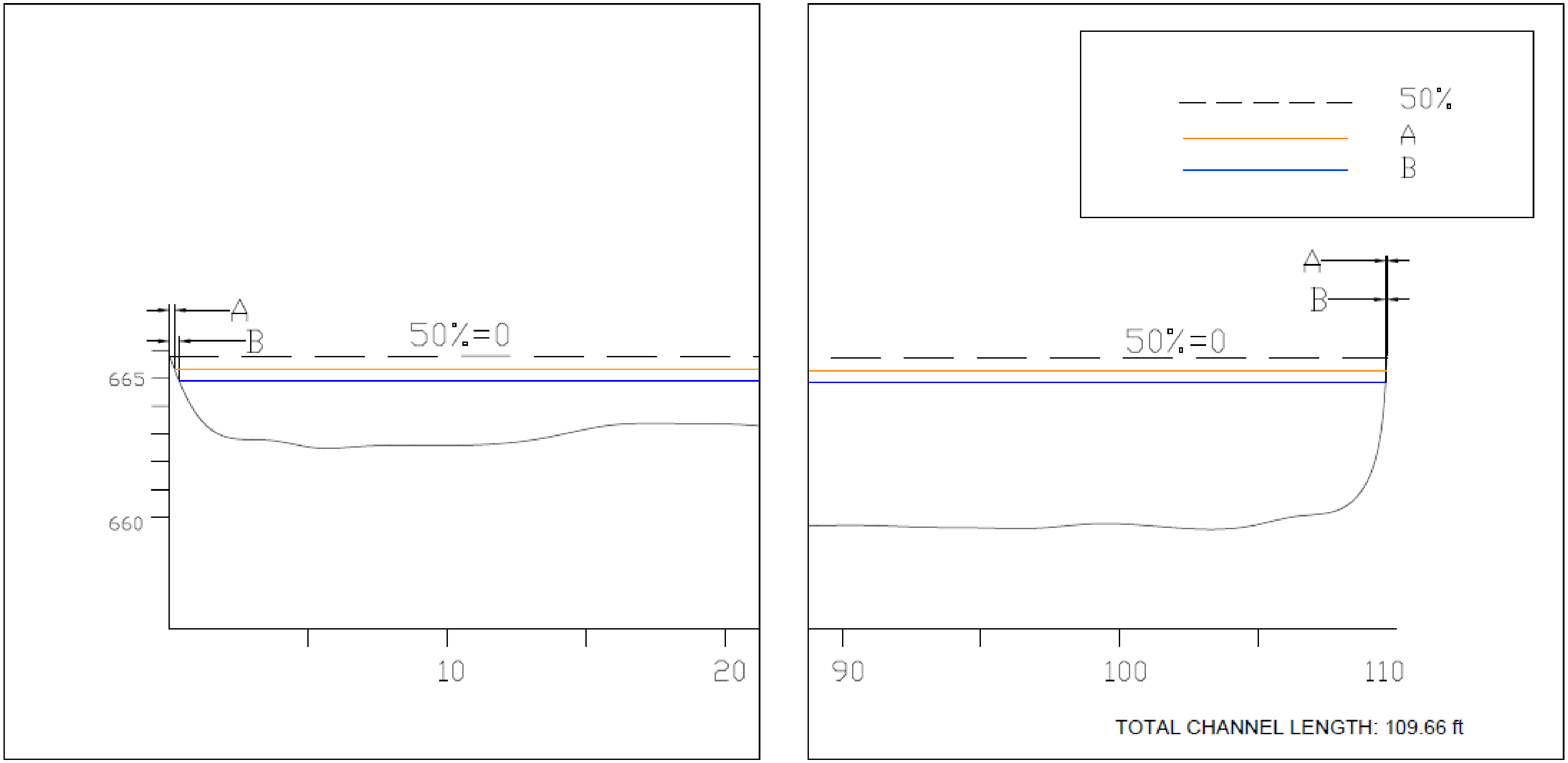


Figure D-6. Bank view of the lowest wetted perimeter predicted by OASIS model at Tarpley Bluff with recent water demands during the winter period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

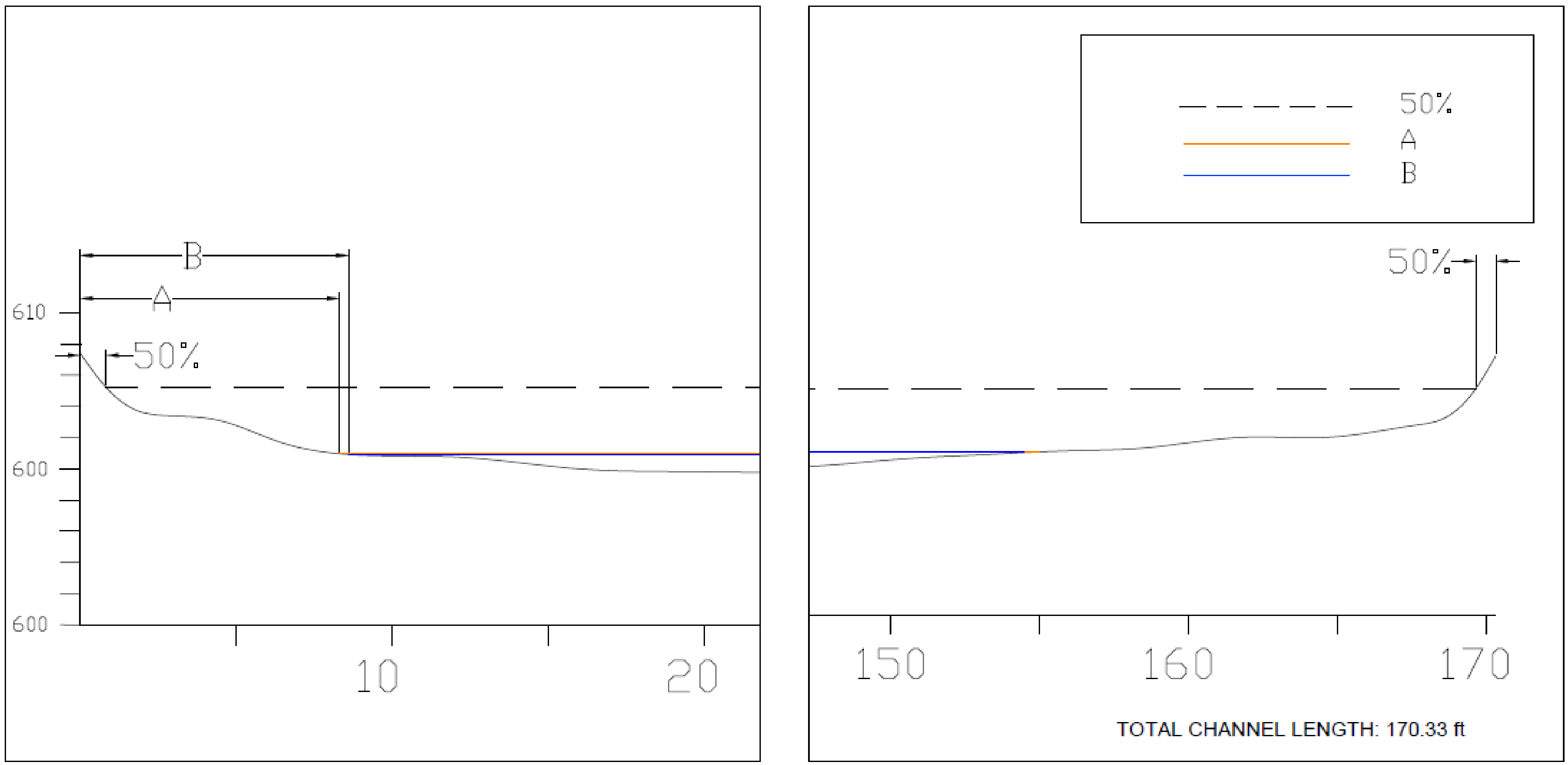


Figure D-7. Bank view of the lowest wetted perimeter predicted by OASIS model at Lillard Mill with recent water demands during the winter period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

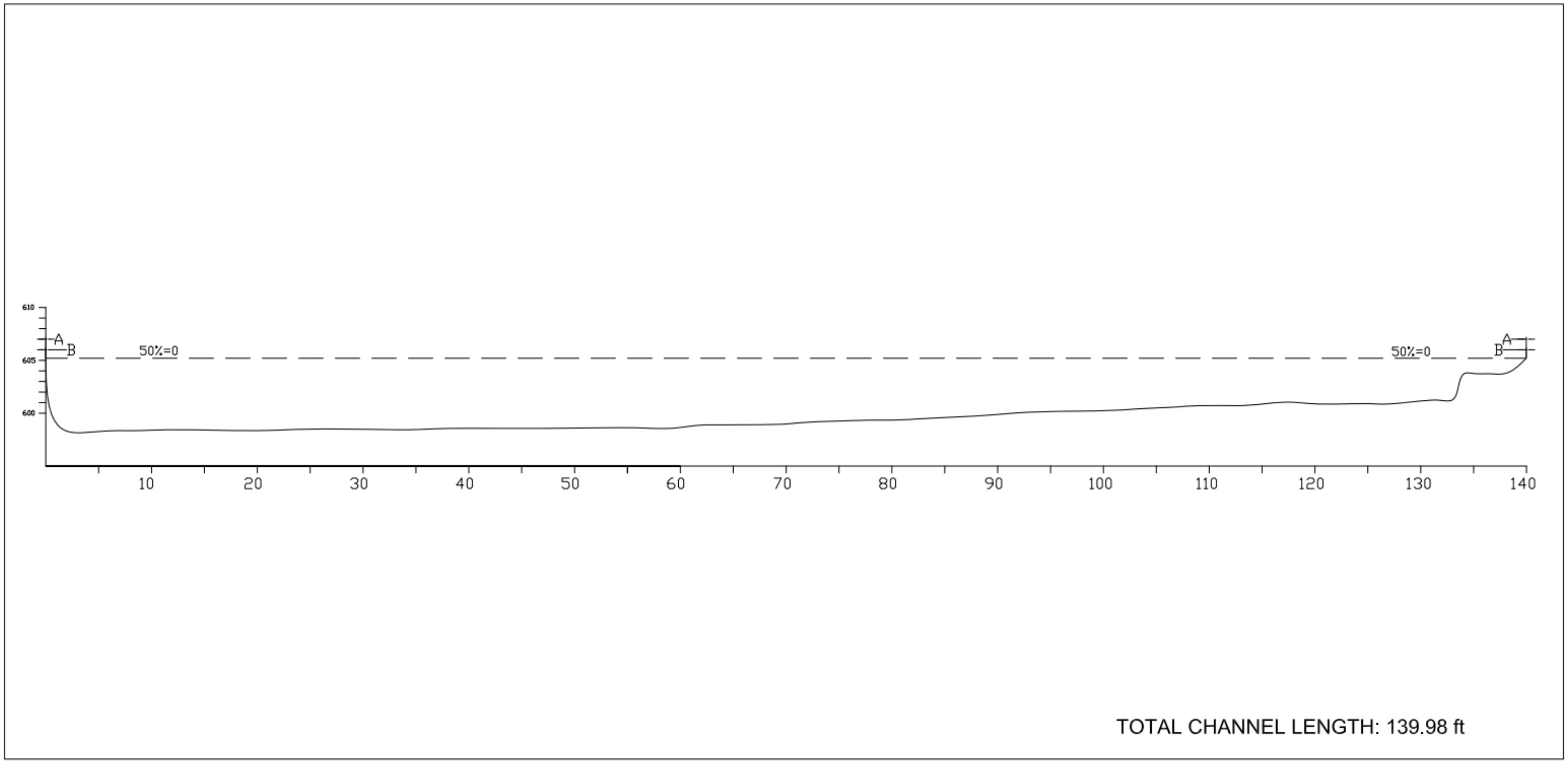


Figure D-8. Bank view of the lowest wetted perimeter predicted by the OASIS model at Venable Spring with recent water demands during the winter period for Alternatives A and B. Note that the wetted perimeters for both alternatives exceed the maximum perimeter of the channel. The 50th percentile wetted perimeter value is depicted by the hashed line.

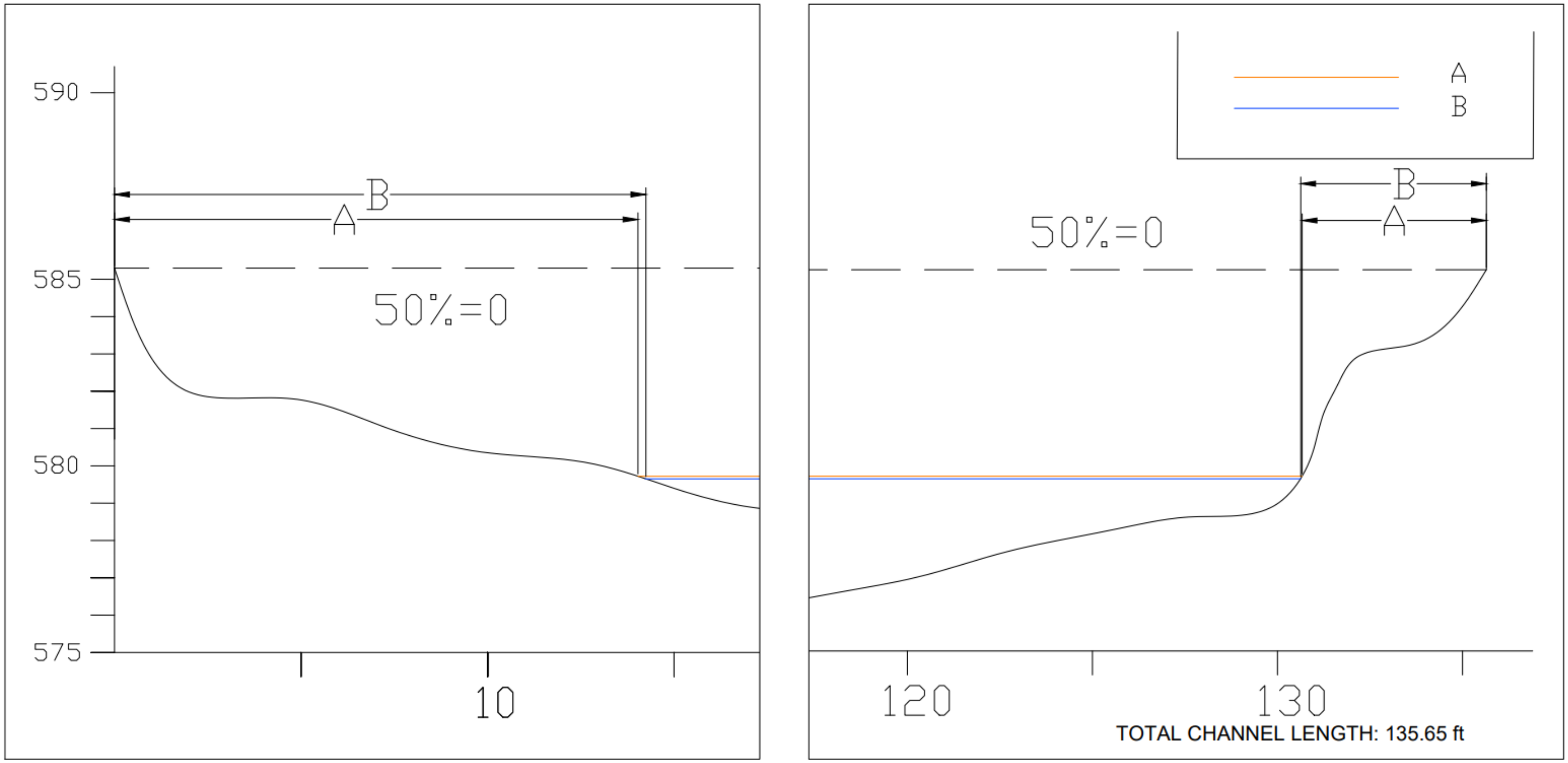


Figure D-9. Bank view of the lowest wetted perimeter predicted by the OASIS model at Hooper Island with recent water demands during the winter period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

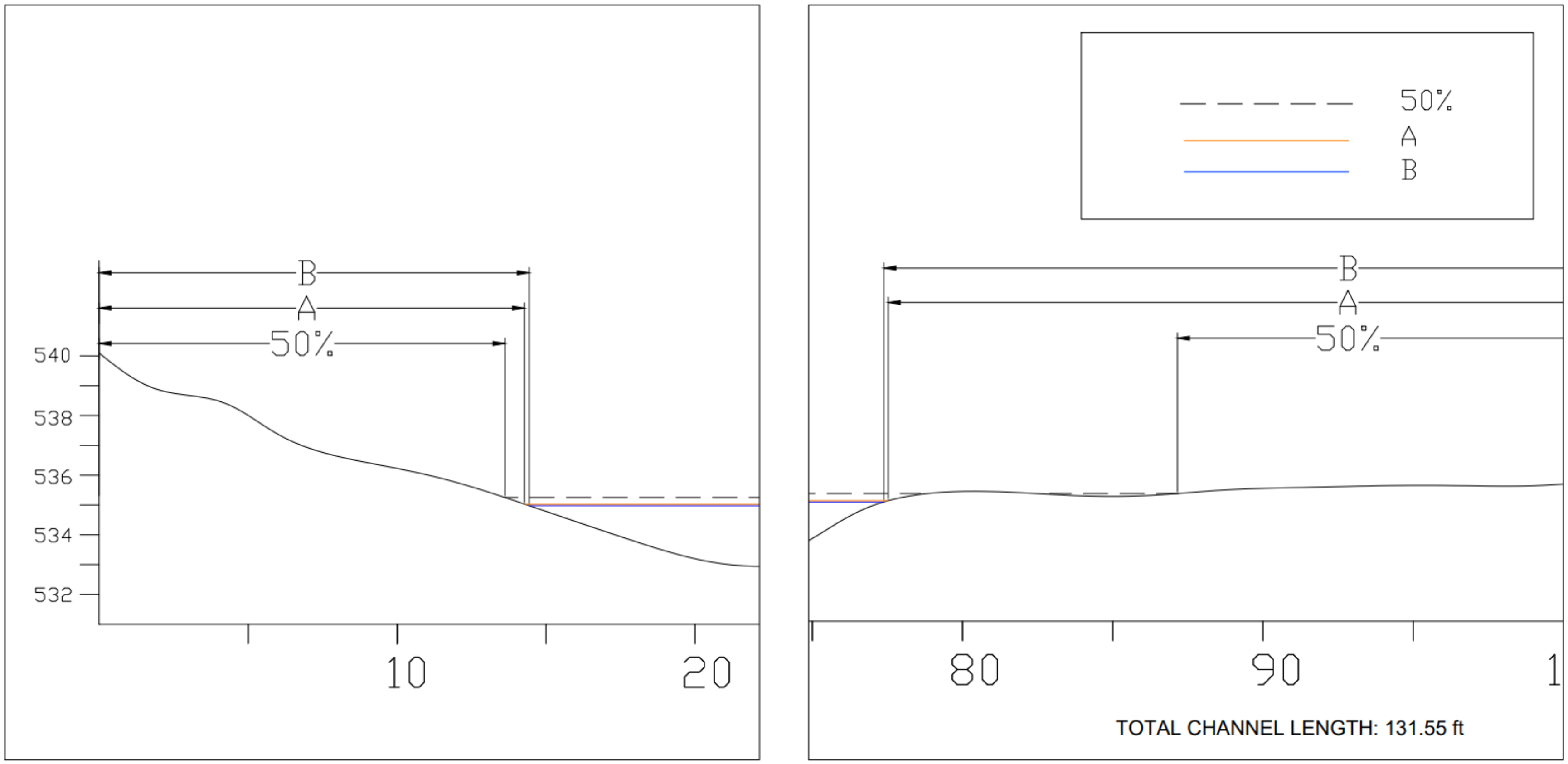


Figure D-10. Bank view of the lowest wetted perimeter predicted by the OASIS model at Riverside Park with recent water demands during the winter period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line. Note that both the A and B lines are depicted, but they are so close that they are hard to distinguish on the graph.

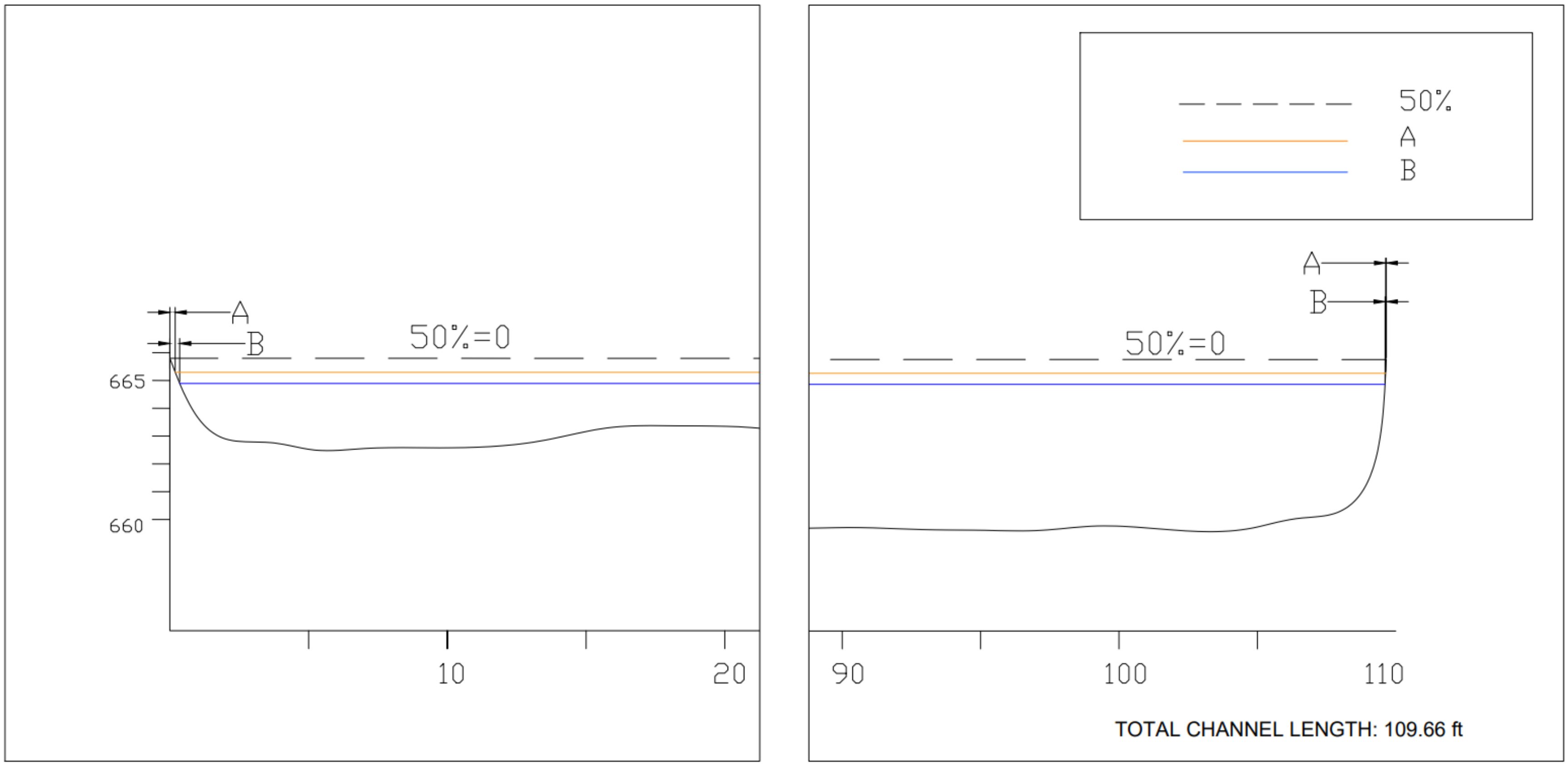


Figure D-11. Bank view of the lowest wetted perimeter predicted by the OASIS model at Tarpley Bluff with future water demands during the summer period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

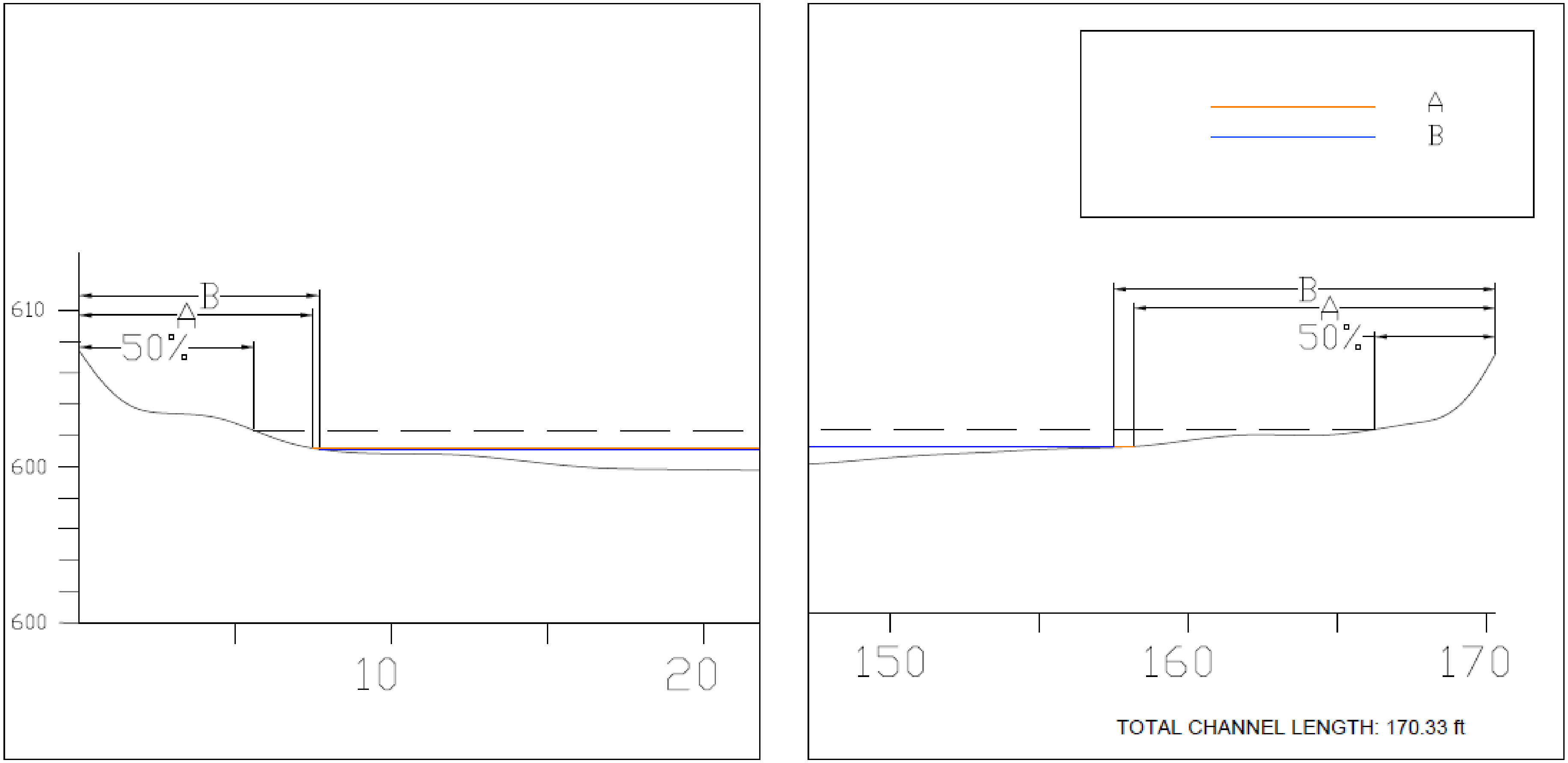


Figure D-12. Bank view of the lowest wetted perimeter predicted by OASIS model at Lillard Mill with future water demands during the summer period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

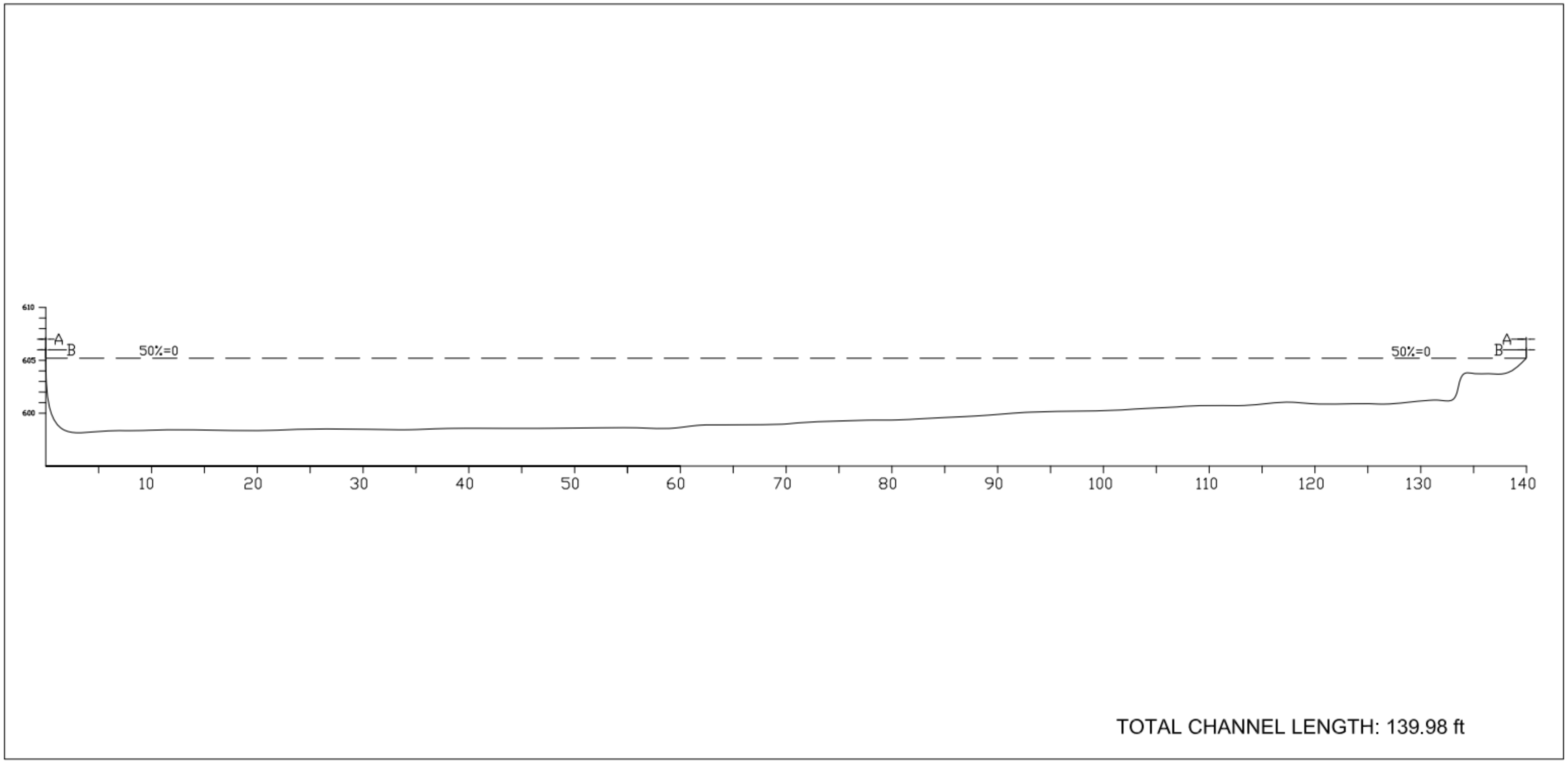


Figure D-13. Bank view of the lowest wetted perimeter predicted by the OASIS model at Venable Spring with future water demands during the summer period for Alternatives A and B. Note that the wetted perimeters for both alternatives exceed the maximum perimeter of the channel. The 50th percentile wetted perimeter value is depicted by the hashed line.

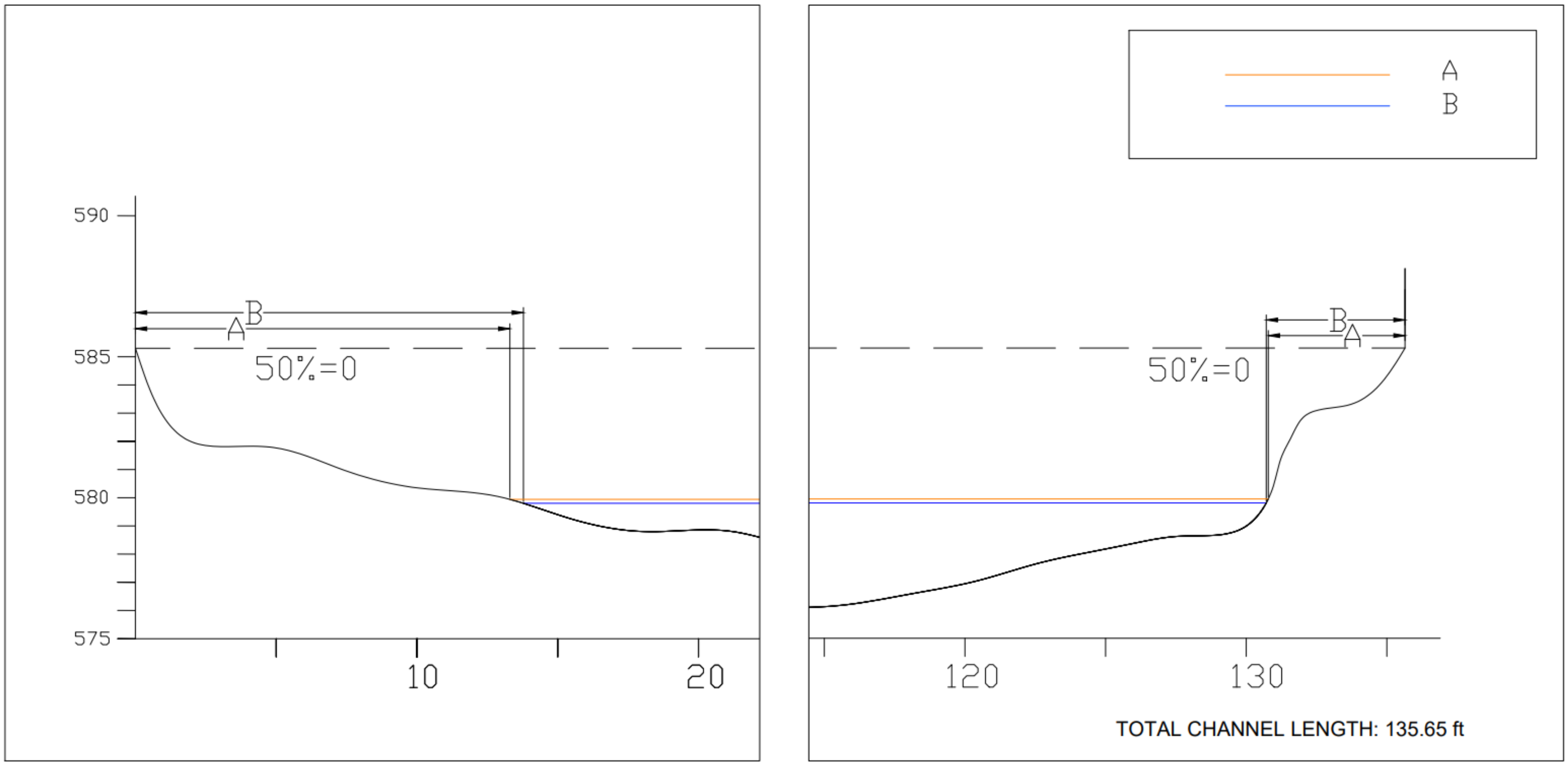


Figure D-14. Bank view of the lowest wetted perimeter predicted by the OASIS model at Hooper Island with future water demands during the summer period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

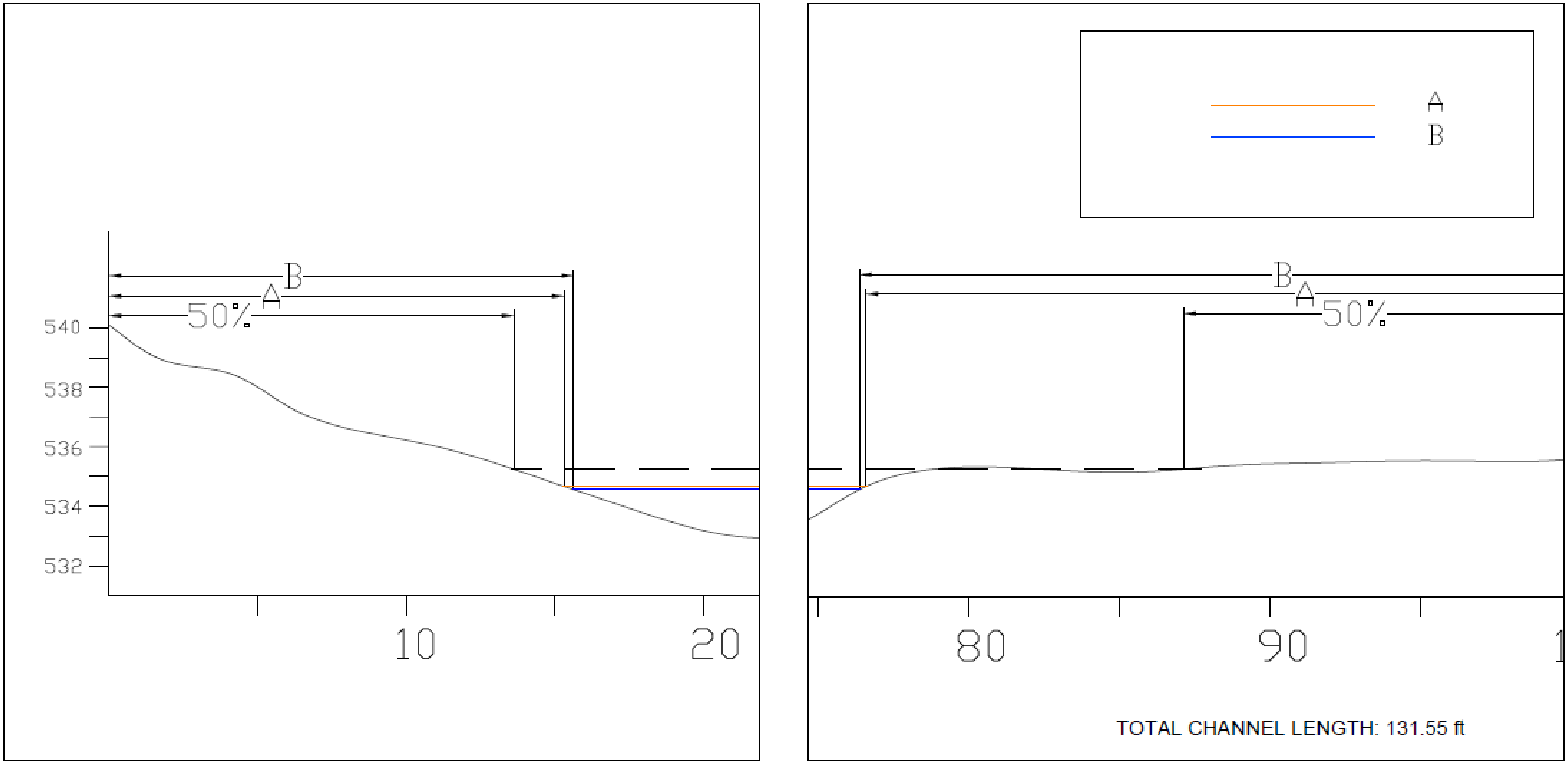


Figure D-15. Bank view of the lowest wetted perimeter predicted by OASIS model at Riverside Park with future water demands during the summer period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

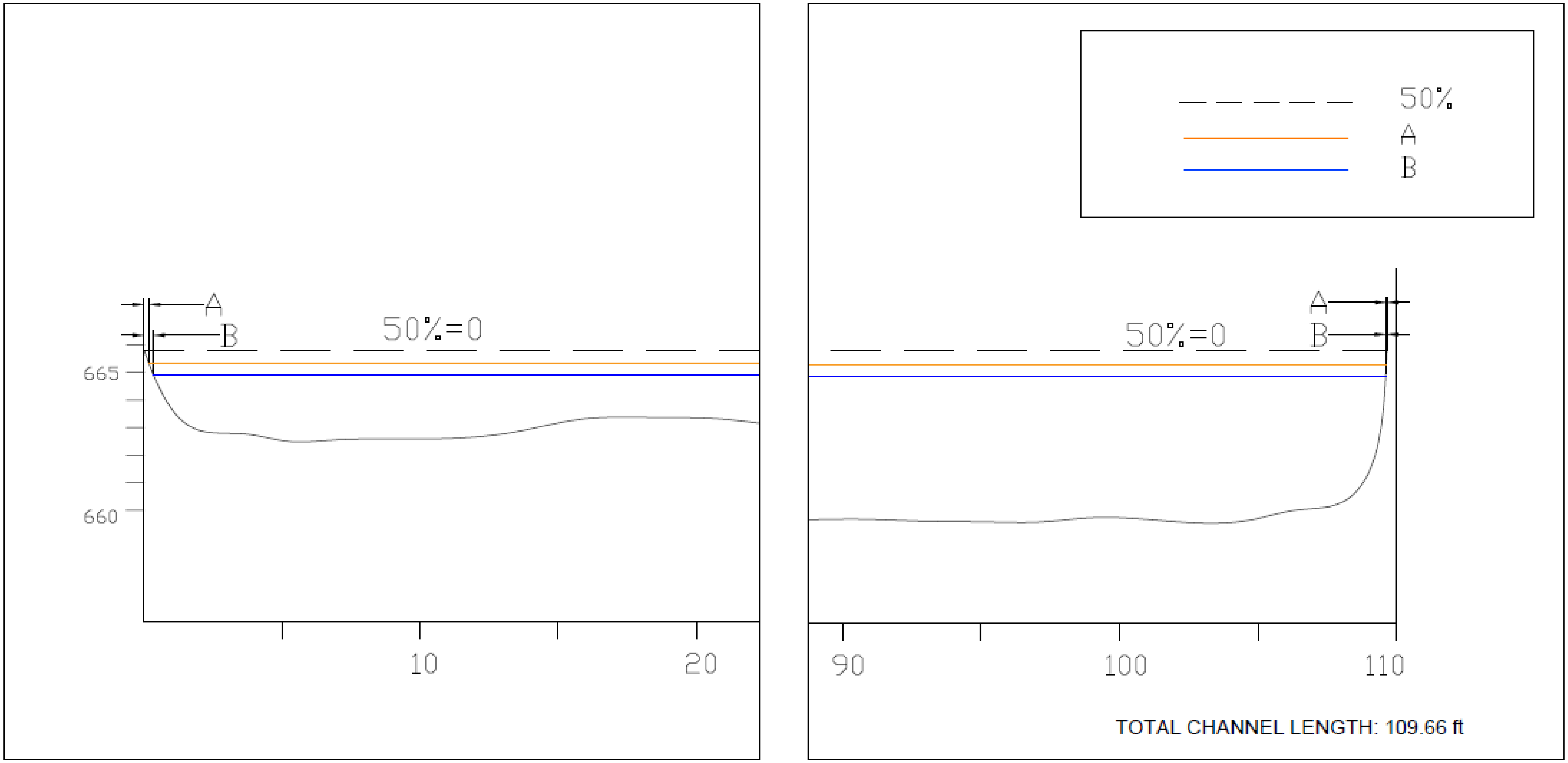


Figure D-16. Bank view of the lowest wetted perimeter predicted by OASIS model at Tarpley Bluff with future water demands during the winter period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

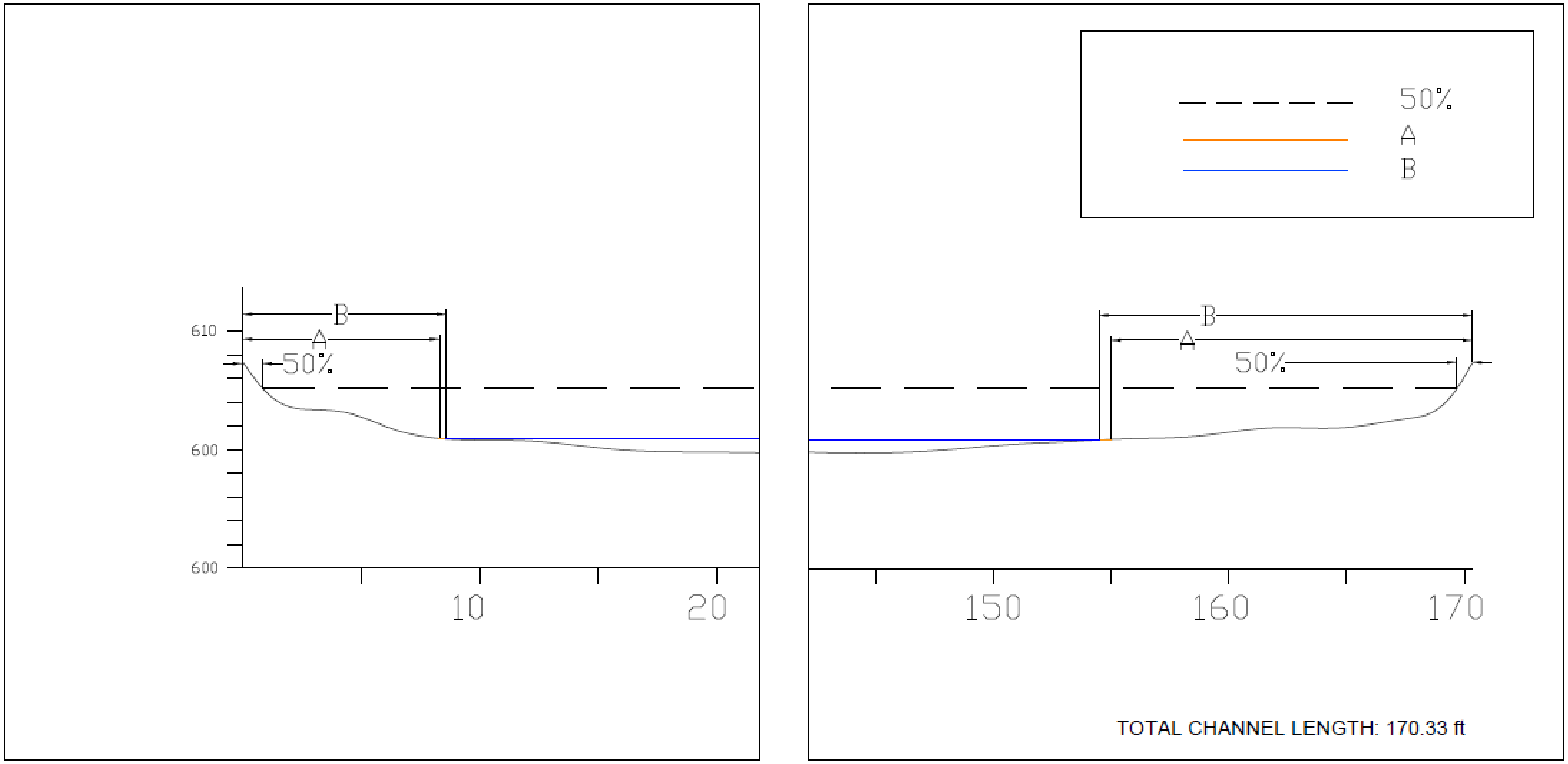


Figure D-17. Bank view of the lowest wetted perimeter predicted by OASIS model at Lillard Mill with future water demands during the winter period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

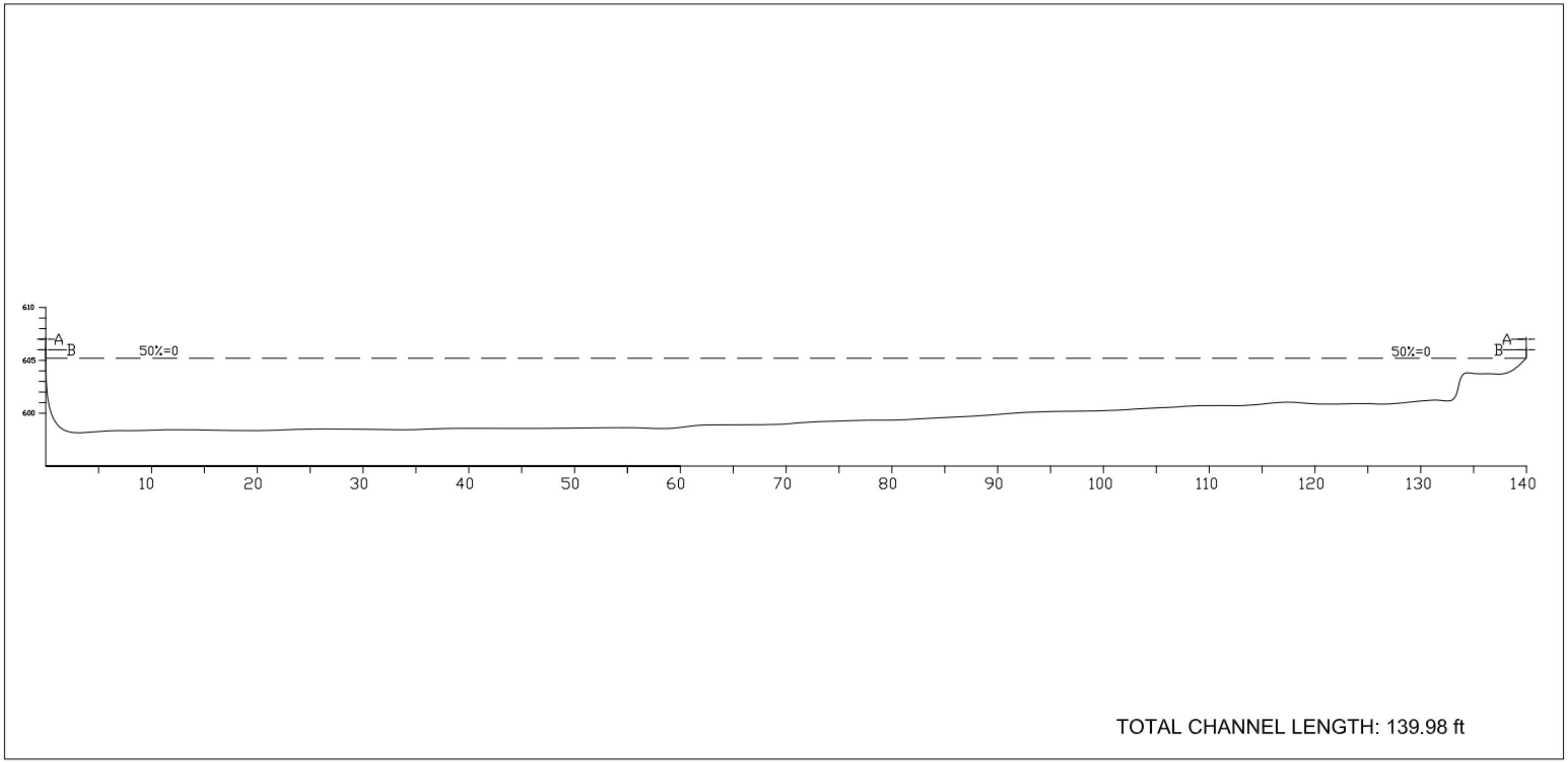


Figure D-18. Bank view of the lowest wetted perimeter predicted by the OASIS model at Venable Spring with future water demands during the winter period for Alternatives A and B. Note that the wetted perimeters for both alternatives exceed the maximum perimeter of the channel. The 50th percentile wetted perimeter value is depicted by the hashed line.

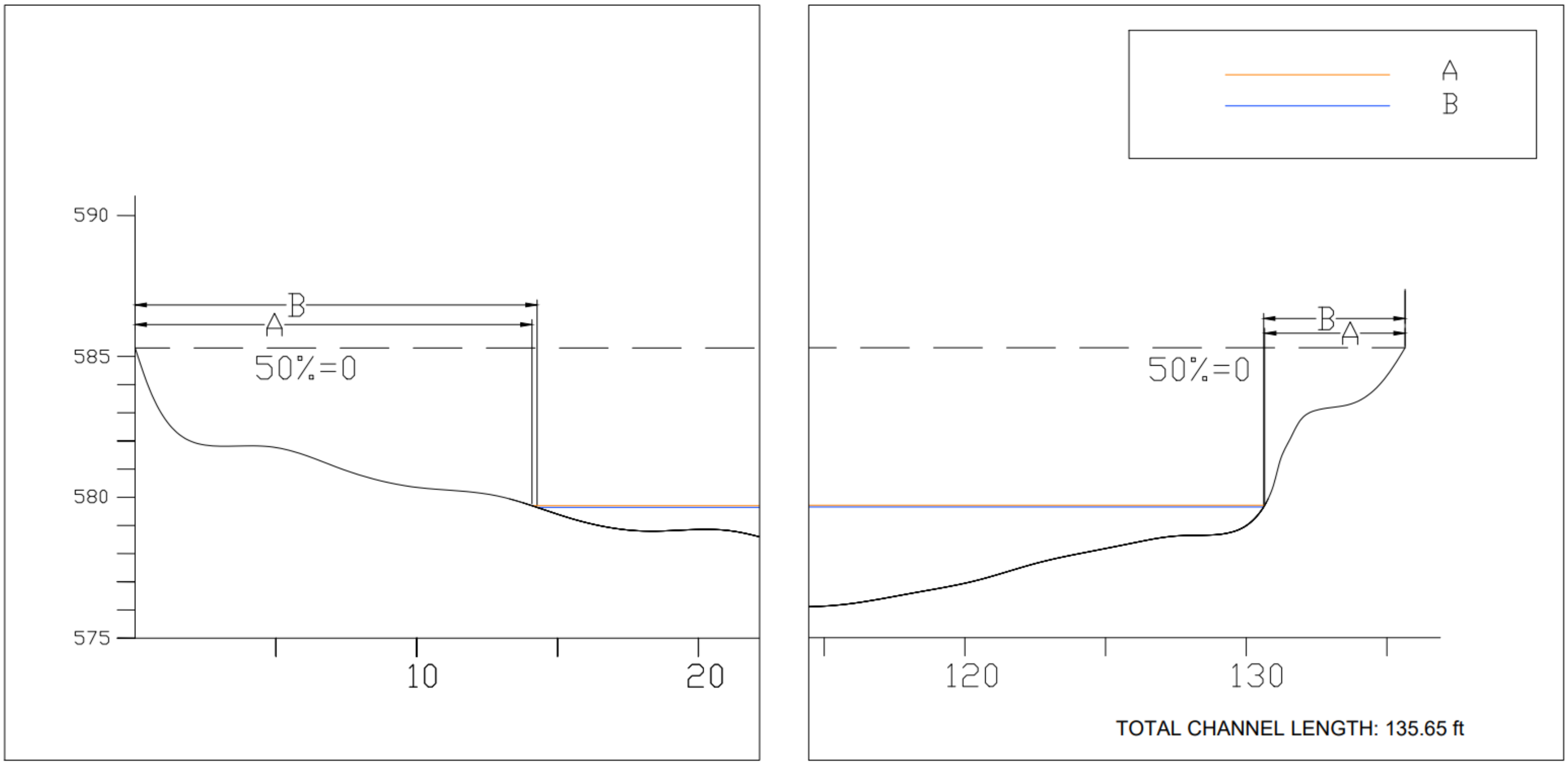


Figure D-19. Bank view of the lowest wetted perimeter predicted by the OASIS model at Hooper Island with future water demands during the winter period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line.

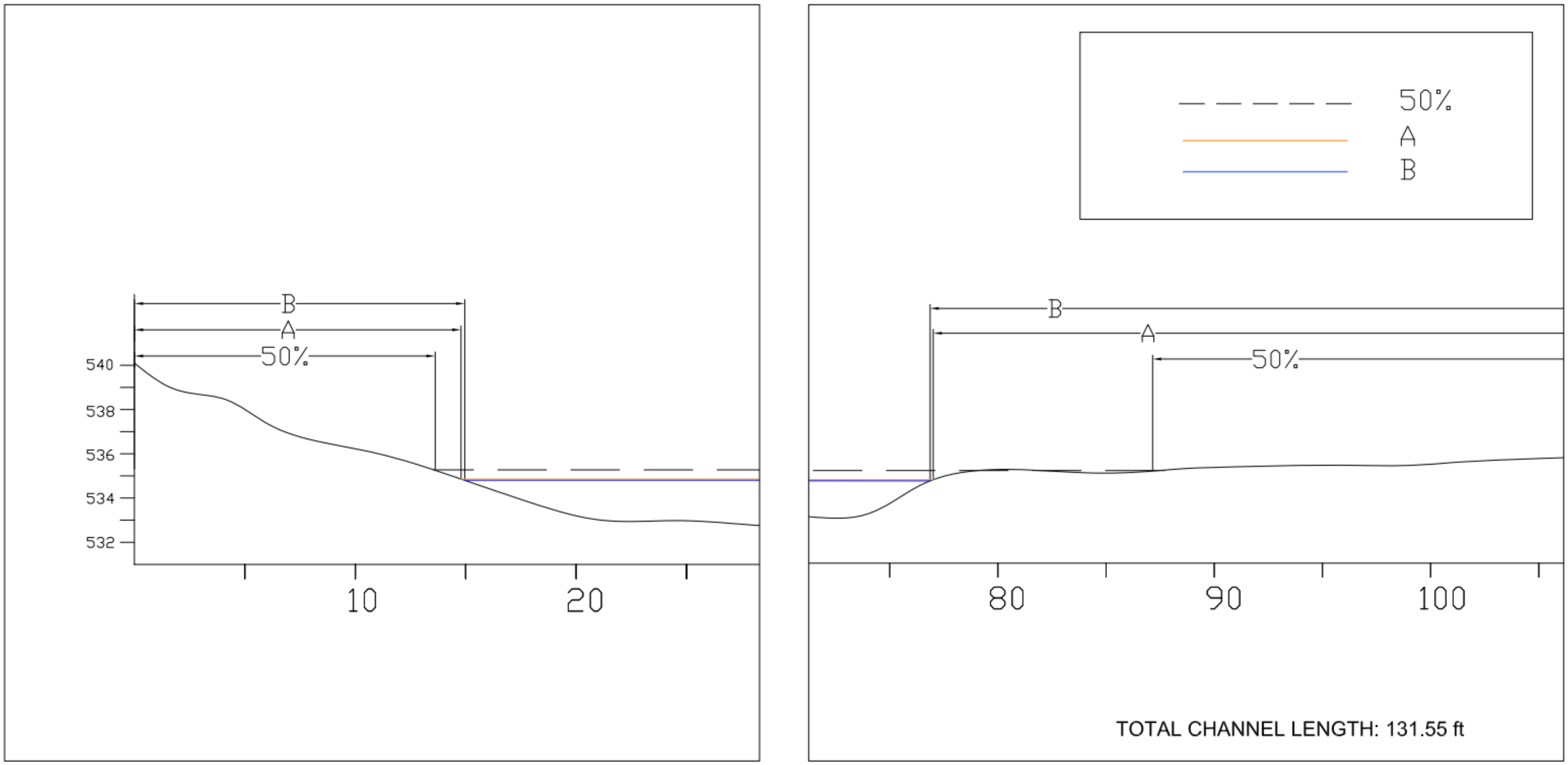


Figure D-20. Bank view of the lowest wetted perimeter predicted by the OASIS model at Riverside Park with future water demands during the winter period for Alternatives A and B. The 50th percentile wetted perimeter value is depicted by the hashed line. Note that both the A and B lines are depicted, but they are so close that they are hard to distinguish on the graph.

APPENDIX E – USFWS INFORMATION FOR PLANNING AND CONSULTATION RESOURCE LIST

IPaC **U.S. Fish & Wildlife Service**

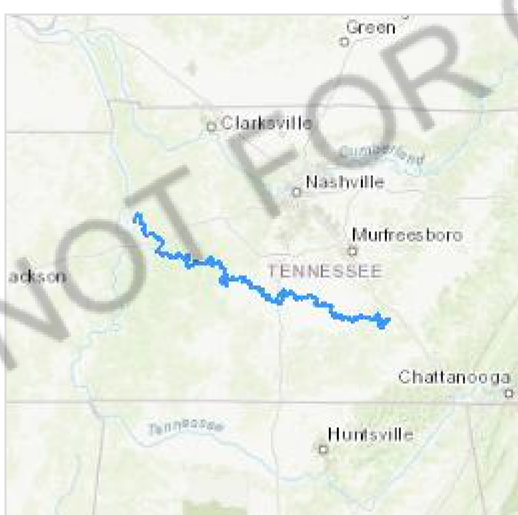
IPaC resource list

This report is an automatically generated list of species and other resources such as critical habitat (collectively referred to as *trust resources*) under the U.S. Fish and Wildlife Service's (USFWS) jurisdiction that are known or expected to be on or near the project area referenced below. The list may also include trust resources that occur outside of the project area, but that could potentially be directly or indirectly affected by activities in the project area. However, determining the likelihood and extent of effects a project may have on trust resources typically requires gathering additional site-specific (e.g., vegetation/species surveys) and project-specific (e.g., magnitude and timing of proposed activities) information.

Below is a summary of the project information you provided and contact information for the USFWS office(s) with jurisdiction in the defined project area. Please read the introduction to each section that follows (Endangered Species, Migratory Birds, USFWS Facilities, and NWI Wetlands) for additional information applicable to the trust resources addressed in that section.

Location

Tennessee



Local office

Tennessee Ecological Services Field Office

(931) 528-6481
(931) 528-7075

446 Neal Street

Cookeville, TN 38501-4027

Endangered species

This resource list is for informational purposes only and does not constitute an analysis of project level impacts.

The primary information used to generate this list is the known or expected range of each species. Additional areas of influence (AOI) for species are also considered. An AOI includes areas outside of the species range if the species could be indirectly affected by activities in that area (e.g., placing a dam upstream of a fish population even if that fish does not occur at the dam site, may indirectly impact the species by reducing or eliminating water flow downstream). Because species can move, and site conditions can change, the species on this list are not guaranteed to be found on or near the project area. To fully determine any potential effects to species, additional site-specific and project-specific information is often required.

Section 7 of the Endangered Species Act **requires** Federal agencies to "request of the Secretary information whether any species which is listed or proposed to be listed may be present in the area of such proposed action" for any project that is conducted, permitted, funded, or licensed by any Federal agency. A letter from the local office and a species list which fulfills this requirement can **only** be obtained by requesting an official species list from either the Regulatory Review section in IPaC (see directions below) or from the local field office directly.

For project evaluations that require USFWS concurrence/review, please return to the IPaC website and request an official species list by doing the following:

1. Draw the project location and click CONTINUE.
2. Click DEFINE PROJECT.
3. Log in (if directed to do so).
4. Provide a name and description for your project.
5. Click REQUEST SPECIES LIST.

Listed species[1] and their critical habitats are managed by the Ecological Services Program of the U.S. Fish and Wildlife Service (USFWS) and the fisheries division of the National Oceanic and Atmospheric Administration (NOAA Fisheries[2]).

Species and critical habitats under the sole responsibility of NOAA Fisheries are **not** shown on this list. Please contact NOAA Fisheries for species under their jurisdiction.

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1. Species listed under the Endangered Species Act are threatened or endangered; IPaC also shows species that are candidates, or proposed, for listing. See the listing status page for more information. IPaC only shows species that are regulated by USFWS (see FAQ).

2. NOAA Fisheries, also known as the National Marine Fisheries Service (NMFS), is an office of the National Oceanic and Atmospheric Administration within the Department of Commerce.

The following species are potentially affected by activities in this location:

Mammals

NAME	STATUS
Gray Bat Myotis grisescens Wherever found No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/6329	Endangered
Indiana Bat Myotis sodalis Wherever found There is **final** critical habitat for this species. Your location does not overlap the critical habitat. https://ecos.fws.gov/ecp/species/5949	Endangered
Northern Long-eared Bat Myotis septentrionalis Wherever found No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/9045	Endangered
Tricolored Bat Perimyotis subflavus Wherever found No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/10515	Proposed Endangered

Birds

NAME	STATUS
Whooping Crane Grus americana No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/758	EXPN

Reptiles

NAME	STATUS

Alligator Snapping Turtle Macrochelys temminckii Wherever found No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/4658	Proposed Threatened

Fishes

NAME	STATUS
Barrens Topminnow Fundulus julisia Wherever found There is **proposed** critical habitat for this species. https://ecos.fws.gov/ecp/species/5045	Endangered
Pygmy Madtom Noturus stanauli Wherever found No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/7873	Endangered

Clams

NAME	STATUS
Birdwing Pearlymussel Lemiox rimosus No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/6636	EXPN
Clubshell Pleurobema clava No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/3789	Endangered
Cracking Pearlymussel Hemistena lata No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/4130	Endangered
Cumberland Moccasinshell Medionidus conradicus Wherever found No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/9881	Proposed Endangered
Cumberland Monkeyface (pearlymussel) Theliderma intermedia No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/6999	EXPN

Cumberlandian Combshell Epioblasma brevidens — Endangered

There is **final** critical habitat for this species. Your location overlaps the critical habitat.
https://ecos.fws.gov/ecp/species/3119

Fluted Kidneyshell Ptychobranchus subtentus — Endangered

Wherever found

There is **final** critical habitat for this species. Your location overlaps the critical habitat.
https://ecos.fws.gov/ecp/species/1397

Longsolid Fusconaia subrotunda — Threatened

Wherever found

There is **final** critical habitat for this species. Your location does not overlap the critical habitat.
https://ecos.fws.gov/ecp/species/9880

Orangefoot Pimpleback (pearlymussel) Plethobasus cooperianus — Endangered

Wherever found

No critical habitat has been designated for this species.
https://ecos.fws.gov/ecp/species/1132

Oyster Mussel Epioblasma capsaeformis — Endangered

There is **final** critical habitat for this species. Your location overlaps the critical habitat.
https://ecos.fws.gov/ecp/species/2099

Pale Lilliput (pearlymussel) Toxolasma cylindrellus — Endangered

Wherever found

No critical habitat has been designated for this species.
https://ecos.fws.gov/ecp/species/3118

Purple Cat's Paw (=purple Cat's Paw Pearlymussel) Epioblasma obliquata — Endangered

No critical habitat has been designated for this species.
https://ecos.fws.gov/ecp/species/5602

Rabbitsfoot Quadrula cylindrica cylindrica — Threatened

Wherever found

There is **final** critical habitat for this species. Your location overlaps the critical habitat.
https://ecos.fws.gov/ecp/species/5165

Rayed Bean Villosa fabalis — Endangered

Wherever found

No critical habitat has been designated for this species.
https://ecos.fws.gov/ecp/species/5862

Round Hickorynut Obovaria subrotunda — Threatened

Wherever found

There is **final** critical habitat for this species. Your location overlaps the critical habitat.
https://ecos.fws.gov/ecp/species/9879

Salamander Mussel Simpsonaias ambigua — Proposed Endangered

Wherever found

There is **proposed** critical habitat for this species.
https://ecos.fws.gov/ecp/species/6208

Sheepnose Mussel Plethobasus cyphyus — Endangered

Wherever found

No critical habitat has been designated for this species.
https://ecos.fws.gov/ecp/species/6903

Slabside Pearlymussel Pleuronaia dolabelloides — Endangered

Wherever found

There is **final** critical habitat for this species. Your location overlaps the critical habitat.
https://ecos.fws.gov/ecp/species/1518

Snuffbox Mussel Epioblasma triquetra — Endangered

Wherever found

No critical habitat has been designated for this species.
https://ecos.fws.gov/ecp/species/4135

Spectaclecase (mussel) Cumberlandia monodonta — Endangered

Wherever found

No critical habitat has been designated for this species.
https://ecos.fws.gov/ecp/species/7867

Tennessee Clubshell Pleurobema oviforme — Proposed Endangered

Wherever found

No critical habitat has been designated for this species.
https://ecos.fws.gov/ecp/species/3254

Tennessee Pigtoe Pleuronaia barnesiana Wherever found No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/9887	Proposed Endangered
Winged Mapleleaf Quadrula fragosa No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/4127	Endangered

Insects

NAME	STATUS
Monarch Butterfly Danaus plexippus Wherever found No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/9743	Candidate

Flowering Plants

NAME	STATUS
Leafy Prairie-clover Dalea foliosa No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/5498	Endangered
Price''s Potato-bean Apios priceana No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/7422	Threatened
Short's Bladderpod Physaria globosa Wherever found There is **final** critical habitat for this species. Your location does not overlap the critical habitat. https://ecos.fws.gov/ecp/species/7206	Endangered
Tennessee Yellow-eyed Grass Xyris tennesseensis Wherever found No critical habitat has been designated for this species. https://ecos.fws.gov/ecp/species/6010	Endangered

Critical habitats

Potential effects to critical habitat(s) in this location must be analyzed along with the endangered species themselves.

This location overlaps the critical habitat for the following species:

NAME	TYPE
Cumberlandian Combshell Epioblasma brevidens https://ecos.fws.gov/ecp/species/3119#crithab	Final
Fluted Kidneyshell Ptychobranchus subtentus https://ecos.fws.gov/ecp/species/1397#crithab	Final
Oyster Mussel Epioblasma capsaeformis https://ecos.fws.gov/ecp/species/2099#crithab	Final
Rabbitsfoot Quadrula cylindrica cylindrica https://ecos.fws.gov/ecp/species/5165#crithab	Final
Round Hickorynut Obovaria subrotunda https://ecos.fws.gov/ecp/species/9879#crithab	Final
Slabside Pearlymussel Pleuronaia dolabelloides https://ecos.fws.gov/ecp/species/1518#crithab	Final

Bald & Golden Eagles

Bald and golden eagles are protected under the Bald and Golden Eagle Protection Act[1] and the Migratory Bird Treaty Act[2].

Any person or organization who plans or conducts activities that may result in impacts to bald or golden eagles, or their habitats[3], should follow appropriate regulations and consider implementing appropriate conservation measures, as described below.

Additional information can be found using the following links:

- Eagle Managment https://www.fws.gov/program/eagle-management
- Measures for avoiding and minimizing impacts to birds https://www.fws.gov/library/collections/avoiding-and-minimizing-incidental-take-migratory-birds

- Nationwide conservation measures for birds https://www.fws.gov/sites/default/files/documents/nationwide-standard-conservation-measures.pdf
- Supplemental Information for Migratory Birds and Eagles in IPaC https://www.fws.gov/media/supplemental-information-migratory-birds-and-bald-and-golden-eagles-may-occur-project-action

There are bald and/or golden eagles in your project area.

For guidance on when to schedule activities or implement avoidance and minimization measures to reduce impacts to migratory birds on your list, click on the PROBABILITY OF PRESENCE SUMMARY at the top of your list to see when these birds are most likely to be present and breeding in your project area.

NAME	BREEDING SEASON
Bald Eagle Haliaeetus leucocephalus This is not a Bird of Conservation Concern (BCC) in this area, but warrants attention because of the Eagle Act or for potential susceptibilities in offshore areas from certain types of development or activities.	Breeds Sep 1 to Jul 31
Golden Eagle Aquila chrysaetos This is not a Bird of Conservation Concern (BCC) in this area, but warrants attention because of the Eagle Act or for potential susceptibilities in offshore areas from certain types of development or activities. https://ecos.fws.gov/ecp/species/1680	Breeds elsewhere

Probability of Presence Summary

The graphs below provide our best understanding of when birds of concern are most likely to be present in your project area. This information can be used to tailor and schedule your project activities to avoid or minimize impacts to birds. Please make sure you read and understand the FAQ "Proper Interpretation and Use of Your Migratory Bird Report" before using or attempting to interpret this report.

Probability of Presence (■)

Each green bar represents the bird's relative probability of presence in the 10km grid cell(s) your project overlaps during a particular week of the year. (A year is represented as 12 4-week months.) A taller bar indicates a higher probability of species presence. The survey effort (see below) can be used to establish a level of confidence in the presence score. One can have higher confidence in the presence score if the corresponding survey effort is also high.

How is the probability of presence score calculated? The calculation is done in three steps:

1. The probability of presence for each week is calculated as the number of survey events in the week where the species was detected divided by the total number of survey events for that week. For example, if in week 12 there were 20 survey events and the Spotted Towhee was found in 5 of them, the probability of presence of the Spotted Towhee in week 12 is 0.25.
2. To properly present the pattern of presence across the year, the relative probability of presence is calculated. This is the probability of presence divided by the maximum probability of presence across all weeks. For example, imagine the probability of presence in week 20 for the Spotted Towhee is 0.05, and that the probability of presence at week 12 (0.25) is the maximum of any week of the year. The relative probability of presence on week 12 is 0.25/0.25 = 1; at week 20 it is 0.05/0.25 = 0.2.
3. The relative probability of presence calculated in the previous step undergoes a statistical conversion so that all possible values fall between 0 and 10, inclusive. This is the probability of presence score.

To see a bar's probability of presence score, simply hover your mouse cursor over the bar.

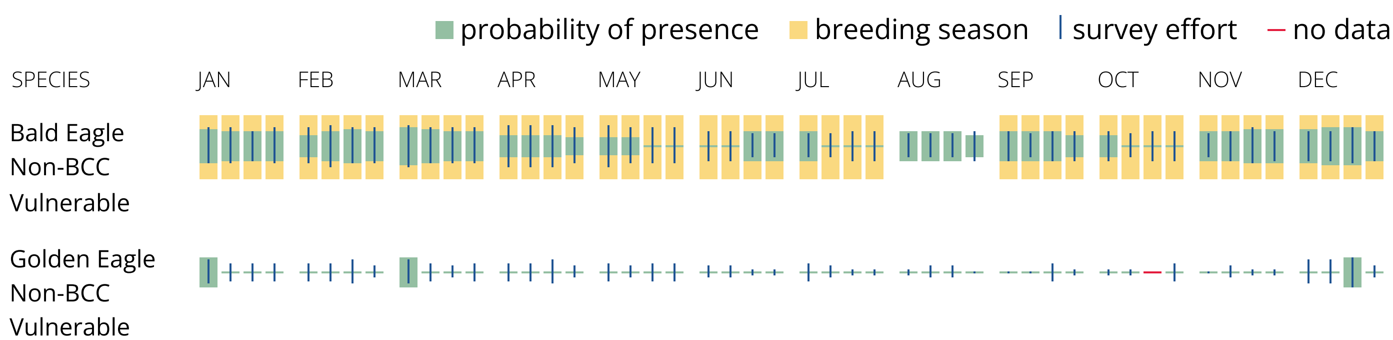
Breeding Season (■)
Yellow bars denote a very liberal estimate of the time-frame inside which the bird breeds across its entire range. If there are no yellow bars shown for a bird, it does not breed in your project area.

Survey Effort (|)
Vertical black lines superimposed on probability of presence bars indicate the number of surveys performed for that species in the 10km grid cell(s) your project area overlaps. The number of surveys is expressed as a range, for example, 33 to 64 surveys.

To see a bar's survey effort range, simply hover your mouse cursor over the bar.

No Data (–)
A week is marked as having no data if there were no survey events for that week.

Survey Timeframe
Surveys from only the last 10 years are used in order to ensure delivery of currently relevant information. The exception to this is areas off the Atlantic coast, where bird returns are based on all years of available data, since data in these areas is currently much more sparse.



What does IPaC use to generate the potential presence of bald and golden eagles in my specified location?

The potential for eagle presence is derived from data provided by the Avian Knowledge Network (AKN). The AKN data is based on a growing collection of survey, banding, and citizen science datasets and is queried and filtered to return a list of those birds reported as occurring in the 10km grid cell(s) which your project intersects, and that have been identified as warranting special attention because they are a BCC species in that area, an eagle (Eagle Act requirements may apply). To see a list of all birds potentially present in your project area, please visit the Rapid Avian Information Locator (RAIL) Tool.

What does IPaC use to generate the probability of presence graphs of bald and golden eagles in my specified location?

The Migratory Bird Resource List is comprised of USFWS Birds of Conservation Concern (BCC) and other species that may warrant special attention in your project location.

The migratory bird list generated for your project is derived from data provided by the Avian Knowledge Network (AKN). The AKN data is based on a growing collection of survey, banding, and citizen science datasets and is queried and filtered to return a list of those birds reported as occurring in the 10km grid cell(s) which your project intersects, and that have been identified as warranting special attention because they are a BCC species in that area, an eagle (Eagle Act requirements may apply), or a species that has a particular vulnerability to offshore activities or development.

Again, the Migratory Bird Resource list includes only a subset of birds that may occur in your project area. It is not representative of all birds that may occur in your project area. To get a list of all birds potentially present in your project area, please visit the Rapid Avian Information Locator (RAIL) Tool.

What if I have eagles on my list?

If your project has the potential to disturb or kill eagles, you may need to obtain a permit to avoid violating the Eagle Act should such impacts occur. Please contact your local Fish and Wildlife Service Field Office if you have questions.

Migratory birds

Certain birds are protected under the Migratory Bird Treaty Act[1] and the Bald and Golden Eagle Protection Act[2].

Any person or organization who plans or conducts activities that may result in impacts to migratory birds, eagles, and their habitats[3] should follow appropriate regulations and consider implementing appropriate conservation measures, as described below.

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1. The Migratory Birds Treaty Act of 1918.
2. The Bald and Golden Eagle Protection Act of 1940.

Additional information can be found using the following links:

- Eagle Management https://www.fws.gov/program/eagle-management
- Measures for avoiding and minimizing impacts to birds https://www.fws.gov/library/collections/avoiding-and-minimizing-incidental-take-migratory-birds
- Nationwide conservation measures for birds https://www.fws.gov/sites/default/files/documents/nationwide-standard-conservation-measures.pdf
- Supplemental Information for Migratory Birds and Eagles in IPaC https://www.fws.gov/media/supplemental-information-migratory-birds-and-bald-and-golden-eagles-may-occur-project-action

The birds listed below are birds of particular concern either because they occur on the USFWS Birds of Conservation Concern (BCC) list or warrant special attention in your project location. To learn more about the levels of concern for birds on your list and how this list is generated, see the FAQ below. This is not a list of every bird you may find in this location, nor a guarantee that every bird on this list will be found in your project area. To see exact locations of where birders and the general public have sighted birds in and around your project area, visit the E-bird data mapping tool (Tip: enter your location, desired date range and a species on your list). For projects that occur off the Atlantic Coast, additional maps and models detailing the relative occurrence and abundance of bird species on your list are available. Links to additional information about Atlantic Coast birds, and other important information about your migratory bird list, including how to properly interpret and use your migratory bird report, can be found below.

For guidance on when to schedule activities or implement avoidance and minimization measures to reduce impacts to migratory birds on your list, click on the PROBABILITY OF PRESENCE SUMMARY at the top of your list to see when these birds are most likely to be present and breeding in your project area.

NAME	BREEDING SEASON
Bald Eagle Haliaeetus leucocephalus This is not a Bird of Conservation Concern (BCC) in this area, but warrants attention because of the Eagle Act or for potential susceptibilities in offshore areas from certain types of development or activities.	Breeds Sep 1 to Jul 31
Black-billed Cuckoo Coccyzus erythropthalmus This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska. https://ecos.fws.gov/ecp/species/9399	Breeds May 15 to Oct 10
Bobolink Dolichonyx oryzivorus This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.	Breeds May 20 to Jul 31

Brown-headed Nuthatch Sitta pusilla — Breeds Mar 1 to Jul 15

This is a Bird of Conservation Concern (BCC) only in particular Bird Conservation Regions (BCRs) in the continental USA

Cerulean Warbler Dendroica cerulea — Breeds Apr 23 to Jul 20

This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.
https://ecos.fws.gov/ecp/species/2974

Chimney Swift Chaetura pelagica — Breeds Mar 15 to Aug 25

This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.

Eastern Whip-poor-will Antrostomus vociferus — Breeds May 1 to Aug 20

This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.

Field Sparrow Spizella pusilla — Breeds Mar 1 to Aug 15

This is a Bird of Conservation Concern (BCC) only in particular Bird Conservation Regions (BCRs) in the continental USA

Golden Eagle Aquila chrysaetos — Breeds elsewhere

This is not a Bird of Conservation Concern (BCC) in this area, but warrants attention because of the Eagle Act or for potential susceptibilities in offshore areas from certain types of development or activities.
https://ecos.fws.gov/ecp/species/1680

Henslow's Sparrow Ammodramus henslowii — Breeds May 1 to Aug 31

This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.
https://ecos.fws.gov/ecp/species/3941

Kentucky Warbler Oporornis formosus — Breeds Apr 20 to Aug 20

This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.

Lesser Yellowlegs Tringa flavipes — Breeds elsewhere

This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.
https://ecos.fws.gov/ecp/species/9679

Prairie Warbler Dendroica discolor — Breeds May 1 to Jul 31

This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.

Prothonotary Warbler Protonotaria citrea — Breeds Apr 1 to Jul 31

This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.

Red-headed Woodpecker Melanerpes erythrocephalus — Breeds May 10 to Sep 10

This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.

Rusty Blackbird Euphagus carolinus — Breeds elsewhere

This is a Bird of Conservation Concern (BCC) only in particular Bird Conservation Regions (BCRs) in the continental USA

Wood Thrush Hylocichla mustelina — Breeds May 10 to Aug 31

This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.

Probability of Presence Summary

The graphs below provide our best understanding of when birds of concern are most likely to be present in your project area. This information can be used to tailor and schedule your project activities to avoid or minimize impacts to birds. Please make sure you read and understand the FAQ "Proper Interpretation and Use of Your Migratory Bird Report" before using or attempting to interpret this report.

Probability of Presence (■)

Each green bar represents the bird's relative probability of presence in the 10km grid cell(s) your project overlaps during a particular week of the year. (A year is represented as 12 4-week months.) A taller bar indicates a higher probability of species presence. The survey effort (see below) can be used to establish a level of confidence in the presence score. One can have higher confidence in the presence score if the corresponding survey effort is also high.

How is the probability of presence score calculated? The calculation is done in three steps:

1. The probability of presence for each week is calculated as the number of survey events in the week where the species was detected divided by the total number of survey events for that week. For example, if in week 12 there were 20 survey events and the Spotted Towhee was found in 5 of them, the probability of presence of the Spotted Towhee in week 12 is 0.25.

2. To properly present the pattern of presence across the year, the relative probability of presence is calculated. This is the probability of presence divided by the maximum probability of presence across all weeks. For example, imagine the probability of presence in week 20 for the Spotted Towhee is 0.05, and that the probability of presence at week 12 (0.25) is the maximum of any week of the year. The relative probability of presence on week 12 is 0.25/0.25 = 1; at week 20 it is 0.05/0.25 = 0.2.
3. The relative probability of presence calculated in the previous step undergoes a statistical conversion so that all possible values fall between 0 and 10, inclusive. This is the probability of presence score.

To see a bar's probability of presence score, simply hover your mouse cursor over the bar.

Breeding Season ( )

Yellow bars denote a very liberal estimate of the time-frame inside which the bird breeds across its entire range. If there are no yellow bars shown for a bird, it does not breed in your project area.

Survey Effort (|)

Vertical black lines superimposed on probability of presence bars indicate the number of surveys performed for that species in the 10km grid cell(s) your project area overlaps. The number of surveys is expressed as a range, for example, 33 to 64 surveys.

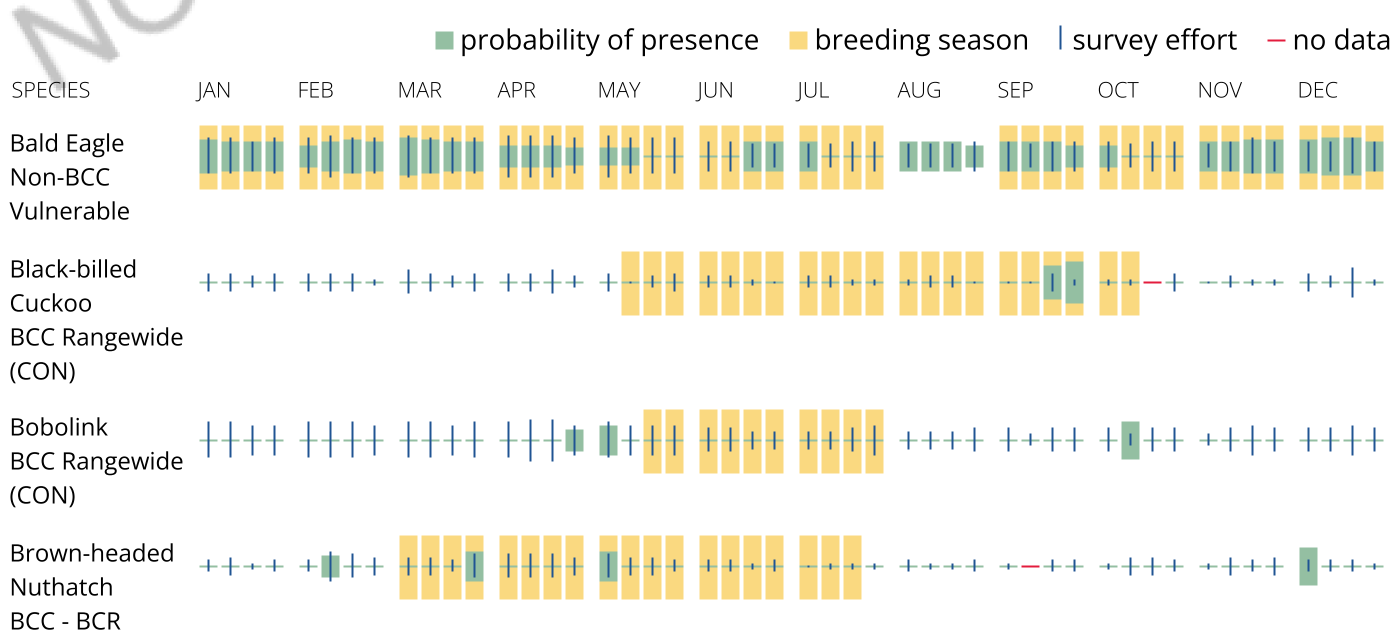
To see a bar's survey effort range, simply hover your mouse cursor over the bar.

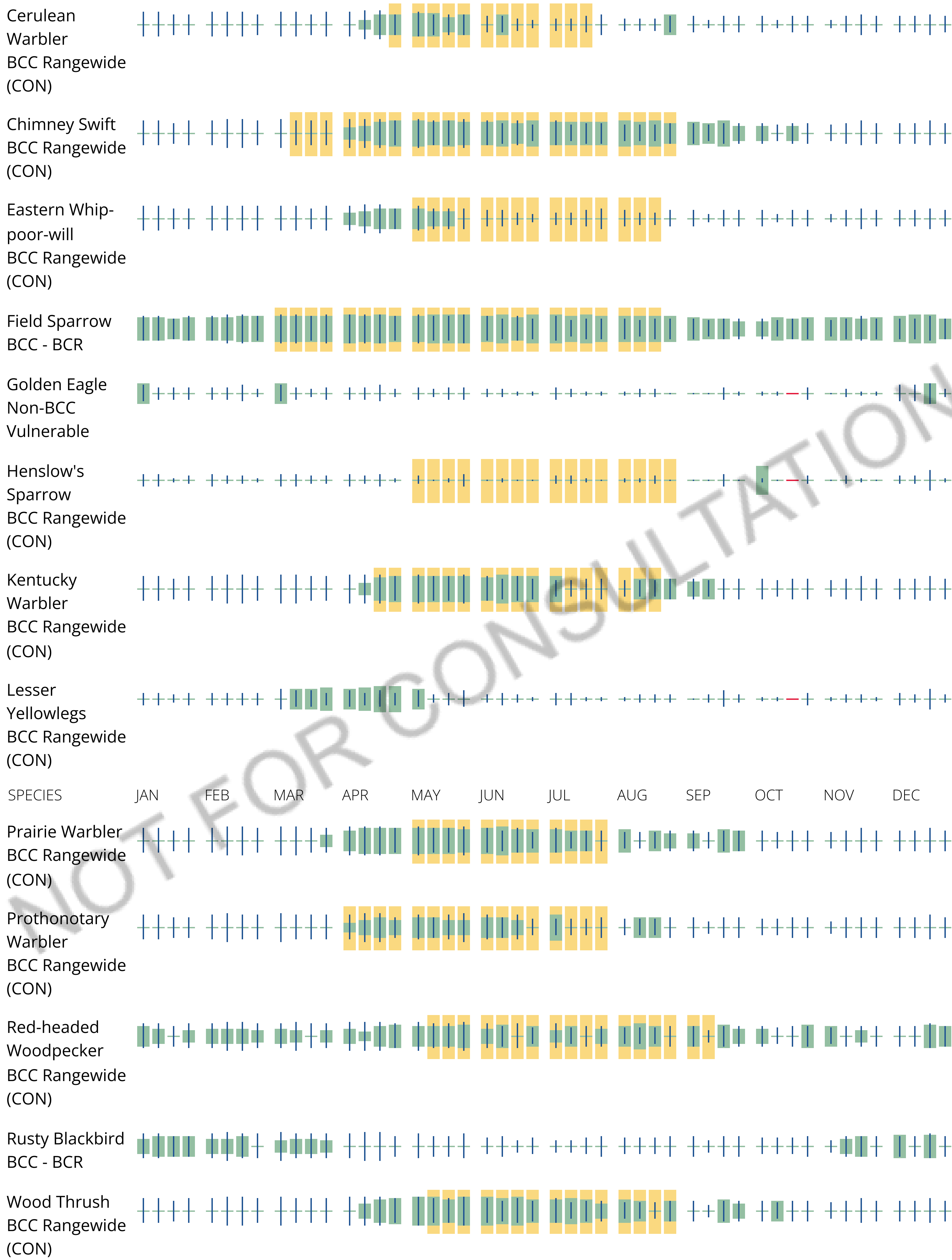
No Data (–)

A week is marked as having no data if there were no survey events for that week.

Survey Timeframe

Surveys from only the last 10 years are used in order to ensure delivery of currently relevant information. The exception to this is areas off the Atlantic coast, where bird returns are based on all years of available data, since data in these areas is currently much more sparse.




Cerulean Warbler
BCC Rangewide (CON)
Chimney Swift
BCC Rangewide (CON)
Eastern Whip-poor-will
BCC Rangewide (CON)
Field Sparrow
BCC - BCR
Golden Eagle
Non-BCC Vulnerable
Henslow's Sparrow
BCC Rangewide (CON)
Kentucky Warbler
BCC Rangewide (CON)
Lesser Yellowlegs
BCC Rangewide (CON)
SPECIES
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Prairie Warbler
BCC Rangewide (CON)
Prothonotary Warbler
BCC Rangewide (CON)
Red-headed Woodpecker
BCC Rangewide (CON)
Rusty Blackbird
BCC - BCR
Wood Thrush
BCC Rangewide (CON)

Tell me more about conservation measures I can implement to avoid or minimize impacts to migratory birds.

Nationwide Conservation Measures describes measures that can help avoid and minimize impacts to all birds at any location year round. Implementation of these measures is particularly important when birds are most likely to occur in the project area. When birds may be breeding in the area, identifying the locations of any active nests and avoiding their destruction is a very helpful impact minimization measure. To see when birds are most likely to occur and be breeding in your project area, view the Probability of Presence Summary. Additional measures or permits may be advisable depending on the type of activity you are conducting and the type of infrastructure or bird species present on your project site.

What does IPaC use to generate the list of migratory birds that potentially occur in my specified location?

The Migratory Bird Resource List is comprised of USFWS Birds of Conservation Concern (BCC) and other species that may warrant special attention in your project location.

The migratory bird list generated for your project is derived from data provided by the Avian Knowledge Network (AKN). The AKN data is based on a growing collection of survey, banding, and citizen science datasets and is queried and filtered to return a list of those birds reported as occurring in the 10km grid cell(s) which your project intersects, and that have been identified as warranting special attention because they are a BCC species in that area, an eagle (Eagle Act requirements may apply), or a species that has a particular vulnerability to offshore activities or development.

Again, the Migratory Bird Resource list includes only a subset of birds that may occur in your project area. It is not representative of all birds that may occur in your project area. To get a list of all birds potentially present in your project area, please visit the Rapid Avian Information Locator (RAIL) Tool.

What does IPaC use to generate the probability of presence graphs for the migratory birds potentially occurring in my specified location?

The probability of presence graphs associated with your migratory bird list are based on data provided by the Avian Knowledge Network (AKN). This data is derived from a growing collection of survey, banding, and citizen science datasets.

Probability of presence data is continuously being updated as new and better information becomes available. To learn more about how the probability of presence graphs are produced and how to interpret them, go the Probability of Presence Summary and then click on the "Tell me about these graphs" link.

How do I know if a bird is breeding, wintering or migrating in my area?

To see what part of a particular bird's range your project area falls within (i.e. breeding, wintering, migrating or year-round), you may query your location using the RAIL Tool and look at the range maps provided for birds in your area at the bottom of the profiles provided for each bird in your results. If a bird on your migratory bird species list has a breeding season associated with it, if that bird does occur in your project area, there may be nests present at some point within the timeframe specified. If "Breeds elsewhere" is indicated, then the bird likely does not breed in your project area.

What are the levels of concern for migratory birds?

Migratory birds delivered through IPaC fall into the following distinct categories of concern:

1. "BCC Rangewide" birds are Birds of Conservation Concern (BCC) that are of concern throughout their range anywhere within the USA (including Hawaii, the Pacific Islands, Puerto Rico, and the Virgin Islands);
2. "BCC - BCR" birds are BCCs that are of concern only in particular Bird Conservation Regions (BCRs) in the continental USA; and
3. "Non-BCC - Vulnerable" birds are not BCC species in your project area, but appear on your list either because of the Eagle Act requirements (for eagles) or (for non-eagles) potential susceptibilities in offshore areas from certain types of development or activities (e.g. offshore energy development or longline fishing).

Although it is important to try to avoid and minimize impacts to all birds, efforts should be made, in particular, to avoid and minimize impacts to the birds on this list, especially eagles and BCC species of rangewide concern. For more information on conservation measures you can implement to help avoid and minimize migratory bird impacts and requirements for eagles, please see the FAQs for these topics.

Details about birds that are potentially affected by offshore projects

For additional details about the relative occurrence and abundance of both individual bird species and groups of bird species within your project area off the Atlantic Coast, please visit the Northeast Ocean Data Portal. The Portal also offers data and information about other taxa besides birds that may be helpful to you in your project review. Alternately, you may download the bird model results files underlying the portal maps through the NOAA NCCOS Integrative Statistical Modeling and Predictive Mapping of Marine Bird Distributions and Abundance on the Atlantic Outer Continental Shelf project webpage.

Bird tracking data can also provide additional details about occurrence and habitat use throughout the year, including migration. Models relying on survey data may not include this information. For additional information on marine bird tracking data, see the Diving Bird Study and the nanotag studies or contact Caleb Spiegel or Pam Loring.

What if I have eagles on my list?

If your project has the potential to disturb or kill eagles, you may need to obtain a permit to avoid violating the Eagle Act should such impacts occur.

Proper Interpretation and Use of Your Migratory Bird Report

The migratory bird list generated is not a list of all birds in your project area, only a subset of birds of priority concern. To learn more about how your list is generated, and see options for identifying what other birds may be in your project area, please see the FAQ "What does IPaC use to generate the migratory birds potentially occurring in my specified location". Please be aware this report provides the "probability of presence" of birds within the 10 km grid cell(s) that overlap your project; not your exact project footprint. On the graphs provided, please also look carefully at the survey effort (indicated by the black vertical bar) and for the existence of the "no data" indicator (a red horizontal bar). A high survey effort is the key component. If the survey effort is high, then the probability of presence score can be viewed as more dependable. In contrast, a low survey effort bar or no data bar means a lack of data and, therefore, a lack of certainty about presence of the species. This list is not perfect; it is simply a starting point for identifying what birds of concern have the potential to be in your project area, when they might be there, and if they might be breeding (which means nests might be present). The list helps you know what to look for to confirm presence, and helps guide you in knowing when to implement conservation measures to avoid or minimize potential impacts from your project activities, should presence be confirmed. To learn more about conservation measures, visit the FAQ "Tell me about conservation measures I can implement to avoid or minimize impacts to migratory birds" at the bottom of your migratory bird trust resources page.

Facilities

National Wildlife Refuge lands

Any activity proposed on lands managed by the National Wildlife Refuge system must undergo a 'Compatibility Determination' conducted by the Refuge. Please contact the individual Refuges to discuss any questions or concerns.

This location overlaps the following National Wildlife Refuge lands:

LAND	ACRES
TENNESSEE NATIONAL WILDLIFE REFUGE	26,405.22 acres

Fish hatcheries

There are no sh hatcheries at this location.

Wetlands in the National Wetlands Inventory (NWI)

Impacts to NWI wetlands and other aquatic habitats may be subject to regulation under Section 404 of the Clean Water Act, or other State/Federal statutes.

For more information please contact the Regulatory Program of the local U.S. Army Corps of Engineers District.

Wetland information is not available at this time

This can happen when the National Wetlands Inventory (NWI) map service is unavailable, or for very large projects that intersect many wetland areas. Try again, or visit the NWI map to view wetlands at this location.

Data limitations

The Service's objective of mapping wetlands and deepwater habitats is to produce reconnaissance level information on the location, type and size of these resources. The maps are prepared from the analysis of high altitude imagery. Wetlands are identified based on vegetation, visible hydrology and geography. A margin of error is inherent in the use of imagery; thus, detailed on-the-ground inspection of any particular site may result in revision of the wetland boundaries or classification established through image analysis.

The accuracy of image interpretation depends on the quality of the imagery, the experience of the image analysts, the amount and quality of the collateral data and the amount of ground truth verification work conducted. Metadata should be consulted to determine the date of the source imagery used and any mapping problems.

Wetlands or other mapped features may have changed since the date of the imagery or field work. There may be occasional differences in polygon boundaries or classifications between the information depicted on the map and the actual conditions on site.

Data exclusions

Certain wetland habitats are excluded from the National mapping program because of the limitations of aerial imagery as the primary data source used to detect wetlands. These habitats include seagrasses or submerged aquatic vegetation that are found in the intertidal and subtidal zones of estuaries and nearshore coastal waters. Some deepwater reef communities (coral or tuberficid worm reefs) have also been excluded from the inventory. These habitats, because of their depth, go undetected by aerial imagery.

Data precautions

Federal, state, and local regulatory agencies with jurisdiction over wetlands may define and describe wetlands in a different manner than that used in this inventory. There is no attempt, in either the design or products of this inventory, to define the limits of proprietary jurisdiction of any Federal, state, or local government or to establish the geographical scope of the regulatory programs of government agencies. Persons intending to engage in activities involving modifications within or adjacent to wetland areas should seek the advice of appropriate Federal, state, or local agencies concerning specified agency regulatory programs and proprietary jurisdictions that may affect such activities.

APPENDIX F – SPECIES, SUITABLE HABITAT, AND CRITICAL HABITAT DESCRIPTIONS

Species, Suitable Habitat, and Critical Habitat Descriptions

1 - Spectaclecase (*Cumberlandia monodonta*)

Spectaclecase occurs in the Mississippi Basin from southern Minnesota and Wisconsin south to the Ouachita River drainage in south-central Arkansas, and in the Ohio River drainage from Ohio and West Virginia downstream to the mouth of the Ohio River, including some tributaries. It was historically widespread in the Cumberland River and is known from throughout the Tennessee River drainage (Williams et al. 2008).

This species inhabits medium to large rivers, where it usually occurs in moderate to swift current. It is generally found under large, flat rocks or in crevices among rocks but is occasionally encountered well buried in gravel substrates (Williams et al. 2008).

A relatively wide-ranging mussel, the Spectaclecase was historically noted only as a museum record from the Duck River. Two recent records are available from the lowermost river in Humphreys County (1 live, D. McKinney, TWRA, pers. comm.; 1 fresh dead, Schilling and Williams 2002), while relict specimens have been found at some other sites (Ahlstedt et al. 2017).

Haag and Warren (2008) found that mussels are highly sensitive to the secondary effects of drought - most likely the low levels of dissolved oxygen caused by low flow, warm temperatures, and high biological oxygen demand - in addition to the direct drying of their habitat. Temperature increases in rivers and streams during drought have been reported in many studies (Mosley 2015). A rise in water temperature may result in a higher metabolic energy demand while altering fitness, behavior, and reproduction (Pandolfo et al. 2010). However, in larger streams with permanent minimum flow (resulting in higher levels of dissolved oxygen), this response probably decreases drought-associated stress and mortality (Golladay et al. 2004). Haag and Warren (2008) found that, at the population level, the magnitude of decline was similar among unionid species, and the likelihood of surviving the drought was mostly a function of pre-drought abundance, which is relatively low for the Spectaclecase.

The Spectaclecase is sporadic in a reach less than 30 miles long in the Duck River, where it occurs in under-sampled habitats such as deeper pools and runs and under slab rocks (Ahlstedt et al. 2017). However, the Tennessee Wildlife Resources Agency (TWRA) has been reintroducing the Spectaclecase to suitable habitat in the Duck River since 2006 (TWRA 2019). Though reintroduced individuals of this species have not been observed reproducing in the portions of the Duck River where reintroductions have taken place, *Cumberlandia monodonta* is considered extant in the upper and lower Duck River and periods of reduced flow could cause sub-lethal and lethal effects on individuals, especially in the upper reaches.

2 - Fanshell (*Cyprogenia stegaria*)

Fanshell historically occurred throughout much of the Ohio, Cumberland, and Tennessee River drainages. In the Ohio River drainage, it is known from headwaters in Pennsylvania downstream to the mouth of the Ohio River, including the Wabash River in Indiana and Illinois, and the Green and Licking rivers in Kentucky. This species was widespread in the Cumberland River and historically occurred throughout the Tennessee River drainage (Williams et al. 2008).

This species occurs in riverine habitat of medium to large rivers at depths of less than 1 meter to more than 6 meters. Its preferred substrates are stable, coarse sand and gravel swept free of silt by current (Williams et al. 2008).

As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is relatively low for the Fanshell. The only record for the Fanshell from the Duck River is from the late 1800s near Columbia (Hinkley and Marsh 1885). Pre-impoundment records are available for the adjacent Tennessee River, indicating that it may also have occurred in the lowermost Duck (Ahlstedt et al. 2017). The Tennessee Wildlife Resources Agency (TWRA) has been reintroducing the Fanshell to suitable habitat in the Duck River since 2013 (TWRA 2019). Though reintroduced individuals of this species have not been observed reproducing in the portions of the Duck River where reintroductions have taken place, *Cyprogenia stegaria* is considered extant in the upper Duck River and periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species.

3 - Cumberland Combshell (*Epioblasma brevidens*)

Cumberlandian Combshell is endemic to the Cumberlandian Region. In the Cumberland River drainage, it is confined to that part of the river downstream of Cumberland Falls. It is known from the Tennessee River headwaters in eastern Tennessee and southwestern Virginia downstream to near the mouth of the Duck River (Williams et al. 2008).
This species occurs in shoal habitat of small to large rivers and large creeks. It occupies silt-free gravel, cobble, and sand substrates, where it remains buried until spring and early summer, when it may be found completely exposed (Williams et al. 2008).

As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is relatively low for this species. The Cumberlandian Combshell, a Cumberlandian endemic, was reported in early studies until the early 1970's. Ahlstedt et al. (2017) found only relict shells at numerous sites in the upper river. The Tennessee Wildlife Resources Agency (TWRA) has been reintroducing the Cumberlandian Combshell to suitable habitat in the Duck River since 2013 (TWRA 2019). Not only is *Epioblasma brevidens* considered extant in the upper Duck River, but gravid females were observed by TWRA biologists actively displaying lures in October 2017. Periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species.

**4 - Oyster mussel (*Epioblasma capsaeformis*) – name listed under ESA:
Duck River Dartersnapper (*Epioblasma ahlstedti*) – current taxonomy**

This mussel in the Duck River was described as a new species based on life-history traits, shell morphology, soft anatomy, genetic markers, and other differences (Jones and Neves 2010). *Epioblasma ahlstedti* is currently restricted to the Duck River in west-central Tennessee. However, museum collections indicate that the species likely occurred in the Buffalo River, TN, a tributary to the Duck River, and in the Tennessee River at Muscle Shoals, Alabama, and lower Shoal Creek, Alabama (Jones and Neves 2010). This species occupies shoal habitats in small to large rivers where it inhabits silt-free gravel and sand substrates (Williams et al. 2008).

The Duck River Dartersnapper is a Cumberlandian endemic reported by most early investigators in the Duck River. It is restricted to a limited reach of the upper river below Lillard Mill Dam but is generally distributed and locally common in this reach. TVA located the species downstream to just above the I-65 Bridge, a distance of 28 miles. Previous investigations found four specimens at Lillard Mill (Ahlstedt 1981), but none were found in 1988. The range expansion and increased numbers (nearly 2% of all mussels sampled) of *Epioblasma ahlstedti* have been extensive (Ahlstedt et al. 2017). The Tennessee Wildlife Resources Agency (TWRA) has augmented and continues to augment *Epioblasma ahlstedti* numbers at several sites in the upper Duck River (TWRA 2019). Periods of reduced flow could cause sub-lethal and lethal effects on individuals of the Duck River Dartersnapper, especially since it is only found in the upper reaches of the river. However, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance. This species is currently considered relatively abundant because successful augmentation efforts have boosted the existing population in the upper Duck River.

5 - Catspaw (*Epioblasma obliquata obliquata*)

Nominal *Epioblasma obliquata obliquata* (Williams et al. 2017 determined that nominotypical subspecies is not required, updating it to be *Epioblasma obliquata*) historically occurred in tributaries of Lake St. Clair and Lake Erie of the Great Lakes Basin. It was found in much of the Ohio River drainage from eastern Ohio to the mouth of the Ohio River. It was historically widespread in the Cumberland River drainage downstream of Cumberland Falls, Kentucky and Tennessee. It occurred in middle and lower reaches of the Tennessee River (Williams et al. 2008).

The Catspaw is primarily a species of medium to large rivers. Morrison (1942) speculated that it was a deep-water species, resulting in its rarity in prehistoric shell middens at Muscle Shoals. However, the Catspaw is extant in Killbuck Creek, a small Ohio stream where a reproducing population was found in 1994 (Williams et al. 2008).

While it is difficult to know if the Catspaw was extirpated from deeper reaches of the lower Duck River, this species was not only presumed extirpated from the Duck River, but from all waters within the state of Tennessee. Lillard Mill was chosen by TWRA as the initial site to release captive-reared individuals and subsequently monitor survival and evaluate the potential for future releases in the Duck River (TWRA 2019). Periods of reduced flow could cause sub-lethal and lethal effects on individuals of the Catspaw, especially since it is only known to occur in the upper reaches of the river. As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is relatively low for this species.

6 - Snuffbox (*Epioblasma triquetra*)

Epioblasma triquetra is the most widespread species in its genus. It is known from tributaries of lakes Erie, Huron, Michigan and St. Clair in Indiana, Michigan, New York, Ohio, Pennsylvania and Wisconsin. In the Mississippi Basin, its historical range extended from Minnesota and southern Wisconsin south to Missouri, and from headwaters of the Ohio River drainage in western Pennsylvania west to eastern Kansas. It was historically widespread in the Cumberland River drainage downstream of Cumberland Falls. It also occurred in most of the Tennessee River drainage. A disjunct population of *Epioblasma triquetra* is known from upper reaches of the White River drainage in Arkansas and Missouri (Williams et al. 2008). This species occurs in shoal habitat of small to large rivers. It is usually found buried in gravel or sand substrate with only the apertures exposed (Williams et al. 2008).

First found in the Duck River in the 1890s, *Epioblasma triquetra* was subsequently reported in all published surveys of the upper river, but these accounts are now considered historic.

Ahlstedt et al. (2017) found a single live large individual (68.8 mm) upstream from the mouth of Fountain Creek (presumably not a reintroduced individual) and also reported numerous sites where relict shells were collected. TWRA has been reintroducing Snuffbox at several sites in the Duck River since 2006 (TWRA 2019). Periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species. As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is relatively low for this species.

7 - Pink Mucket (*Lampsilis abrupta*)

Lampsilis abrupta occurs in middle and lower reaches of the Mississippi Basin from Missouri and Illinois downstream to Louisiana. It is known from much of the Ohio River drainage from headwaters in Pennsylvania to the mouth of the Ohio River in Illinois and Kentucky. There are Pink Mucket records from the Cumberland River upstream to the Obey River, Tennessee. This species occurs in much of the Tennessee River drainage from headwaters in southwestern Virginia to the mouth of the Tennessee River (Williams et al. 2008).

This species typically occurs in free-flowing reaches of large rivers, though it is occasionally reported from large creeks and small rivers. Its preferred substrate appears to be gravel with interstitial sand, kept free of silt by current (Williams et al., 2008), though it also occurs in overbank habitat of reservoirs under certain conditions (D.W. Hubbs, pers. comm.).

Presumed extirpated from the entirety of the Duck River, *Lampsilis abrupta* was reintroduced in 2013 by TWRA in both the upper and lower sections of the river (TWRA 2019), due to the lower Duck River being one of the highest priority sites selected for Pink Mucket in the Plan for the Population Restoration and Conservation of Freshwater Mollusks of the Cumberlandian Region (CRMRC 2010). During an October 2017 survey effort, previously reintroduced Pink Mucket individuals were observed alive at Lillard Mill. Periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species. As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is relatively low for this species.

8 - Birdwing Pearlymussel (*Lemiox rimosus*)

Lemiox rimosus is endemic to the Tennessee and Cumberland River drainages. It was described from material collected from the Cumberland River (Rafinesque 1831). However, there are no subsequent reports or museum material from that drainage. All other records of *L. rimosus* are from the Tennessee River drainage, southwestern Virginia downstream to Muscle Shoals, Alabama (Williams et al. 2008).

This species inhabits shoal habitats in small to large rivers but is extirpated from large rivers (though some individuals still persist below Wilson Dam following a NEP reintroduction effort) (Jeff Garner, pers. comm.).

Lemiox rimosus has been reported in all previous surveys except in the lower river. Apparently rare historically, the Birdwing Pearlymussel in the Duck River has increased dramatically in population size and now represents the last significant population range-wide (Ahlstedt et al. 2017). It is generally distributed and fairly common although restricted to the 35-mile upper river reach between the old Columbia and Lillard Mill dams, a near doubling of the range distribution of *L. rimosus* since 1988 (numbers of *L. rimosus* sampled qualitatively via Ahlstedt et al. 2017 were 324, increasing nearly 5-fold from the 1988 investigation that yielded 65) (Ahlstedt et al.

2017). From 1974–75, 33 individuals were translocated into the upper river below Shelbyville Dam (P. Yokley, pers. comm.). However, no live individuals were found to occur in the river upstream from Lillard Mill Dam. A few individuals are documented (D.W. Hubbs, TWRA, pers. comm.) downstream from the old Columbia Dam and may either be cohorts from 49 translocated individuals placed here in 1975 (P. Yokley, pers. comm.) or more likely represent downstream movement of infected fish carrying glochidia. It is a candidate for restoration upstream from Lillard Mill Dam and downstream from the old Columbia Dam. Periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species. However, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is relatively high for the Birdwing Pearlymussel.

9 - Slabside Pearlymussel (*Lexingtonia dolabelloides*)

Lexingtonia dolabelloides is endemic to the Cumberland and Tennessee River drainages. Only a few records exist from the Cumberland River in Kentucky and Tennessee. This species is widespread in the Tennessee River drainage, where it historically occurred from headwaters in southwestern Virginia downstream at least to, and including, the Duck River, Tennessee (Williams et al. 2008).

This species occurs in shoal habitats of large creeks to large rivers. It was historically present in the Tennessee and Cumberland rivers but was extirpated with their impoundment. *P. dolabelloides* is generally found in gravel substrates with some interstitial sand (Williams et al. 2008).

The Cumberlandian endemic Slabside Pearlymussel was reported in all previous surveys of the Duck River, sometimes abundantly (*e.g.*, Ortmann 1924). Ahlstedt et al. (2017) found *Lexingtonia dolabelloides* to be common (nearly 3% of all mussels collected), where they were most abundant between Lillard Mill and old Columbia Dam. The Slabside Pearlymusssel is encountered sporadically in the lower river (D.W. Hubbs, TWRA, pers. comm.; Schilling and Williams 2002). Periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species. However, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is relatively high for this species.

10 - Fluted Kidneyshell (*Ptychobranchus subtentum*)

Ptychobranchus subtentum is endemic to the Cumberland and Tennessee River drainages. There are a few widespread records of this species from the Cumberland River drainage downstream of Cumberland Falls. In the Tennessee River drainage *P. subtentum* occurred historically from headwaters in southwestern Virginia downstream to Muscle Shoals, with disjunct populations in the Buffalo and Duck rivers in central Tennessee. This species appears to have prehistorically occurred in the Tennessee River downstream of Muscle Shoals (Williams et al. 2008). This species occurs in shoal habitats, primarily in small to large rivers. However, a few records exist from medium to large creeks. Its preferred substrate appears to be a mixture of sand and gravel. It can often be found under large, flat rocks (Williams et al. 2008).

Ortmann (1924) was the last investigator to publish a record of this Cumberlandian endemic, although a 1965 record is available from collections made, but unpublished, by Isom and Yokley (1968). In the years leading up to Ahlstedt et al.'s 2017 publication on the *Historical and current examination of freshwater mussels in the Duck River basin*, only relic shells were found, and it was considered to be likely extirpated from the river. In 2006, TWRA began reintroducing *P. subtentum* into the Duck River. Subsequent monitoring surveys have shown that this species is not only persisting but has also successfully recruited (a juvenile *P. subtentum* was discovered in a muskrat midden) (Kendal Moles, TTU Cooperative Fisheries Research Unit, 2013). Periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species. As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is relatively low for this species.

11 - Rabbitsfoot (*Quadrula cylindrica cylindrica*)

Quadrula cylindrica cylindrica is found throughout the Ohio River drainage from headwaters in Pennsylvania to the mouth of the Ohio River. It is widespread in the Cumberland River drainage downstream of Cumberland Falls and in the Tennessee River drainage from headwaters in southwestern Virginia downstream to the mouth of the Tennessee River. It occurs in some tributaries of the lower Mississippi river from southeastern Kansas and Missouri south to Arkansas and northern Louisiana and Mississippi (Williams et al. 2008).

This species occurs in large creeks to large rivers. It is often found along margins of shoals in gravel substrate in slow to moderate current. In Pickwick Dam tailwaters on the Tennessee River it is most often encountered in muddy sand substrates on the submerged shelf along the river margin, in water approximately 2 meters deep (Williams et al. 2008).

The wide-ranging Rabbitsfoot was reported in all previous surveys of the Duck River. This sub-species is generally distributed in the upper river and occasional downstream. Major populations were found at some sites. Its distinctive habitat is in shallow, low-flow shoreline areas. The Rabbitsfoot population in the Duck River represents one of the best-known range wide (Ahlstedt et al. 2017). Periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species. However, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is relatively high for this species.

12 - Winged Mapleleaf (*Quadrula fragosa*)

The species was once extremely widespread (15 states historically). Currently, it is limited to 4-5 isolated populations (depending upon connectivity of the two Arkansas populations): The Little River in Oklahoma, the Saline and Ouachita Rivers in Arkansas, the Bourbeuse River in Missouri, and the St. Croix River bordering Minnesota and Wisconsin. This does not include locations where re-introduction attempts are taking place. Because of misidentifications (confusion with *Quadrula quadrula*), published records cannot be relied upon to accurately reflect the distribution of this rare species (NatureServe Explorer 2020a).

Locality records for this species indicate that it inhabited riffle areas with relatively shallow water depths and substrates ranging from sand and gravel to mixtures that include some cobble and boulder sized particles. The remnant population in the St. Croix River is found in riffles with clean gravel, sand, or rubble substrates and in clear water of high-water quality, but this may not reflect ideal habitat (NatureServe Explorer 2020a).

The once widely distributed species was last reported in the early 1900s. Relic shells were collected in 1990 and 1991 at Wilhoite Mills and Lillard Mill Dam. The Winged Mapleleaf was not only considered extirpated from the Duck River but was also considered possibly extirpated from the entire Ohio River system (Ahlstedt et al. 2017). Two parallel efforts to propagate Winged Mapleleaf are ongoing – one in the northern part of the species' range that uses mussels from the St. Croix River for propagation and one in the south that relies on the Saline River population in Arkansas for brood stock. The current and ongoing Duck River reintroduction is part of the southern ('Saline River') effort. Reintroduction of the endangered Winged Mapleleaf to the Duck River in Tennessee is listed as a highest priority species (TWRA 2019). Periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species. As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is relatively low for this species.

13 - Cumberland Monkeyface (*Quadrula intermedia*)

Quadrula intermedia is endemic to the Tennessee River drainage of Alabama, Tennessee, and Virginia (Williams et al. 2008).This species occurs in flowing waters in medium to large rivers. It generally occurs in substrates comprised of gravel with interstitial sand (Williams et al. 2008).

This Cumberlandian endemic was reported in all previous surveys but not in the lower river. The Cumberland Monkeyface is restricted to an approximately 22-mile reach of upper-river from Lillard Mill Dam to Jackson's Bend where it is generally distributed but rare. This is an increase of 9 miles from previous surveys (1977), and numbers increased over 7-fold. The Duck has the best remaining population range-wide of this species (Ahlstedt et al. 2017). Periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species. However, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is relatively high for this species.

14 - Pale Lilliput (*Toxolasma cylindrellus*)

Toxolasma cylindrellus is endemic to middle reaches of the Tennessee River drainage in Alabama and Tennessee and the Duck River system in central Tennessee (Williams et al. 2008).

Before being re-introduced to the Duck River, this species had been considered eliminated from all medium to large river habitats and was thought to persist only in small to medium reaches of the Paint Rock River system in Alabama. However, in May 2015 TWRA (Don Hubbs) discovered a second viable population in the headwaters of Lick Creek located in southwest Williamson and northwest Maury counties, TN (TWRA 2019). It occurs in moderate current, usually in gravel substrates (Williams et al. 2008). It also occurs often in shallow water with muddy substrate on stream margins (Michael Bunting, ADCNR, pers. comm. 2020).

A Cumberlandian endemic, the Pale Lilliput was first reported in the Duck River in the original description by Isaac Lea. Except for Ortmann (1924), subsequent investigators often failed to differentiate this species from the very similar Purple Lilliput making, its collection history in the Duck problematic (Ahlstedt et al. 2017). For instance, van der Schalie (1939, 1973) combined the two species, while Isom and Yokley (1968) misidentified several Pale Lilliput specimens. The last confirmed records for the Pale Lilliput were by H. D. Athearn in 1970 and 1980 (Ahlstedt et al. 2017). This species was considered extirpated from the Duck River before it was first reintroduced at Venable Spring. The initial release utilized 802 cultured *T. cylindrellus* propagated from 6 different females, collected from the Estill Fork of the Paint Rock River. Periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species. As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is relatively low for this species.

15 - Rayed Bean (*Villosa fabalis*)

In the Great Lakes Basin *Villosa fabalis* is known only from Lake St. Clair and nearby Lake Erie. It is widespread in the Ohio River drainage, from headwaters in western New York and Pennsylvania downstream to near the mouth of the Ohio River. There are no records of *V. fabalis* from the Cumberland River drainage. It is widespread in the upper Tennessee River drainage of southwestern Virginia and eastern Tennessee as well as upper reaches of the Elk River. The only historical record of *V. fabalis* from middle and lower reaches of the Tennessee River drainage is from the Duck River (Williams et al. 2008).

This species occurs primarily in flowing water of small to large streams but may also be found in small or medium rivers and occasionally in natural lakes, including Lake Erie. In lakes it is usually found in areas that are subject to frequent wave action. It usually occurs in sand and gravel substrates, often in and around roots of aquatic plants (Williams et al. 2008).

The rayed bean, a wide-ranging but imperiled species, was recorded in most early surveys. It was last reported in 1982 (2 live) downstream from Lillard Mill Dam. However, historical records of the species in the Duck River were not uncommon (Ahlstedt et al. 2017). Periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species. As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance. This small mussel is considered extant but quite rare in the Duck River (TWRA 2019).

16 - Pygmy Madtom (*Noturus stanauli*)

Noturus stanauli has been found, and still exists, in only two short reaches of the Duck and Clinch Rivers. These river reaches are about 600 river miles apart and separated by impoundments. No historical records exist for the reintroduction (NEP) sites in the lower French Broad River or lower Holston Rivers, but historically the species likely was more widespread in the Tennessee River system and probably inhabited these waters (NatureServe Explorer 2020b).

Etnier and Jenkins (1980) described the habitat of *N. stanauli*’s type locality as being at the head of a prominent bed of water willow (*Justicia americana*). In this area substrates were of medium gravel, water depths were typically 0.5 meters or less, and current was about 0.3 m/sec. In the lower Duck River, Humphreys County, Tennessee, several specimens were encountered over fine gravel substrates at depths of 1 meter, and with a velocity of 0.6 m/sec. Many occur in flowing portions of pools during the reproductive season (Dinkins and Shute 1993). Other aspects of its biology are unknown.

Drought are known to slow down the natural flow of streams, compromise water quality, hamper fish movement, limit available prey, and prevent waste and fine sediments from flushing out of the stream (USFWS, retrieved 2020). Piniewski et al. (2017) synthesized data from 82 case studies regarding floods and droughts and demonstrated that in many cases the studied metrics (abundance, density, richness, and diversity) showed statistically significant decreases after or during the flood/drought event occurrence. However, the responses in invertebrate density and richness were in general more negative than the corresponding responses in fish. Biota resistance to floods was also found to be lower than the resistance to droughts. Because Etnier and Jenkins (1980) postulated that Pygmy Madtoms have a short, one-year lifespan, it is unknown to what degree this aspect of its life history would be affected by drought conditions, though periods of reduced flow could cause sub-lethal and lethal effects on individuals of this species.

17 - Tan Riffleshell (*Epioblasma florentina walkeri*)

The Tan Riffleshell, a Cumberlandian endemic, has a sporadic collecting history in the Duck River. The last records were for two individuals collected in 1964 and a fresh dead shell found in 1988 upstream from the old Columbia Dam (Ahlstedt et al. 2017). The Tan Riffleshell is considered to be extremely rare in the Duck River and is likely completely extirpated. It has not been reintroduced by state or federal agencies. As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is very low for this species. If any individuals of this species do persist, then periods of reduced flow could cause sub-lethal and lethal effects.

18 - Sheepnose (*Plethobasus cyphyus*)

There are no published reports of the widely distributed Sheepnose, but an early museum record exists from the lower Duck River collected by C. M. Wheatley. In 2003, a live individual was found just downstream from the old Columbia Dam by TVA fisheries biologists (A. Wales, TVA, pers. comm.). The individual was photographed, and its identification confirmed. This represents its first occurrence in the river in over a century (Ahlstedt et al. 2017). The Sheepnose is considered extremely rare in the Duck River and it has not been reintroduced (or had its population augmented) by state or federal agencies. If any individuals of this species do persist, then periods of reduced flow could cause sub-lethal and lethal effects.

19 - Scaleshell (*Leptodea leptodon*)

Formerly a widely distributed species, Hinkley and Marsh (1885) is the only published record for the Scaleshell from the Duck, but one additional record from the Duck River (with no other accompanying information) is housed at the University of Michigan Museum of Zoology. Currently *L. leptodon* is extirpated from the entire Ohio River system but is a candidate for restoration (Ahlstedt et al. 2017). The Scaleshell is likely completely extirpated from the Duck River but is otherwise considered extremely rare. It has not been reintroduced by state or federal agencies. As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is very low for this species. If any individuals of this species do persist, then periods of reduced flow could cause sub-lethal and lethal effects.

20 - Ring Pink (*Obovaria retusa*)

Hinkley and Marsh (1885) were the only individuals to report this big river Ohio River system endemic from the Duck River. Ortmann (1924) subsequently accepted their record based on its easy identification. Further, the now extirpated lower Tennessee River populations had ready access to the Duck. This species is now restricted to the Green River in Kentucky (Ahlstedt et al. 2017). The Ring Pink is almost certainly extirpated from the Duck River. It has not been successfully propagated in captivity and has not been reintroduced by state or federal agencies in any water body. As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance, which is very low for this species. If any individuals of this species do persist, then periods of reduced flow could cause sub-lethal and lethal effects.

21 - Littlewing Pearlymussel (*Pegias fabula*)

A single specimen of this Cumberlandian endemic was collected in the Duck River in 1888, but archaeological specimens are known from the upper river including Fountain Creek (Parmalee and Klippel, 1986). No other records exist. This species is a candidate for restoration in the upper river (Ahlstedt et al. 2017). This species is notoriously difficult to detect due to its small size. As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance. The Littlewing Pearlymussel is likely completely extirpated from the Duck River but is otherwise considered extremely rare. It has not been reintroduced by state or federal agencies. If any individuals of this species do persist, then periods of reduced flow could cause sub-lethal and lethal effects.

22 - Cracking Pearlymussel (*Hemistena lata*)

Affected Environment – The amount of physical habitat available would be temporarily reduced during periods of reduced flow stemming from drought conditions. After drought conditions cease and standard operations return at Normandy Dam, the amount of physical habitat available for freshwater mussels to colonize would return to the amount indicative of pre-drought conditions.

Though historical records place this Ohio River endemic up to Columbia, *Hemistena lata* was generally considered rare range wide (Ortmann 1924) and was last reported in the Buffalo River (Isom and Yokley 1968). This species is a candidate for restoration in the Duck River (Ahlstedt et al. 2017). As discussed above, Haag and Warren (2008) found that the likelihood of surviving drought conditions was primarily a function of pre-drought abundance. The Cracking Pearlymussel is likely completely extirpated from the Duck River but is otherwise considered extremely rare. It has not been reintroduced by state or federal agencies. If any individuals of this species do persist, then periods of reduced flow could cause sub-lethal and lethal effects.

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