U.S. Army Corps of Engineers Louisville District

Science and Concepts for Environmental Flows
Green River Basin – Barren, Nolin, and Rough River Lakes

Sustainable Rivers Program

Nolin River, Nolin River Dam and outflow (USACE photo)

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Introduction

The Nature Conservancy (TNC) and the U.S. Army Corps of Engineers (USACE) have partnered to form the Sustainable Rivers Program (SRP) to examine opportunities to optimize reservoir releases and river flows to benefit river ecology while maintaining the federal mandates of the reservoir system in the United States. The mission of SRP is to improve the health and life of rivers by changing water infrastructure operations to restore and protect ecosystems, while maintaining or enhancing other project benefits. The founding objective of SRP is implementation of environmental flows (e-flows), which are defined as the quantity, timing, and quality of water flows required to sustain ecosystems. The SRP has grown from 8 rivers in 2002 to 55 rivers in 2025, influencing over 13,500 miles of U.S. waterways and including 90 associated reservoirs and 7 lock and dam facilities. This represents 38% of USACE's water resource portfolio.

Dams, especially large ones, are the most common anthropogenic mechanism that alters flow regimes and their variability (Graf 2006). The ecological and physical impacts of the damming of waterways are pervasive and persist well downstream. Dams encumber native species life cycles, decrease species richness, divorcing the river from its floodplain, and aid in the establishment of non-native species. (Acreman et al. 2009, Chen and Olden 2017, Richter and Thomas 2007, Risley et al. 2010, Warner et al. 2014). Dams cause hydrologic alterations that reduce peaks, prolong baseflows, smooth hydrographs, produce unseasonably high flows, and impact water quality, in particular water temperature and dissolved oxygen (DO). Through the SRP, USACE and TNC intend document the ecological needs of the basin and develop reservoir operational strategies to improve downstream conditions, where feasible, for 3 impoundments in the Green River Basin (GRB) in central Kentucky – Barren River Lake, Nolin River Lake, and Rough River Lake.

History of Environmental Flows

The concept of e-flows emerged as a response to the widespread ecological consequences of altering natural river systems for human purposes such as agriculture, hydropower, and flood control. During the 20th century, dam construction and river regulation significantly disrupted natural flow regimes, resulting in habitat loss, reduced biodiversity, and the degradation of ecosystem services essential for both human and environmental health (Poff et al. 1997). Early efforts to address these impacts focused narrowly on maintaining "minimum flows" for specific species or uses, often without considering the broader ecological needs of river systems (Acreman & Dunbar 2004).

In the 1970s and 1980s, scientific understanding of riverine ecosystems advanced, emphasizing the importance of flow variability to sustain ecological integrity. Researchers recognized that ecosystems depend on a full range of flows, from high flows that maintain channel structure and floodplain connectivity to low flows that sustain aquatic habitats during dry periods (Poff et al. 1997, Arthington et al. 2006). This shift led to the development of the "natural flow paradigm," which identifies the magnitude, frequency, duration, timing, and rate of change of flows as essential components of ecological health (Richter et al. 1996).

A significant milestone in the history of e-flows was the Brisbane Declaration of 2007, which provided a widely accepted definition of environmental flows as "the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods that depend on them" (Arthington et al. 2018). This global commitment emphasized the integration of e-flows into water management policies and underscored the need for interdisciplinary collaboration to address challenges such as climate change and competing water demands (Poff & Zimmerman 2010).

In the United States, the SRP has been a leader in e-flow implementation. Initially focusing on eight river systems, the SRP has expanded to more than 40 river systems, demonstrating the feasibility of balancing ecological and human water needs through collaborative management (Richter & Thomas 2007). By integrating ecological science into reservoir operations, the SRP has helped improve downstream ecosystems while maintaining project benefits such as flood control and water supply.

Today, e-flows are recognized as a cornerstone of sustainable water management. Advances in ecological science, hydrology, and adaptive management strategies continue to refine their implementation. As water systems face mounting pressures from climate change and increasing demands, e-flows offer a vital pathway to maintain the resilience and functionality of riverine ecosystems for the benefit of both nature and society (Poff et al. 2010).

Goals and Objectives

The goal of this project is to analyze the effects of water management operations on downstream conditions and ultimately develop flow prescriptions for Barren, Nolin, and Rough Rivers below their respective reservoir dams to support ecosystem health and resilience while aiding in the conservation of federally threatened and endangered species as well as other species of conservation concern. The objective of this report is to bolster e-flows science for the GRB and to serve as a primer for an e-flows workshop held on May 7th, 2025, by providing:

- Background on the GRB and its rivers,
- Details on operations of Nolin River, Barren River, and Rough River dams,
- Known impacts to Nolin River, Barren River, and Rough River hydrology, and
- A coordinated list of target species around which to develop e-flow recommendations.

Green River Basin Characteristics and Water Management

The Green River watershed (Figure 1), encompassing approximately 9,230 square miles, is located in west-central Kentucky and extends into north-central Tennessee. The headwaters of the Green River originate in Lincoln and Casey Counties, Kentucky in the Mississippian Plateau where it then flows in a northwesterly direction for 330 miles through the Western Coal Field region to its confluence with the Ohio River near Henderson, KY. As the largest of the twelve river watersheds in Kentucky, six sub-basins are contained within the Green River watershed, including the Barren River, Upper Green, Middle Green, Rough River, Pond Creek and Lower Green watersheds. The Green River Basin has a long history of human use and is one of the most ecologically diverse river systems in the United States. Targeted exploitation of freshwater mussels along the Green River dates back 6000 years before present (Jefferies 1996) and shell midden archaeological sites along the Green River have contributed significantly "… in establishing the very concept of an Archaic Tradition or Period in Eastern North America" (Morey and Crothers 1998: 907-8).

The GRB contains four reservoirs owned and operated by USACE Louisville District (LRL) – Green River Lake, Barren River Lake, Nolin River Lake, and Rough River Lake. These multi-purpose reservoirs on the mainstem and tributaries to the Green River support flood control, water supply, water quality, and recreation. The use of each reservoir is guided by project-specific water control manuals (WCMs) to ensure project compliance with congressionally approved operating purposes.

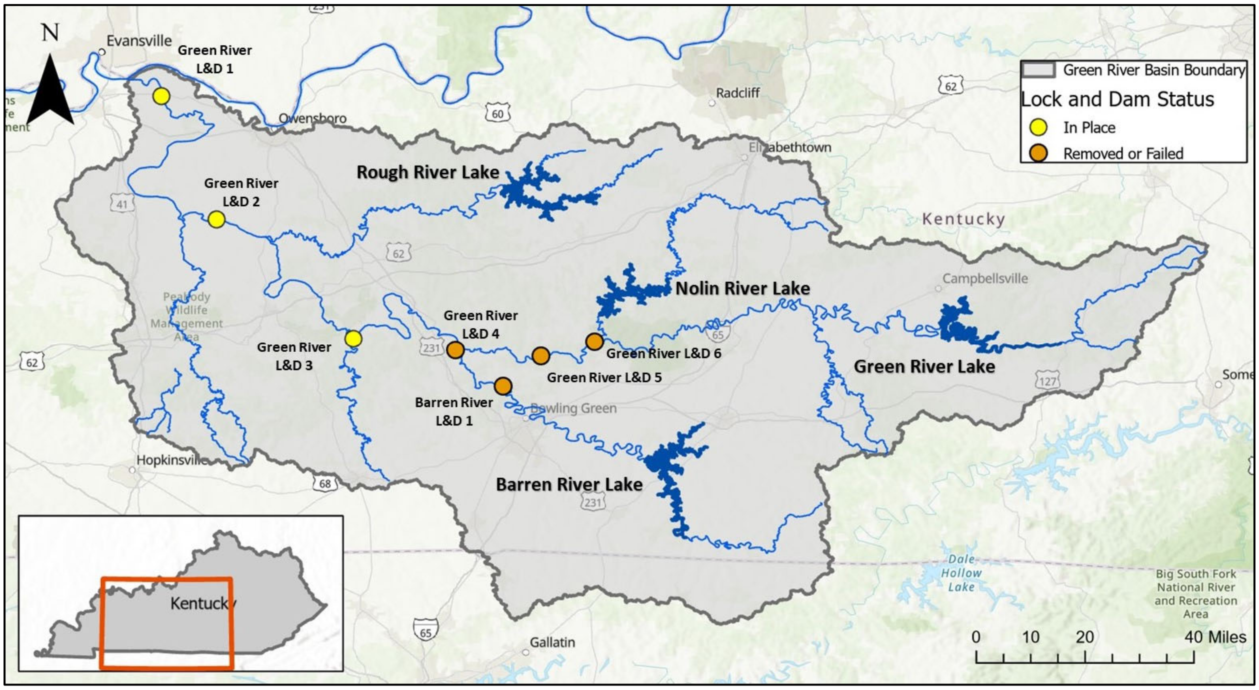

Figure 1. Green River watershed its water control structures showing the U.S. Army Corps of Engineers Lake Projects and Lock and Dams throughout the basin.

Remaining unglaciated during the most recent Ice Ages, the GRB provided an environment where species could persist and diversify. Therefore, the Green River System is one of the most ecologically significant aquatic systems in the United States, and the most biologically diverse branch of the greater Ohio River Basin. At least 20 federally threatened & endangered (T&E) mussel species have been documented in the basin, with the Kentucky Department of Fish and Wildlife Resources (KDFWR) recognizing that the river is the last refugia for some mussel species that were once common in the Ohio Valley but are "tenuously holding onto their presence on Earth in the [GRB]" (McClellan 2025).

Karstic landscapes influence the nature of the Green River throughout its journey to the Ohio River. Many springs feed the river, and the cool, clean water provides microhabitats for wildlife and give the river its pellucid color. Approximately 110 miles downstream of Green River Reservoir, the Green River flows into the cave systems of Mammoth Cave National Park (MCNP). This stretch of river, from the reservoir dam through MCNP, holds the greatest aquatic diversity in the whole watershed (KDFWR 2023). MCNP has one of the most biodiverse subterranean habitats in the world with approximately 40 cave-adapted organisms, including the endemic Kentucky cave shrimp whose range exists only within the National Park boundary. Inside MCNP, nearly 200 species of benthic macroinvertebrates have been found. With six miles of the Nolin River and 25 miles of the Green River flowing through the National Park, both directly impact the delicate aquatic ecological communities present in the cave systems below. Mammoth Cave and other caves in the region depend on backflow from the GRB to anchor the food web that supports the rare subterranean ecosystems found there (NPS 2023).

The rise of commercial river commerce following the impoundment of several rivers of the basin in the mid-1800s resulted in major ecological changes to the major tributaries of the GRB, including the Green and Barren Rivers. The subsequent decline of the logging economy and steamboat trade in the late 1800's was followed by a rise of a coal-based economy in the 1900's, which catalyzed modernization of Green

River lock and dam (L&D) #1 and #2 and clearing of the lower 1/3 of the Green River for modern barge traffic. It was decades of instream development and wholesale changes to the hydrology and flow regimes of the major streams of the basin which ultimately precipitated and/or accelerated decline of many of the species now known to be imperiled there (Crocker 1976).

The middle of the 20th century saw alterations to the lower stretch of the Green River and creation of flood control reservoirs on the upper sections of the GRB. USACE currently operates four federal reservoir projects (Green River Dam, Nolin River Dam, Barren River Dam, and Rough River Dam) in the GRB system. These reservoirs, providing needed flood security to downstream residents, were praised by many in the region, but also criticized by some looking at the environmental effects of the water control structures built on the river over the previous 100 years. These environmental concerns only heightened in the late 20th century as the importance of the GRB for preserving unique, endemic, and T&E species was understood.

The history of the Green River Watershed over the last two centuries is one of river control for commerce and flood reduction. In recent decades, scientists, conservation organizations, and governments have recognized the importance of the greater Green River basin ecosystem and the need to preserve and, where possible, restore it. In the 1990s, these groups came together for that common, unified purpose. A collaboration between USACE, TNC, and other stakeholders saw the completion of the first Sustainable Rivers Program (SRP) project in the GRB in 2002. This SRP project reestablished more natural water flow and hydrology in the Green River below Green River Lake Dam which helped to prevent unnatural backflows into Mammoth Cave from water releases at the upstream dam. A need was eventually identified for the removal of L&Ds in the basin. In 2014, Congress recommended that the Green River L&D #'s 3, 4, 5, 6 and Barren River L&D #1 be deauthorized. Subsequent dam removal efforts both completed (Green River #6 in 2017 and #5 2024, and Barren River #1 in 2022) and ongoing (Green River #4) have moved towards reestablishing the original hydrological regimes and connectivity of lotic ecosystems of the GRB system. This is expected to have both short- and long-term benefits on fish and mussel populations as well as recreation activities within the watershed.

Since 2002, the SRP has demonstrated how successful cooperation between stakeholders can affect change, generate ideas, and spur future action to improve ecological function in the GRB. Recent and current work, such as L&D removals and the establishment of SRP working groups, offer ideas and solutions for potential future actions to further benefit and protect the natural heritage of the GRB.

Barren River

The largest tributary to the Green River is Barren River. The Barren River lies in south-central Kentucky and north-central Tennessee, and includes an area of 2,262 miles, of which 1,852 are in Kentucky and 410 in Tennessee. It is bounded on the north and west by the watershed of the Green River and on the south and east by the Cumberland River basin. The drainage area of the Barren River comprises 40 percent of the area in the Green River basin above the confluence of the two streams (Green River Mile 149.6) and about 25 percent of the entire drainage area. The Barren River watershed is roughly triangular in shape, about 55 miles long and 40 miles wide. Barren River is formed by the confluence of Line Creek and East Fork in Monroe County, Kentucky, and generally flows in a northwesterly direction for 139 miles until its junction with the Green River at Woodbury, Kentucky, 149 miles upstream from the Ohio River. It drains part of all of five counties in Kentucky – Allen, Barren, Butler, Monroe, and Warren.

Nolin River

Nolin River is the fourth largest tributary of Green River, entering at mile 183.5 and draining an area of 727 square miles. The confluence is 1.8 miles upstream of the former Green River L&D No. 6 location. The Nolin River basin encompasses portions of Edmonson, Grayson, Hardin, Hart, and Larue Counties. Major tributaries which drain into the lake include Bacon Creek and Rock Creek. The river flows through Mammoth Caver National Park and confluences with the Green River within the Park boundary. Most of the watershed is rural.

Rough River

Rough River is the second largest tributary of Green River and drains an area of 1,081 square miles including major parts of Breckinridge, Grayson, Hardin, and Ohio Counties. This comprises approximately 12 percent of the Green River watershed. Rough River flows 141 miles in a westerly direction from its headwaters in west central Hardin County to its confluence with the Green River in McLean County at Green River Mile 71.3. Many small tributary streams to Rough River lie both above and below Rough River Lake. Major tributaries which drain into the lake include the North Fork Rough River, Rough Creek, and Clifty Creek. Rock Like Creek, Adams Fork, Halla Creek, and Caney Creek enter the Rough River downstream from the lake. The Rough River watershed is rural in nature, with the major land usage being agriculture.

Climate

Green River Basin

Climate of the GRB is temperate continental with well-defined seasons; summers are hot and humid and winters are moderately cold and dry. Large daily and annual variations in temperature and precipitation are characteristic. Climate data of the GRB was gathered from the nearest National Oceanic and Atmospheric Administration (NOAA) weather station at USACE Reservoirs for Barren, Nolin, and Rough Rivers. The data from these stations was then averaged to obtain the mean for the watershed. The 25 years from 2000-2025 were queried at each weather station to represent recent climate trends. Mean annual precipitation was 54.8 inches with the wettest months occurring in late spring and summer and the driest months occurring late summer and early fall. Mean annual temp was 57.7 degrees, with July being the hottest month (77.7°F) and January being the coolest (34.7°F).

Historically, large rainfall events have the potential to cause serious flooding in the GRB, with most floods typically occurring from late winter to early spring. These weather patterns occur as a result of quasi-stationary fronts that originate from the southwestern United States and the Gulf of Mexico and move northeastwardly towards the north Atlantic Coast. Heavy rainfall events of this type are most impactful during the winter and early spring months due to freezing conditions that work to increase runoff rates.

Physiology and Geology

The GRB in Kentucky is characterized by a combination of physiographic features, including karst topography and river valleys, and geological formations of limestone, shale, and sandstone. The basin is divided into four structural and topographic subbasins by intra-basin anticlines, with the Rock Springs uplift being the largest.

Much of the Mississippian Plateau is underlain primarily by Mississippian-aged limestone. The upland or Pennyroyal Plain area of the Mississippian Plateau is permeated by tens of thousands of sinkholes that are eroded in the underlying limestones. These limestones are soluble and can easily be eroded by waters moving through the ground. This resulting "karst" topography forms an extensive network of subsurface channels that impact surface-runoff drainage systems across the region. Creeks often disappear into sinkholes and reappear as springs at lower elevations. Most of the Mississippian Plateau is drained by the Green River and its tributaries including the Barren and Nolin rivers. It was the collapsed topography, sinking streams, and erosion of the limestone strata over millennia that created the extensive cave networks that are common in the area, including Mammoth Cave which is the is the longest cave system in the world

The Barren River Lake Project is situated in the Pennyroyal physiographic areas. The lake itself lies within the Interior Low Plateau Physiographic Province. This province lies south of the limit of glaciation and along the axis of the Cincinnati Arch. The Pennyroyal Region is the largest physiographic region (12,000 sq. miles) of the state, stretching along the southern border of Kentucky from the Appalachian Plateau west all the way to Lake Barkley. The Eastern Pennyroyal is an area of steep sloping uplands and narrow ridges with underground drainage and karst areas (USACE 1985).

Nolin River Lake is situated in a transition zone of the Western Coal Field and Pennyroyal physiographic areas. The lake itself lies within the Pennyroyal Interior Lower Plateau Province (Shawnee Hills Section, Mammoth Cave Plateau Subsection) of the Mississippian Plateau. The Pennyroyal Region is the largest physiographic region (12,000 sq. miles) of the state, stretching along the southern border of Kentucky from the Appalachian Plateau west all the way to Lake Barkley. The Dripping Springs Escarpment is also present in this area and encircles the sandstone and shale portion of Western Pennyroyal, separating it from the limestone of the Western Pennyroyal (NRCS 2006).

Rough River Lake is located within the eastern-most portion of the Western Kentucky Coal Field physiographic region near its boundary with the Mississippian Plateaus region of south-central Kentucky. The Mississippian Plateaus region is subdivided into the western Mammoth Cave Plateau and the eastern Pennyroyal Plateau, which are separated by the Dripping Springs Escarpment. The Green River marks the approximate southern boundary between the Western Kentucky Coal Field region and the Mammoth Cave Plateau (NRCS 2006).

Reservoir History, Operations, and Relevant Data

Barren River Lake

Barren River Lake is located 95 miles south of Louisville in south-central Kentucky. It is about 20 miles north of the Kentucky-Tennessee border, 10 miles northeast of Scottsville, Kentucky, and 16 miles southwest of Glasgow, Kentucky (see Figure 1). The dam site is located on the Barren River, a tributary of the Green River, approximately 79 river miles above the confluence of these rivers. The reservoir spans sections of Allen, Barren, and Monroe counties in Kentucky. Construction of the operating tower and outlets works began in March 1960 and was completed in December 1961. Construction of the dam and spillway began in April 1962 and was completed in October 1964. The earthen dam is 3,970 feet long at its crest and 146 feet high at the highest point (above the riverbed). An open-cut spillway allows the release of excess water to prevent flow over the dam. The maximum water depth is 74 feet at the dam. The control tower on the upstream side of the dam has inlets at the bottom which allow the water to pass through a conduit under the dam. The 3,970-foot-long embankment section (Saddle Dam) consists of rolled earth fill with random rock fill. Table 1 provides characteristics of the Barren River Lake Dam including physical data, hydrology, and operating levels.

The Barren River basin lies in south-central Kentucky and north-central Tennessee. The Barren River watershed is approximately 55 miles long and 40 miles wide and has a drainage area of 2,262 sq. miles.

The watershed is bounded on the north and west by the watershed of the Green River and on the south and east by the Cumberland River basin.

Barren River, the largest tributary of the Green River, is formed by the confluence of Line Creek and East Fork in Monroe County, Kentucky, and flows in a north-westerly direction for 139 miles to its junction with the Green River at Woodbury, Kentucky, 149 miles upstream from the Ohio River. The Barren River watershed drains part or all of eight counties in Kentucky and three in Tennessee. The principal tributaries of Barren River are Drakes Creek (draining 503 sq. miles in the southwest section of the basin), Skaggs Creek (draining 313 sq. miles in the northeast corner), and Gasper River (211 sq. miles in the western portion of the basin). The topography of the general area of the Barren River basin is relatively rugged to rolling, with the more gently rolling area near the center of the basin and the more rugged areas in the headwaters and the near the mouth of the Barren River. The lower 30-mile reach of Barren River, starting from Bowling Green, Kentucky, has been canalized for navigation, with a minimum depth of 5.5 feet.

Nolin River Lake

Nolin River Lake is located about 8 miles above the confluence of the Nolin and Green Rivers near the community of Bee Spring, Kentucky. While the dam is in Edmonson County, Kentucky, the lake also covers portions of Grayson and Hart counties in Kentucky (see Figure 1). The dam is about 8 miles north of Brownsville, Kentucky; 20 miles from Leitchfield, Kentucky; and 95 miles southwest of Louisville, Kentucky. The 5,795-acre lake was created from the impoundment of the Nolin River in 1963, and the 333-acre park is located along the northern edge of Mammoth Cave National Park in Edmonson County, Kentucky. Table 2 provides characteristics of the project including physical data, hydrology, and operating levels.

Rough River Lake

Rough River Lake is situated in Breckinridge, Hardin, and Grayson counties in south central Kentucky. The dam is located on the Rough River near the community of Falls of Rough, about 20 miles from Leitchfield and 80 miles southwest of Louisville.

The Rough River basin lies entirely within Kentucky, with the headwaters originating in west central Hardin County. Rough River meanders 141 miles in a west-by-southwesterly direction, draining portions of six counties, to its confluence with the Green River at mile 71.3. The watershed is roughly rectangular in shape, about 63 miles in length with an average width of 17 miles wide. The drainage area at Rough River Dam is 454 square miles, and total drainage area of the Rough River basin at the Green River confluence is 1,081 square miles. See Figure 1 regarding the project area hydrology. Table 3 provides characteristics of the project including physical data, hydrology, and operating levels.

Table 1. Summary data of Barren River Lake.

Physical Data		
Dam Type	Rolled earth fill with random rockfill	
Maximum Height	146 feet	
Length	3,970 feet	
Top Elevation	617.6 feet NAVD88	
Spillway Type	Uncontrolled open cut through right abutment	
Spillway Crest Elevation	589.6 feet NAVD88	
Spillway Base Width	300 feet	
Outlet Works	Three 6.5 x 14 feet slide gates in an 17 x 17 feet semi-elliptical concrete conduit. Two 36-inch bypass pass pipes with two multi-level gates	
Conduit Inlet Invert Elevation	477.6 feet NAVD88	
Bypass Inlet Invert Elevation	Two multi-level gates with invert elevations 530.6 NAVD88 and 512.6 NAVD88	
Hydrology		
Drainage Area	940 mi^2	
Basin Average Rainfall from PMP	25.68 inches (Barren Periodic Assessment #1, 2016)	
Probable Maximum Flood (PMF) Peak Inflow	734,300 cfs (Barren Periodic Assessment #1, 2016)	
Max. PMF Pool Elevation	620.3 feet NAVD88 (Barren Periodic Assessment #1, 2016)	
Maximum 6-Hour Inflow	130,814 cfs; 3 May 2010*	
Maximum Period-of-Record Release	5,900 cfs; March 1964	
Maximum Period-of-Record Pool Elevation	582.6 feet NAVD88; 8 March 1989*	
Average Discharge from Dam site	1,492 cfs*	
Operating Levels		
Pool	*Elevation (feet NAVD88)*	*Storage (acre-ft)*
Top of Dam	617.6	1,539,750
Top of Flood Control Pool (spillway crest elevation)	590	815,150
Seasonal Pool (April 14 – October 15)	552	256,360
Water Quality and Water Supply Pool	519.7 – 521.5	6,350
Minimum Pool	528	79,860
Upstream projects, River Mile, and Drainage Area	Not applicable	

**Values from district provided database.*

***Storage above seasonal pool calculated as part of the hydrologic model development using the elevation storage curve developed using the Barren River Lake water control manual.*

****From most recent Inspection Report.*

Source: USACE 1967

Table 2. Summary data of Nolin River Lake.

Physical Data		
Main Dam:		
Dam Type	Rock Fill with earth core	
Maximum Height	166 feet	
Length	980 feet	
Top Elevation	581 feet NGVD29	
Spillway Type	Uncontrolled open cut	
Spillway Crest Elevation	560 feet NGVD29	
Spillway Base Width	300 feet	
Outlet Works	Three 7.25 x 14 feet slide gates in an 18 x 18 feet semi-elliptical concrete conduit. Two 36-inch bypass pass pipes with three multil-level gates	
Conduit Inlet Invert Elevation	422 feet NGVD29	
Bypass Inlet Invert Elevation	Three multi-level gates with invert elevations 470 NGVD29, 484.3 NGVD29 and 497.7 NGVD29	
Hydrology		
Drainage Area	703 mi^2	
Basin Average Rainfall from PMP	26.5 inches (Nolin Issue Evaluation Study, 2011)	
Probable Maximum Flood (PMF) Peak Inflow	376,000 cfs (Nolin Issue Evaluation Study, 2011)	
Max. PMF Pool Elevation	579.1 feet NGVD29 (Nolin Issue Evaluation Study, 2011)	
Maximum 6-Hour Inflow	51,481 cfs; 5 May 1984*	
Maximum Period-of-Record Release	10,328 cfs; 26 May 1983*	
Maximum Period-of-Record Pool Elevation	559.7 feet NGVD29; 6 May 2011*	
Average Discharge from Dam site	950 cfs (Nolin Issue Evaluation Study, 2011)	
Operating Levels		
Pool	*Elevation (feet NGVD29)*	*Storage (acre-ft)*
Top of Dam	581	975,170
Top of Flood Control Pool (spillway crest elevation)	560	609,425
Seasonal Pool (April 14 – October 15)	515	170,610
Water Quality and Water Supply Pool	N/A	N/A
Minimum Pool	492	69,811
Upstream projects, River Mile, and Drainage Area	Not applicable	
**Values from district provided database.*		

Table 3. Summary data of Rough River Lake.

Physical Data		
Main Dam:		
Dam Type	Rolled Earth Fill	
Maximum Height	130 feet	
Length	1,590 feet	
Top Elevation	556 feet NGVD29 + 3-foot parapet wall	
Spillway Type	Uncontrolled open cut	
Spillway Crest Elevation	524 feet NGVD29	
Spillway Base Width	65 feet	
Outlet Works	Three 4.75 x 9.5 feet slide gates in an 12 x 12 feet semi-elliptical concrete conduit. Two 24-inch bypass pass pipes	
Conduit Inlet Invert Elevation	430 feet NGVD29	
Bypass Inlet Invert Elevation	449.8 feet NGVD29	
Hydrology		
Drainage Area	454 mi^2	
Basin Average Rainfall from PMP	27.83 inches	
Probable Maximum Flood (PMF) Peak Inflow	344,000 cfs	
Max. PMF Pool Elevation	556.7 feet NGVD29	
Maximum 6-Hour Inflow	54,400 cfs; 14 Feb 1989*	
Maximum Period-of-Record Release	6,400 cfs; 4 May 2011*	
Maximum Period-of-Record Pool Elevation	527.4 feet NGVD29; 4 May 2011*	
Maximum release and Minimum release during normal operation	3,000 cfs/50 cfs	
Mean Annual Discharge	680 cfs	
Maximum Design Discharge Capacity of the conduit and outlet works	5,600 cfs	
Discharge Capacity of the Bypass system with the Reservoir at seasonal pool	200 cfs	
Average Discharge from Dam site	670 cfs	
Operating Levels		
Pool	*Elevation (feet NGVD29)*	*Storage (acre-ft)*
Top of Dam	559	869,100
Top of Flood Control Pool (spillway crest elevation)	524	334,380
Seasonal Pool (April 14 – October 15)	495	120,010
Water Quality and Water Supply Pool	N/A	N/A
Minimum Pool	470	29,800
Upstream projects, River Mile, and Drainage Area	Not applicable	
**Values from district provided database.*		

Selective Withdrawal and Thermal Stratification

During the warmer season, most reservoirs undergo a process called thermal stratification. Thermal stratification results in a separation of the lake into three distinct layers. From top to bottom, these layers are called the epilimnion, metalimnion, and hypolimnion. While this process is driven by temperature, each of these layers have unique physical, chemical, and biological characteristics. Primarily, the epilimnion (top layer) consists of warmer water and high levels of dissolved oxygen, while the hypolimnion (bottom layer) consists of colder water, low levels of dissolved oxygen, and higher levels of hydrogen sulfide and metals. The metalimnion is a transition zone between the epi- and hypolimnions.

Selective withdrawal capabilities (i.e., multi-level intakes) describe a reservoir's ability to select and release water from different depths within a reservoir. Selective withdrawal is one of the most common and significant methods for dams to mitigate impacts to the downstream ecosystem as it can allow dam outlets to create a more natural regime for temperature, dissolved oxygen, and other water quality components.

Barren River Lake has a moderate selective withdrawal system with two intakes located near the border of the epi- and metalimnions, depending on the pool level; Barren's intakes cannot pass as much flow as Nolin but are more typical of other Louisville District lakes.

Nolin River Lake has a good selective withdrawal system with three intakes located typically within the epi-, meta-, and hypolimnions; and they are relatively large intakes that allow for higher flows to be released while still using those intakes.

Rough River Lake does not have selective withdrawal; both intakes are located within the typical hypolimnion.

Recreation

Wildlife Management Areas (WMAs)

Barren River Lake WMA

Barren River Lake WMA surrounds Barren River Lake and is leased from USACE and managed by Kentucky Department of Fish and Wildlife Resources (KDFWR). The WMA spans 8,735 acres in Allen and Barren Counties. The habitat of the WMA is comprised of open land (10.03%), forest (84.28%), wetland (0.78%), open water (5.03%). Terrain is hilly to gently sloping, with woodlands and cleared bottomlands maintained for wildlife (KDFWR 2025a).

Nolin River Lake WMA

Nolin River Lake WMA surrounds Nolin River Lake and is leased from USACE and manage by KDFWR. The WMA covers 6456 acres in Edmonson, Grayson, and Hart Counties. The habitat of the WMA is comprised of open land (1.64%), forest (90.43%), wetland (0.73%), open water (7.23%). Topography is rolling to rugged, containing mixed forests, fields, and some food plots for wildlife (KDFWR 2025b).

Rough River Lake WMA

Rough River Lake WMA surrounds Rough River Lake and is leased from USACE by KDFWR. The WMA covers 4180 acres in Breckenridge, Grayson, and Hardin counties, with a habitat of open land (3.33%), forest (85.62%), wetland (0.36%), open water (10.43%). The rugged terrain and steep banks limit access to some areas. The WMA is heavily wooded and surrounded by heavy development of private residences.

Fish Stocking

Nolin River Lake Tailwater

The trout fishery below Nolin River Lake Dam is managed as a recreational resource maintained by KDFWR, who stocks both rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) in the tailwater. In 2024 for example, 7,000 rainbow trout and 500 brown trout were stocked. These species are non-endemic to Kentucky, with brown trout non-native to North America. KDFWR attempts to stock trout monthly from March – November when water temperature conditions are favorable for this cold-water species (KDFWR personal communication). In the summer months, as water temperature increases past the trout's tolerance threshold, stockings may be skipped. However, there have been documentations of holdover fish in the Nolin Lake tailwater reach.

Water Quality

According to Kentucky's list of impaired waters (303d list) for 2024, the following impairments are found in or near Barren, Nolin and Rough River reservoirs. Barren River has one segment above the lake (from the lake backwaters to LaFayette Water District) that does not support primary contact recreation due to E. coli. Two other major inflows to the lake (Skaggs Creek and Beaver Creek) also have segments that are not supporting their primary contact recreation designated use due to E. coli, and only partially support warmwater aquatic habitat based on macroinvertebrate and habitat assessments. Barren River Lake does not support its warm water aquatic habitat designated use due to nutrients/eutrophication. There is one segment of the tailwater near the confluence with the Green River that does not support primary contact recreation due to E. coli.

Various segments of Nolin River and Bacon Creek (major inflows to Nolin River Lake) do not support warm water aquatic habitat due to sedimentation and nutrients/eutrophication, and do not support primary contact recreation due to E. coli. The reservoir and tailwater are fully supporting their designated uses.

Rough River has one segment above the lake (from the lake backwaters to Linders Creek) that does not support primary contact recreation due to E. coli, and only partially support warmwater aquatic habitat based on macroinvertebrate and habitat assessments. North Fork of Rough River also has a segment that is not supporting the warmwater aquatic habitat designated use based on macroinvertebrate and habitat assessments. The reservoir is not supporting its fish consumption designated use due to mercury in fish tissue. Two segments of the tailwater are not fully supporting their warm water aquatic habitat designated use due to iron and lead, or their primary contact recreation designated use due to E. coli.

The LRL Water Quality Team historically collected chemical data in the tailwaters of GRB reservoirs once per year during stratification and collected temperature and dissolved oxygen (DO) data in the reservoirs and tailwaters every two weeks during stratification. Data from 2012 through 2023 show that there were four exceedances of water quality criteria in the immediate tailwaters of GRB reservoirs:

- Rough River tailwater on 9/2/2014: unionized ammonia (result: 0.1 mg/L, criteria: <0.05 mg/L)
    - At the time of this exceedance, the project was releasing from the bypasses which draws water from the hypolimnion. In other sampling years, whether the project is releasing from the bypasses or main gates, there have not been any other exceedances of ammonia in the tailwater.
- Rough River tailwater on 9/27/2021: DO (result: 4.82 mg/L, criteria: >5 mg/L)
    - At the time of this exceedance, the project was releasing from the main gates, which draws water from the anoxic hypolimnion. However, in other sampling years, whether the project is releasing from the epilimnion or hypolimnion, there have not been any other exceedances of DO in the tailwater.
- Barren River tailwater on 9/21/2021: DO (result: 3.92 mg/L, criteria: >4 mg/L)
    - At the time of this exceedance, the project was releasing from the main gates, which draws water from the anoxic hypolimnion. However, in other sampling years, whether the project is releasing from the epilimnion or hypolimnion, there have not been any other exceedances of DO in the tailwater.

- Nolin River tailwater on 8/8/2013: DO (result: 4.69 mg/L, criteria: >5 mg/L)
    - At the time of this exceedance, the project was releasing water from the lowest bypass level, which, at that time of year, was nearly anoxic. However, in other sampling years, whether the project is releasing from the bypasses or main gates, there have not been any other exceedances of DO levels below water quality criteria in the tailwater.

Temperature

The LRL Water Quality Team and project staff monitor temperature in the GRB reservoirs near the dams and in the tailwaters throughout the stratification period (approximately May through November) and fund USGS gages in the tailwater, which record continuous temperature data. Both datasets are used to assess compliance with the LRL-defined tailwater temperature guide curves for each reservoir, which were developed by LRL in coordination with project stakeholders when the reservoir was built. At projects with selective withdrawal capabilities (Barren River Lake and Nolin River Lake), under certain conditions, release settings can be changed to adjust outflow temperature from the dam to better meet the guide curve. When a change is needed to increase or decrease the temperature in the tailwater, the most recent temperature profile from the lake is analyzed to determine which tower level to release from to target specific temperatures. Figures 2a-c show graphs of temperature profiles throughout the year. The green bars on the graph represent the bypass inlet locations shown in the tower (see arrows). The gray bar at the bottom of the graph represents the main gates inlets which are much larger than the bypass inlets. At all three reservoirs, turnover typically occurs in October or November.

Figure 3a-c shows guide curves and actual tailwater temperatures from 2024 for Barren Lake, Nolin Lake, and Rough River Lake. The water quality and water management teams try to keep the tailwater temperatures within guide curve as much as possible throughout the year at Barren and Nolin lakes using their selective withdrawal capabilities. Because Rough River Lake Dam has no selective withdrawal capabilities, little can be done to affect the tailwater temperature. At Nolin River Lake Dam, an effort is made to keep tailwater temperatures below 20 degrees C for as long as possible to support the downstream trout fishery. It is common at all three reservoirs to run out of cold-water storage and be unable to maintain cold enough temperatures to meet the guide curve in the fall and early winter.

Dissolved Oxygen

Project staff in LRL collect dissolved oxygen data in the lake and the tailwater approximately every two weeks during stratification (roughly May through October). Dissolved oxygen levels in the lakes vary throughout the year (Figure 4 a-c). When the lakes are stratified, dissolved oxygen in the thermocline and hypolimnion is often very low or zero.

However, despite often releasing water from levels in the lake with little to no dissolved oxygen during stratification, dissolved oxygen in the immediate tailwater rarely falls under the state criteria of 5 mg/L for Nolin and Rough, and 4 mg/L for Barren (Figure 5 a-c).

In 2024, dissolved oxygen saturation was collected in the tailwater (Figure 6 a-c). As a general rule, approximately 82% is the minimum for fish and 90% is the minimum for mussels before seeing impacts to recruitment (Monte McGregor, KDFWR, pers. comm. 2024). LRL will continue collecting DO saturation data every two weeks during stratification in future years. Additionally, the LRL is considering deploying DO monitors to obtain continuous data to better assess project performance with respect to dissolved oxygen.

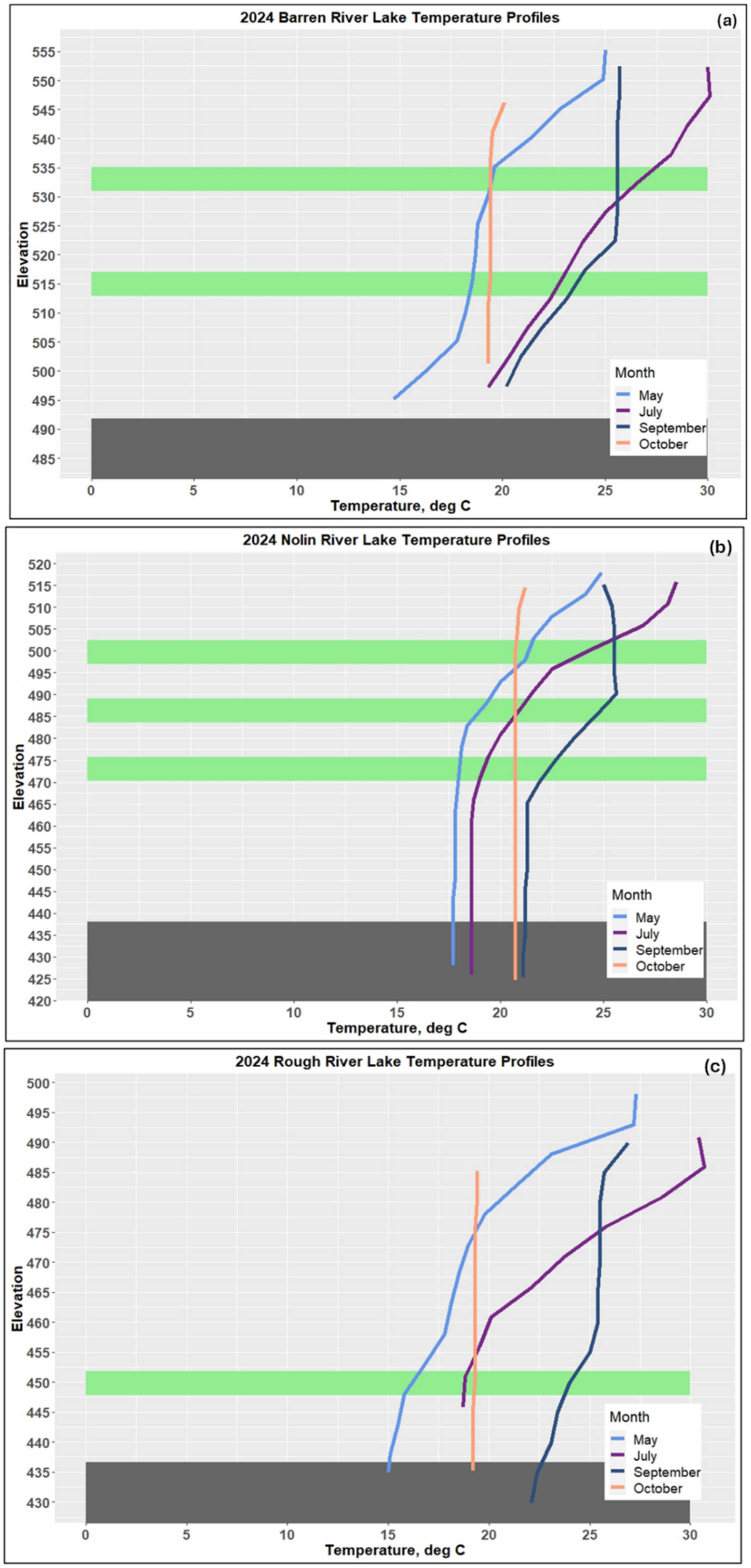

Figure 2. Temperature profiles at Barren River Lake (a), Nolin River Lake (b), and Rough River Lake (c) dams, 2024. Green bars represent the bypass levels and the gray bar represents the main release gate for the three dams.

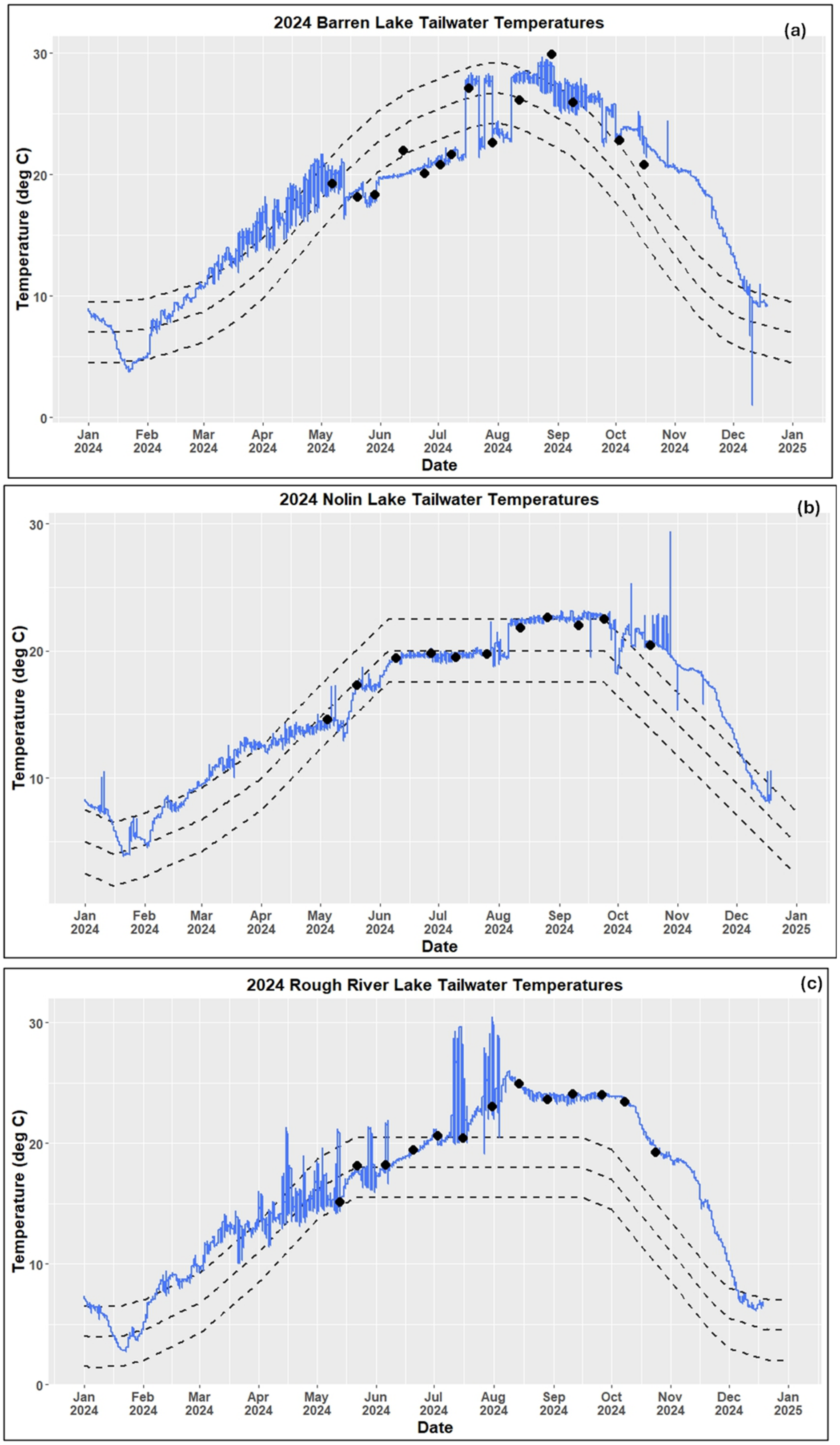

Figure 3. Graph showing temperature in the immediate tailwater (blue) and tailwater temperature guide curve with maximum and minimum bounds (gray dashed lines) for Barren River Lake (a), Nolin River Lake (b), and Rough River Lake (c), 2024.

Figure 4. Dissolved oxygen profiles for Barren River Lake (a), Nolin River Lake (b), and Rough River Lake (c), 2024.

Figure 5. Tailwater dissolved oxygen measurements (blue dots) and water quality criteria for dissolved oxygen (red dashed line) for Barren River Lake (a), Nolin River Lake (b), and Rough River Lake (c), 2012-2024.

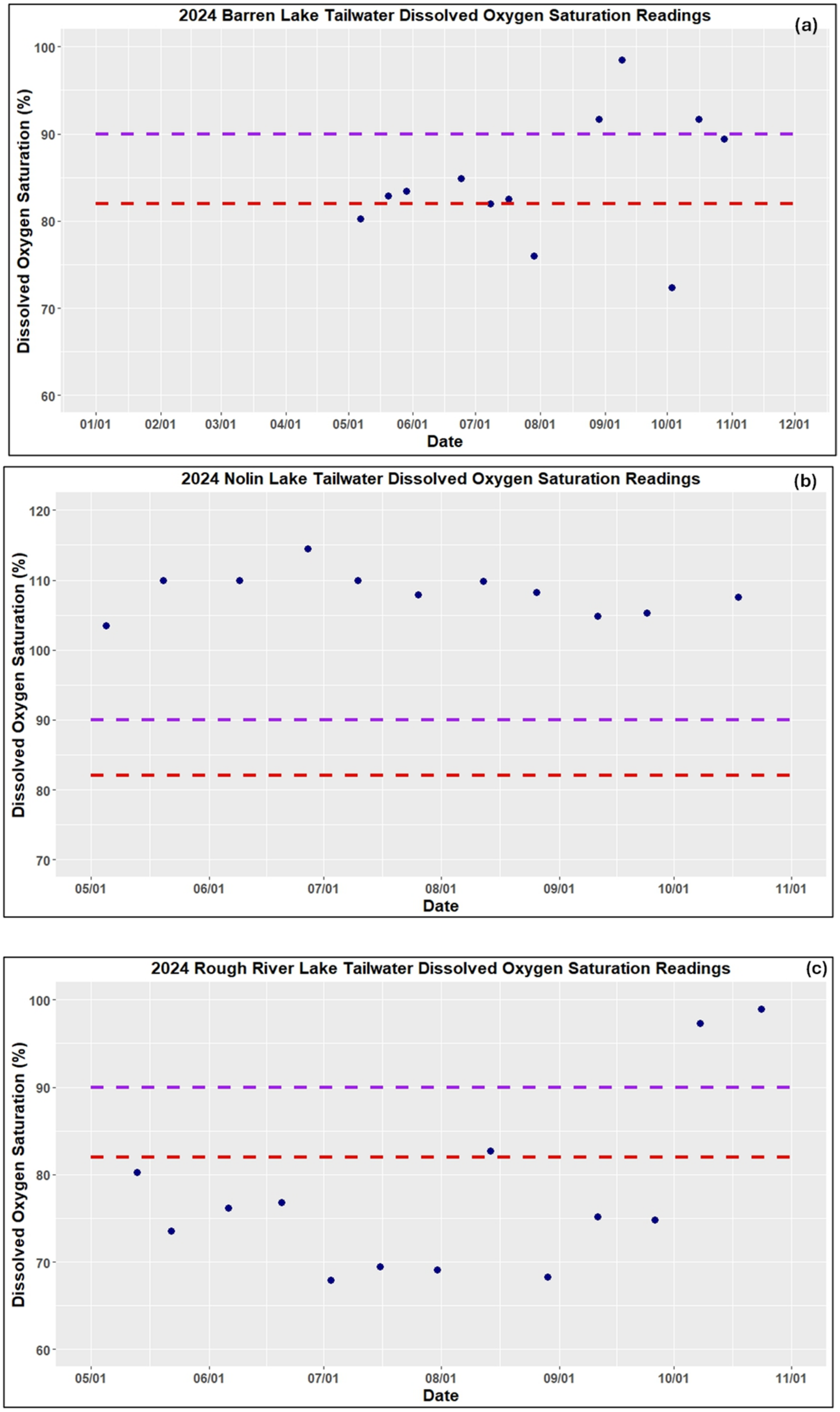

Figure 6. Tailwater dissolved oxygen saturation measurements (blue dots) from Barren River Lake (a), Nolin River Lake (b), and Rough River Lake (c), 2024. The red and purple dashed lines represent the minimum DO saturation requirements for fish (82%) and mussels (90%), respectively (Monte McGregor, KDFWR, pers. comm. 2024).

Biological and Ecological Conditions

Mussel and Fish Assemblages of the Barren, Nolin, and Rough Rivers

There are 65 native mussel species and 158 native fishes living in the Barren, Nolin, and Rough rivers, including 13 federally listed mussel species. Table 4 lists known mussel species of the Barren, Nolin, and Rough rivers. Table 5 lists known fish species of the Barren, Nolin, and Rough rivers.

Table 4. Mussel species of the Barren, Nolin, and Rough rivers. Yellow highlighted species are those identified as target species for the environmental flows workshop.

Common Name	Scientific Name	Federal Status	Barren	Nolin	Rough
mucket	*Actinonaias ligamentina*		x	x	x
elktoe	*Alasmidonta marginata*		x	x	x
slippershell mussel	*Alasmidonta viridis*		x	x	x
threeridge	*Amblema plicata*		x	x	x
rock pocketbook	*Arcidens confragosus*		x		x
Cumberland River rainbow	*Cambarunio dactylus*				x
rainbow	*Cambarunio iris*		x	x	x
painted creekshell	*Cambarunio taeniatus*		x		
Chinese basket clam*	*Corbicula fluminea*		x	x	x
Spectaclecase	*Cumberlandia monodonta*	FE	x	x	
wartyback	*Cyclonaias nodulata*		x		x
pimpleback	*Cyclonaias pustulosa*		x		x
purple wartyback	*Cyclonaias tuberculata*		x	x	
fanshell	*Cyprogenia stegaria*	FE	x	x	
zebra mussel*	*Dreissena polymorpha*				x
butterfly	*Ellipsaria lineolata*		x		
elephantear	*Elliptio crassidens*		x		x
northern riffleshell	*Epioblasma rangiana*	FE	x	x	
tubercled blossom	*Epioblasma torulosa*	EX	x	x	
snuffbox	*Epioblasma triquetra*	FE	x	x	
spike	*Eurynia dilatata*		x	x	x
wabash pigtoe	*Fusconaia flava*		x	x	x
longsolid	*Fusconaia subrotunda*	FT	x	x	x
pink mucket	*Lampsilis abrupta*	FE	x		
plain pocketbook	*Lampsilis cardium*		x		x
wavyrayed lampmussel	*Lampsilis fasciola*		x	x	x
pocketbook	*Lampsilis ovata*		x	x	x
fatmucket	*Lampsilis siliquoidea*		x	x	x
yellow sandshell	*Lampsilis teres*		x	x	x
white heelsplitter	*Lasmigona complanata*		x		x

Common Name	Scientific Name	Federal Status	Barren	Nolin	Rough
flutedshell	*Lasmigona costata*		x	x	x
little spectaclecase	*Leaunio lienosa*		x	x	x
Kentucky creekshell	*Leaunio ortmanni*	PE, PDCH	x	x	x
black sandshell	*Ligumia recta*		x		x
washboard	*Megalonaias nervosa*		x		x
long fingernailclam	*Musculium transversum*			x	
threehorn wartyback	*Obliquaria reflexa*		x		x
hickorynut	*Obovaria olivaria*		x		
ring pink	*Obovaria retusa*	FE	x		
round hickorynut	*Obovaria subrotunda*	FT	x	x	
rayed bean	*Paetulunio fabalis*	FE	x	x	
orangefoot pimpleback	*Plethobasus cooperianus*	FE			x
sheepnose	*Plethobasus cyphyus*	FE	x		
clubshell	*Pleurobema clava*	FE	x	x	x
Ohio pigtoe	*Pleurobema cordatum*		x		x
rough pigtoe	*Pleurobema plenum*	FE	x		
pyramid pigtoe	*Pleurobema rubrum*		x		
round pigtoe	*Pleurobema sintoxia*		x	x	x
pink heelsplitter	*Potamilus alatus*		x		x
fragile papershell	*Potamilus fragilis*		x	x	x
pink papershell	*Potamilus ohiensis*		x		x
kidneyshell	*Ptychobranchus fasciolaris*		x	x	x
giant floater	*Pyganodon grandis*		x	x	x
mapleleaf	*Quadrula quadrula*		x	x	x
ebonyshell	*Reginaia ebenus*		x		x
river fingernail clam	*Sphaerium fabale*			x	
grooved fingernail clam	*Sphaerium simile*			x	
creeper	*Strophitus undulatus*		x	x	
rabbitsfoot	*Theliderma cylindrica*	FT	x	x	x
monkeyface	*Theliderma metanevra*		x		
pistolgrip	*Tritogonia verrucosa*		x	x	x
fawnsfoot	*Truncilla donaciformis*		x		
deertoe	*Truncilla truncata*		x	x	x
paper pondshell	*Utterbackia imbecillis*		x	x	x
flat floater	*Utterbackiana suborbiculata*		x		x
		Total =	**58**	**37**	**43**

FT = Federally Threatened, FE = Federally Endangered, EX = Extirpated, PDCH = Proposed Designated Critical Habitat, * = exotic/non-native invasive

Table 5. Fish species of the Barren, Nolin, and Rough rivers. Yellow highlighted species are those identified as target species for the environmental flows workshop.

Common Name	Scientific Name	KDFWR	OKNP	USFWS	Barren	Rough	Nolin
Ohio lamprey	*Ichthyomyzon bdellium*				N		N
chestnut lamprey	*Ichthyomyzon castaneus*	SGCN	S		N	N	N
mountain brook lamprey	*Ichthyomyzon greeleyi*	SGCN	T		N		
silver lamprey	*Ichthyomyzon unicuspis*						N
least brook lamprey	*Lampetra aepyptera*				N	N	N
American brook lamprey	*Lethenteron appendix*	SGCN	T		N		
paddlefish	*Polyodon spathula*	SGCN				N	
spotted gar	*Lepisosteus oculatus*				N	N	
longnose gar	*Lepisosteus osseus*				N	N	N
shortnose gar	*Lepisosteus platostomus*					N	
emerald bowfin	*Amia ocellicauda*				N	N	
American eel	*Anguilla rostrata*	SGCN-DD		At-Risk	N	?	?
goldeye	*Hiodon alosoides*				N		N
mooneye	*Hiodon tergisus*				N	N	N
skipjack herring	*Alosa chrysochloris*				N	N	N
gizzard shad	*Dorosoma cepedianum*				N	N	N
threadfin shad	*Dorosoma petenense*				I		I
river carpsucker	*Carpiodes carpio*				N		N
quillback	*Carpiodes cyprinus*				N	N	N
highfin carpsucker	*Carpiodes velifer*	SGCN-DD			?	N	
white sucker	*Catostomus commersonii*				N	N	N
blue sucker	*Cycleptus elongatus*	SGCN-DD					N
western creek chubsucker	*Erimyzon claviformis*				N	N	
lake chubsucker	*Erimyzon sucetta*	SGCN	T			N	
northern hog sucker	*Hypentelium nigricans*				N	N	N
smallmouth buffalo	*Ictiobus bubalus*				N	N	?
bigmouth buffalo	*Ictiobus cyprinellus*				N	N	
black buffalo	*Ictiobus niger*	SGCN-DD	S			N	
spotted sucker	*Minytrema melanops*				N	N	N
silver redhorse	*Moxostoma anisurum*				N	N	N
smallmouth redhorse	*Moxostoma breviceps*				N		N
river redhorse	*Moxostoma carinatum*				N	N	?
black redhorse	*Moxostoma duquesnei*				N	N	N
golden redhorse	*Moxostoma erythrurum*				N	N	N
blackfin sucker	*Vexillichthys atripinnis*	SGCN	S	At-Risk	E		
goldfish	*Carassius auratus*				EXO		EXO

Common Name	Scientific Name	KDFWR	OKNP	USFWS	Barren	Rough	Nolin
common carp	*Cyprinus carpio*				EXO	EXO	EXO
silver carp	*Hypophthalmichthys molitrix*						EXO
largescale stoneroller	*Campostoma oligolepis*				N	N	N
southern redbelly dace	*Chrosomus erythrogaster*				N	N	N
rosyside dace	*Clinostomus funduloides*				I		
whitetail shiner	*Cyprinella galactura*				I		
spotfin shiner	*Cyprinella spiloptera*				N	N	N
steelcolor shiner	*Cyprinella whipplei*				N	N	N
silverjaw minnow	*Ericymba buccata*						N
streamline chub	*Erimystax dissimilis*				N		N
gravel chub	*Erimystax x-punctatus*	SGCN-DD	X				
flame chub	*Hemitremia flammea*	SGCN	E		N		
Mississippi silvery minnow	*Hybognathus nuchalis*				EP	N	N
bigeye chub	*Hybopsis amblops*				N	N	N
pallid shiner	*Hybopsis amnis*	SGCN	E		EP		
striped shiner	*Luxilus chrysocephalus*				N	N	N
scarlet shiner	*Lythrurus fasciolaris*				N	N	N
ribbon shiner	*Lythrurus fumeus*					N	
redfin shiner	*Lythrurus umbratilis*				N	N	
shoal chub	*Macrhybopsis hyostoma*	SGCN			N		N
silver chub	*Macrhybopsis storeriana*					N	N
bigeye shiner	*Miniellus boops*				N		
redtail chub	*Nocomis effusus*				N		
golden shiner	*Notemigonus crysoleucas*				N	N	N
Popeye shiner	*Notropis ariommus*			At-Risk	N		N
emerald shiner	*Notropis atherinoides*				N	N	N
highland shiner	*Notropis micropteryx*				N		N
silver shiner	*Notropis photogenis*				N	N	N
telescope shiner	*Notropis telescopus*				N		
pugnose minnow	*Opsopoeodus emiliae*	SGCN-DD			N	N	?
ghost shiner	*Paranotropis buchanani*	SGCN-DD				N	N
tennessee shiner	*Paranotropis leuciodus*				N		
mimic shiner	*Paranotropis volucellus*				N	N	N
suckermouth minnow	*Phenacobius mirabilis*					N	
stargazing minnow	*Phenacobius uranops*	SGCN	S		N		N
bluntnose minnow	*Pimephales notatus*				N	N	N
fathead minnow	*Pimephales promelas*				I	?	I
bullhead minnow	*Pimephales vigilax*				N	N	N

Common Name	Scientific Name	KDFWR	OKNP	USFWS	Barren	Rough	Nolin
western blacknose dace	*Rhinichthys obtusus*				N		N
creek chub	*Semotilus atromaculatus*				N	N	N
black bullhead	*Ameiurus melas*				N	N	N
yellow bullhead	*Ameiurus natalis*				N	N	N
brown bullhead	*Ameiurus nebulosus*					N	
blue catfish	*Ictalurus furcatus*				I	N	I
channel catfish	*Ictalurus punctatus*				N	N	N
elegant madtom	*Noturus elegans*				N		N
mountain madtom	*Noturus eleutherus*						N
slender madtom	*Noturus exilis*	SGCN	E		EP		EP
stonecat	*Noturus flavus*						
tadpole madtom	*Noturus gyrinus*				N	N	
brindled madtom	*Noturus miurus*				N	N	N
freckled madtom	*Noturus nocturnus*				N	N	N
northern madtom	*Noturus stigmosus*	SGCN	S				
flathead catfish	*Pylodictis olivaris*				N	N	N
grass pickerel	*Esox americanus*				N	N	N
muskellunge	*Esox masquinongy*				N		N
rainbow trout	*Oncorhynchus mykiss*				I	I	I
brown trout	*Salmo trutta*				EXO		
trout-perch	*Percopsis omiscomaycus*	SGCN	S				
western pirate perch	*Aphredoderus gibbosus*				N	N	
northern cavefish	*Amblyopsis spelaea*	SGCN	S	At-Risk		N	N
Shawnee Hills cavefish	*Forbesichthys papilliferus*	SGCN-DD			N		?
southern cavefish	*Typhlichthys subterraneus*	SGCN	S		N		
brook silverside	*Labidesthes sicculus*				N	N	N
northern studfish	*Fundulus catenatus*				N		
blackstripe topminnow	*Fundulus notatus*				N	N	N
blackspotted topminnow	*Fundulus olivaceus*					N	
western mosquitofish	*Gambusia affinis*				N	N	N
rock bass	*Ambloplites rupestris*				N	N	N
flier	*Centrarchus macropterus*					N	
green sunfish	*Lepomis cyanellus*				N	N	N
warmouth	*Lepomis gulosus*				I	N	N
orangespotted sunfish	*Lepomis humilis*				N	N	N
bluegill	*Lepomis macrochirus*				N	N	N
longear sunfish	*Lepomis megalotis*				N	N	N
redear sunfish	*Lepomis microlophus*				I	N	NI

Common Name	Scientific Name	KDFWR	OKNP	USFWS	Barren	Rough	Nolin
smallmouth bass	*Micropterus dolomieu*				N	N	N
largemouth bass	*Micropterus nigricans*				N	N	N
spotted bass	*Micropterus punctulatus*				N	N	N
white crappie	*Pomoxis annularis*				N	N	N
black crappie	*Pomoxis nigromaculatus*				N	N	N
banded sculpin	*Cottus carolinae*				N	N	N
white bass	*Morone chrysops*				N	N	N
striped bass	*Morone saxatilis*				I	?	I
western sand darter	*Ammocrypta clara*	SGCN	E				
eastern sand darter	*Ammocrypta pellucida*					EP	
diamond darter	*Crystallaria cincotta*		X	LE, PCH			
mud darter	*Etheostoma asprigene*					N	
teardrop darter	*Etheostoma barbouri*	SGCN			E		E
splendid darter	*Etheostoma barrenense*				E		
greenside darter	*Etheostoma blennioides*				N	N	N
rainbow darter	*Etheostoma caeruleum*				N	N	N
bluntnose darter	*Etheostoma chlorosoma*					N	
fantail darter	*Etheostoma flabellare*				N	N	N
slough darter	*Etheostoma gracile*				N	N	
harlequin darter	*Etheostoma histrio*					N	
bluegrass darter	*Etheostoma jimmycarter*				E	E	E
highland rim darter	*Etheostoma kantuckeense*				E		
stripetail darter	*Etheostoma kennicotti*					N	N
headwater darter	*Etheostoma lawrencei*						N
johnny darter	*Etheostoma nigrum*				N	N	N
Kentucky darter	*Etheostoma rafinesquei*				E		E
spottail darter	*Etheostoma squamiceps*				N	N	N
banded darter	*Etheostoma zonale*				N	N	
orangefin darter	*Nothonotus bellus*				E		
spotted darter	*Nothonotus maculatus*	SGCN	T		N		
tippecanoe darter	*Nothonotus tippecanoe*			At-Risk	N		
logperch	*Percina caprodes*				N	N	N
channel darter	*Percina copelandi*				N	N	
gilt darter	*Percina evides*				N	?	
longhead darter	*Percina macrocephala*	SGCN	E	At-Risk	N		
blackside darter	*Percina maculata*				N	N	N
slenderhead darter	*Percina phoxocephala*				N	N	N
dusky darter	*Percina sciera*				N	N	N
river darter	*Percina shumardi*				N	EP	
frecklebelly darter	*Percina stictogaster*				N		N

Common Name	Scientific Name	KDFWR	OKNP	USFWS	Barren	Rough	Nolin
saddleback darter	*Percina vigil*					EP	
sauger	*Sander canadensis*				N	N	N
walleye	*Sander vitreus*				N	N	N
freshwater drum	*Aplodinotus grunniens*				N	N	N

SGCN = Species of Greatest Conservation Need, SGCN- DD = Species of Greatest Conservation Need – Data Deficient, N = native, I = introduced, S = Special Concern, EXO = exotic, EP = extirpated, ? = suspected present, but lacking records

Critical Habitat

On 17 September 2024, the USFWS proposed listing (Federal Register, Docket No. FWS-R4-ES-2024-0065) the Kentucky creekshell (*Villosa ortmanni*) as an endangered species and proposed designating critical habitat for the species. The Kentucky creekshell is found in rivers and streams in both Kentucky and Tennessee. Historically, the species was found in thirteen river basins in southern Kentucky and northern Tennessee, but it has been extirpated from four of those basins. Due to the substantial decrease in suitable habitat for the species, the USFWS proposes to designate 544.6 river miles in 10 streams in Kentucky and Tennessee as critical habitat. This proposed listing includes stream channels up to bankfull height for sections of the Barren, Green, Middle Nolin, Upper Nolin, and Rough rivers.

Other species who have designated critical habitats or proposed designated critical habitats which could be affected by operations at Nolin River Lake are the longsolid, round hickorynut, sheepnose, snuffbox, and spectaclecase as these species' critical habitats occur on the mainstem of the Green River below the Nolin River confluence.

Endemic Species to the GRB

The Green River basin ranks second to the Cumberland River basin in Kentucky with respect to species diversity and endemism. Endemic species in the Green River basin include six darters (family Percidae), one sucker (family Catostomidae), one freshwater mussel (family Unionidae), and one cave shrimp (family Atyidae). Five of these species are distributed throughout the basin. The remaining species are more restricted in their distribution. The Barren River contains three endemic species. No species are known to be endemic to the Nolin River.

Bottlebrush Crayfish

The bottlebrush crayfish (*Barbicambarus cornutus*) is the one of the largest species of crayfish in Kentucky, reaching total lengths of up to 5.3 inches (Taylor and Schuster 2004). The bottlebrush crayfish is endemic the Green River Basin and is found throughout the basin. It is most common in the Barren River basin, the Green River (below Green River Dam), and the Nolin River above Nolin Lake (Taylor and Schuster 2004).

Teardrop Darter

The teardrop darter (*Etheostoma barbouri*) is found throughout the Green River basin. It prefers pools with fine substrates, such as sand, that are relatively free of debris.

Splendid Darter

The splendid darter (*Etheostoma barrenense*) typically occurs in gravel riffles in small tributaries and in riffle margins in the main stem of the Barren River.

Orangefin Darter

The orangefin darter (*Etheostoma bellum*) is found throughout the Green River basin above the confluence of the Green and Barren Rivers.

Highland Rim Darter

The Highland Rim darter (*Etheostoma kantuckeense*) is a member of the orange throat darter (*E. spectabile*) species complex and is closely related to the Shawnee darter. The Highland Rim darter is endemic to the Barren River and its tributaries.

Kentucky Snub Nose Darter

The Kentucky snub nose darter (*Etheostoma rafinesquei*) is found throughout the upper Green River basin but is most common upstream of the confluence of the Nolin River.

Kentucky Creekshell

The Kentucky creekshell (*Leaunio ortmanni*) is endemic to the Green River basin with extant populations in the Rough River basin, Nolin River basin, Green River, and multiple tributaries of the Barren River. The lower Nolin River and the Barren River mainstem are among the historic populations that are now considered extirpated.

Relationship Between Streamflow Alteration and Ecological Response

A natural flow regime, or hydrologic regime, refers to the typical pattern of unaltered river flows, including their quantity, timing, and natural variability. This flow regime plays a crucial role in shaping the river system's key characteristics and processes, such as physical habitat (channel structure and substrate types), water quality (including chemical composition and temperature), nutrient input and availability, and species interactions. The effects of the flow regime on ecosystems vary depending on whether the flow is low, high, or experiencing flooding, but all conditions can contribute positively to the ecological health of the river.

The amount and timing of stream flow are fundamental hydrologic factors that shape the structure and function of aquatic ecosystems. Natural flow patterns fluctuate over time based on landscape characteristics such as basin size, climate, geology, and topography (Poff et al. 1997). Stream-dwelling organisms are significantly influenced by key components of the natural flow regime, including magnitude, frequency, duration, timing, and rate of change (Poff and Ward 1989, Knight et al. 2008). These flow regimes interact with ecosystems across various spatial and temporal scales, ultimately linking flow variability to habitat conditions and the composition of biotic communities in streams (DiMaoi and Corkum 1995, Poff and Allan 1995).

When a river's flow pattern is altered by a dam, significant changes can occur in the natural flow regime including timing, duration, magnitude, frequency, and rate of change. The Green River Basin SRP project seeks to enable more ecologically supporting flow regimes for fish, aquatic invertebrates (especially mussels), and overall aquatic ecosystem function.

Green River Basin Inflow and Outflow Duration Comparison

The Hydrologic Engineering Center Statistical Software Package (HEC-SSP) was used to plot flow duration curves for the digitized period of record for Barren River Lake, Nolin River Lake, and Rough River Lake. The 6-hour average recorded outflows were available from the Corps Water Management System (CWMS) database starting in 1983. The calculated inflows are computed using the change in reservoir storage and recorded outflows. The change in storage is calculated using the change in pool elevation at each reservoir and an elevation-storage relationship developed from surveyed terrain within each reservoir footprint prior to construction. Inflows are also stored as 6-hour average values.

Period of Record

By comparing inflow and outflow values, there are observable differences in the magnitude and frequency of flow values. Outflow values plateau at either end of the curve for all three reservoirs, corresponding to the minimum and maximum outflow targets specified in the corresponding water control manuals. Inflow values are notably higher than outflows in the 10% - 0.001% probability range for Barren and Rough River Lakes. The 50%-10% probability range for Barren and Rough also show higher outflow values in comparison with inflows. Nolin River Lake has a different trend, where the inflow and outflow values track much closer together, with inflows significantly diverging from outflows only in the 1% - 0.001% probability range (Figures 7-9). This difference is reflective of the higher maximum release allowed at Nolin.

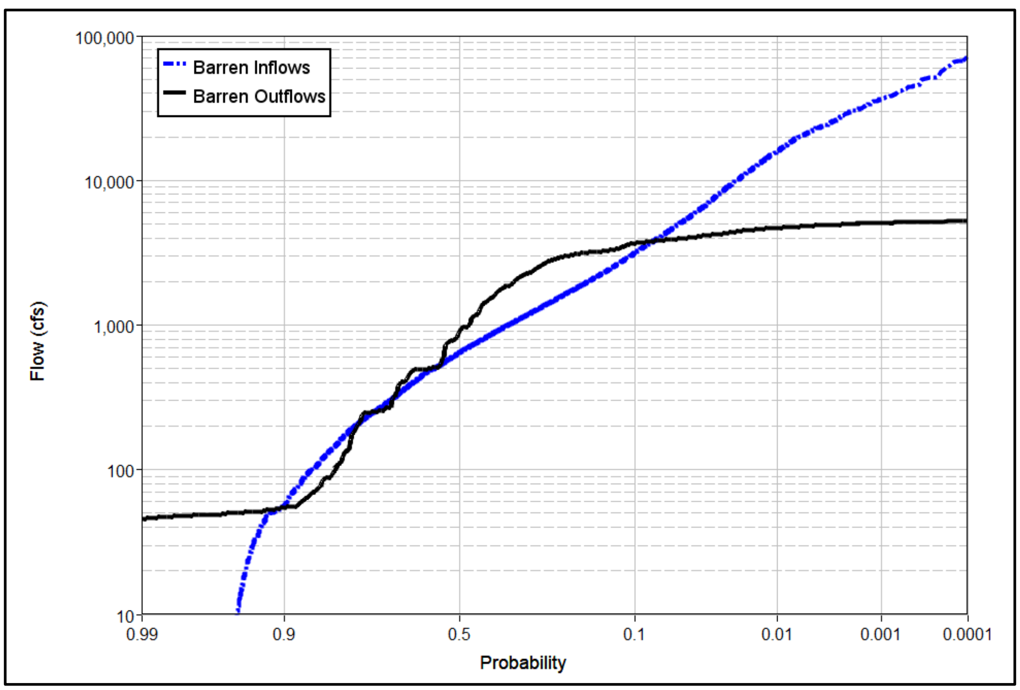

Figure 7. Flow duration curves for recorded outflows (solid black line) and computed inflows (dashed blue line), Barren River Lake, water years 1983-2024.

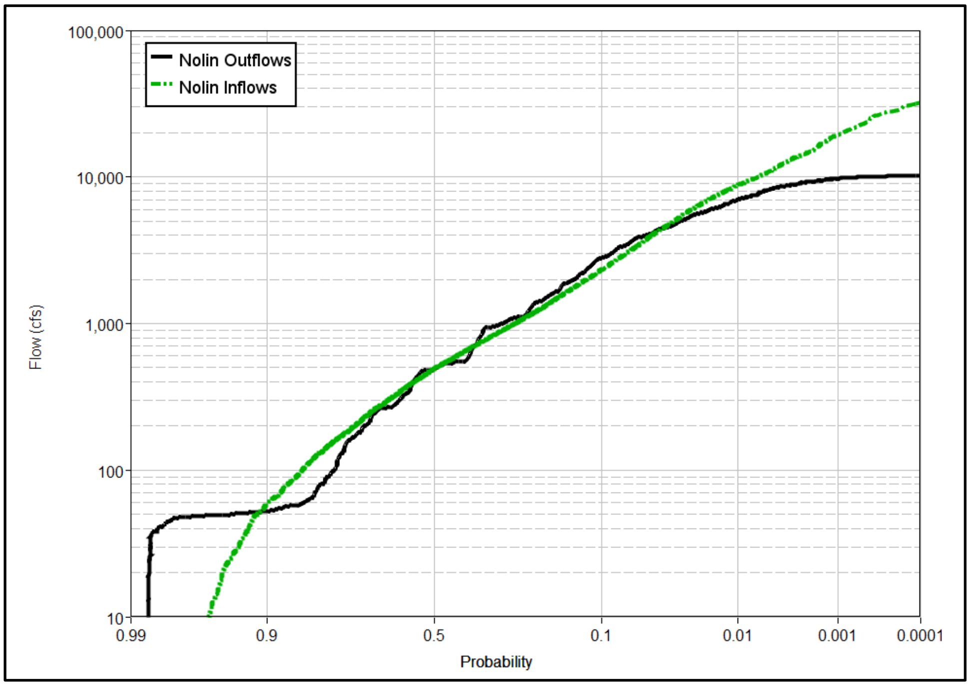

Figure 8. Flow duration curves for recorded outflows (solid black line) and computed inflows (dashed green line) for Nolin River Lake, water years 1983-2024.

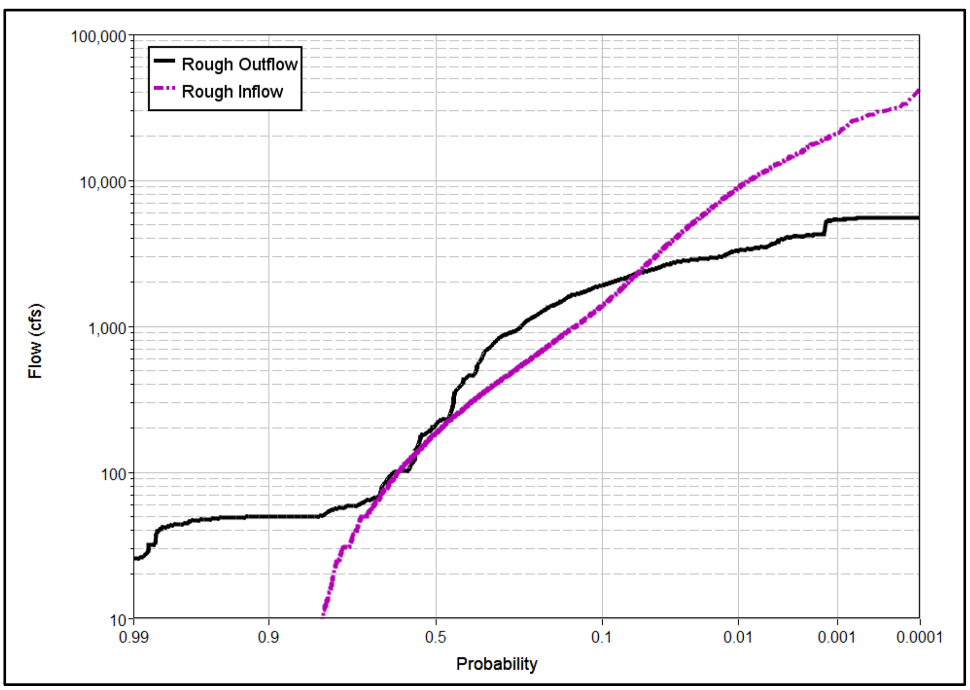

Figure 9. Flow duration curves for recorded outflows (solid black line) and computed inflows (dashed purple line) for Rough River Lake, water years 1983-2024.

Monthly

The same outflow and inflow data was used to create graphs for each lake showing the difference in monthly values (Figures 10-15). Inflow graphs have been scaled to 100,000 cfs and outflow graphs have been scaled to 10,000 cfs to aid in comparing the reservoirs. While some of the rarest flow values are not displayed on the graphs due to this presentation, all of the significant regularly occurring flows are displayed.

The horizontal plateaus that can be observed in the outflow graphs are due to repetitive gate settings that each reservoir is holding for extended periods. These reoccurring settings can be due to regulated limits, gate operation rules, or simply operator preference. Some notably frequent settings can be observed in the summer months at lower flows, these values likely indicate the bypass capacity at that reservoir. Bypasses can only release low flows and are required for use when utilizing multi-level selective withdraw capability (for temperature and DO management).

Barren River Lake

Notably for Barren, the outflow duration curve for November has the highest flow values in the 99%-50% probability ranges when compared with other months. For the same probability range, November inflows at Barren are ranked in the middle of all other months. October inflows and outflows follow a similar pattern. These discrepancies reflect the high releases required in October and November to complete the fall draw down by Dec 1st each year.

The pattern for April and March monthly flows is reversed with inflows greatly exceed outflows. This is due the filling period required for the reservoir to reach summer pool.

Nolin River Lake

Also, for Nolin, the outflow duration curve for November has the highest flow values in the 99%-50% probability ranges when compared with other months. For the same probability range, November inflows at Nolin are ranked 9th compared to other months. October inflows and outflows follow the same pattern. These discrepancies reflect the high releases required in October and November to complete the fall draw down by Dec 1st each year.

Again, the pattern for April and March monthly flows is reversed with inflows exceeding outflows. This is due the filling period required for the reservoir to reach summer pool.

Rough River Lake

As for Barren and Nolin lakes, the outflow duration curve at Rough for November has the highest flow values in the 99%-50% probability ranges when compared with other months. For the same probability range, November inflows at Nolin are ranked 9th compared to other months. October inflows and outflows follow the same pattern. These discrepancies reflect the high releases required in October and November to complete the fall draw down by Dec 1st each year.

Again, the pattern for April and March monthly flows is reversed with inflows greatly exceed outflows. This is due the filling period required for the reservoir to reach summer pool.

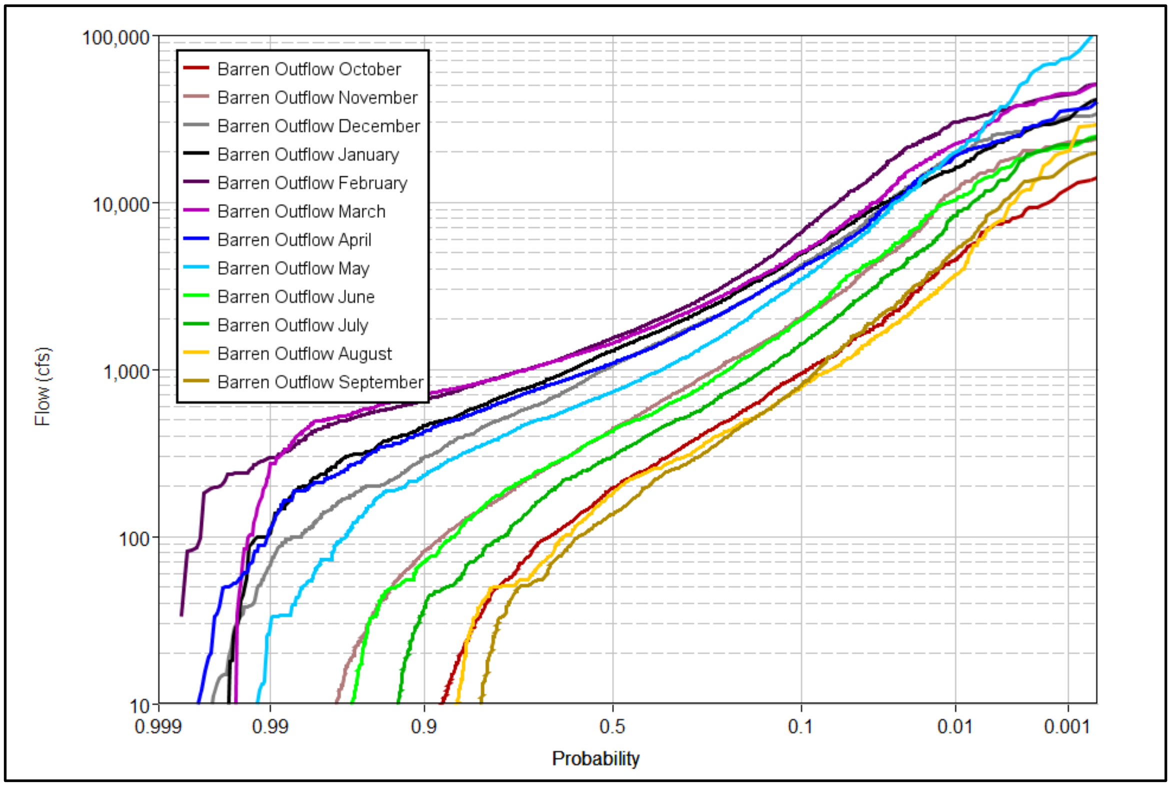

Figure 10. Flow duration curves for computed Inflows, Barren River Lake, January 1, 1983 to September 30, 2024.

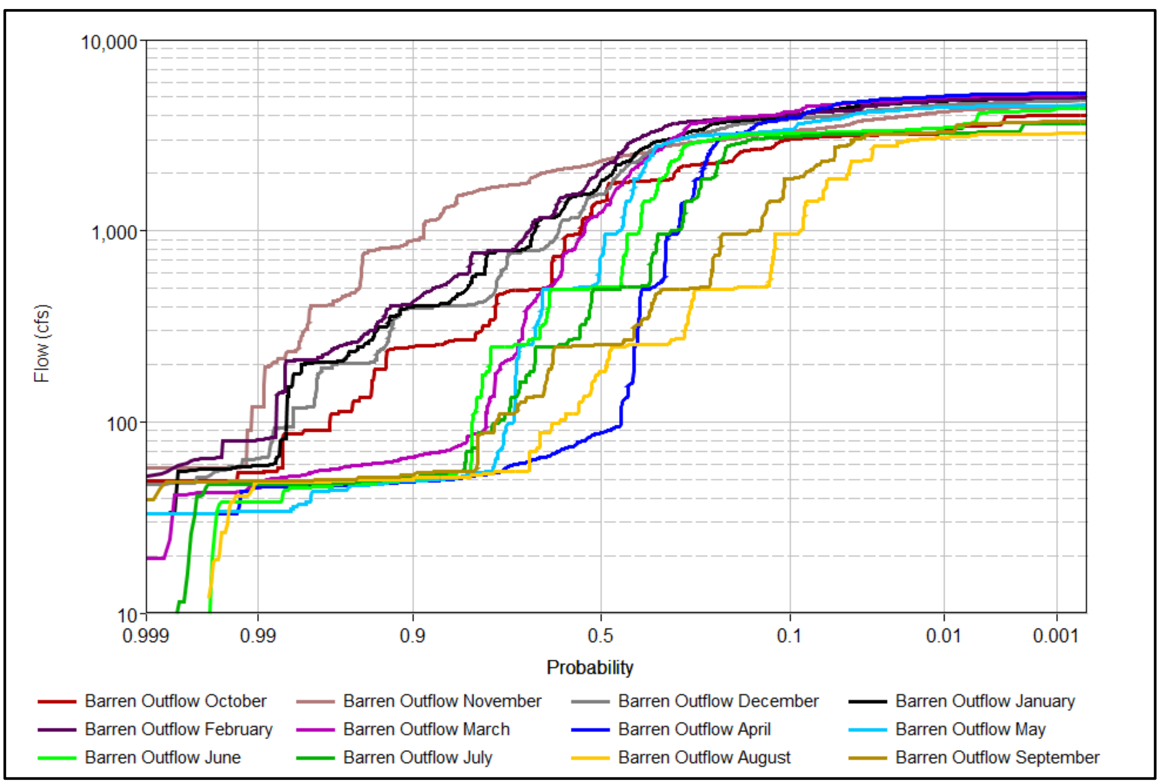

Figure 11. Flow duration curves for recorded outflows, Barren River Lake, January 1, 1983 to September 30, 2024.

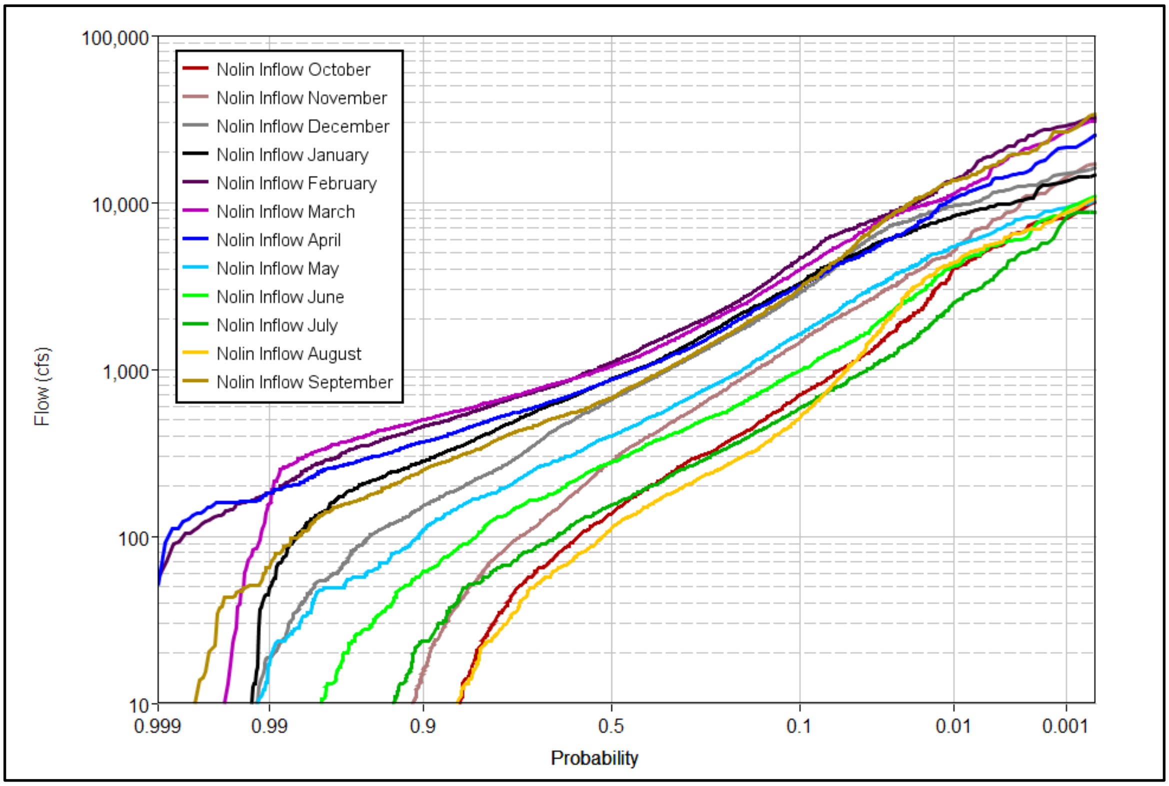

Figure 12. Flow duration curves for computed inflows, Nolin River Lake, January 1, 1983 to March 1, 2025.

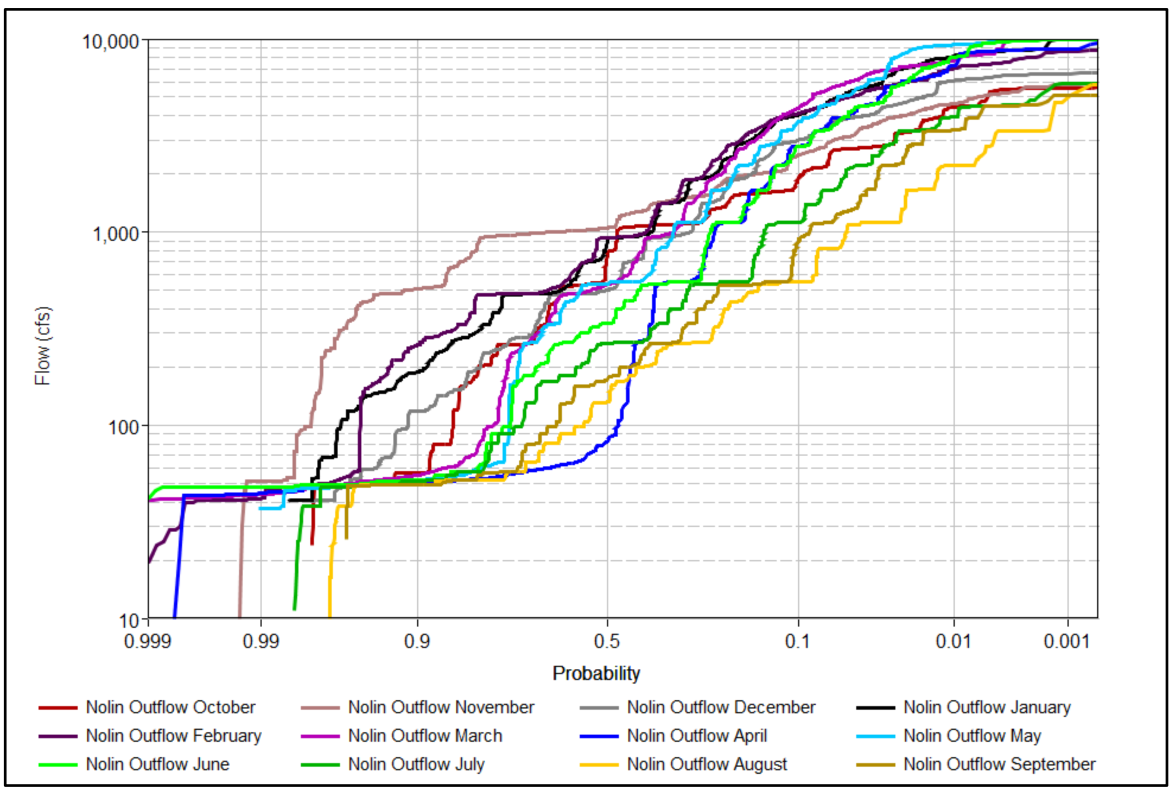

Figure 13. Flow duration curves for recorded outflows, Nolin River Lake, January 1, 1983 to March 1, 2025.

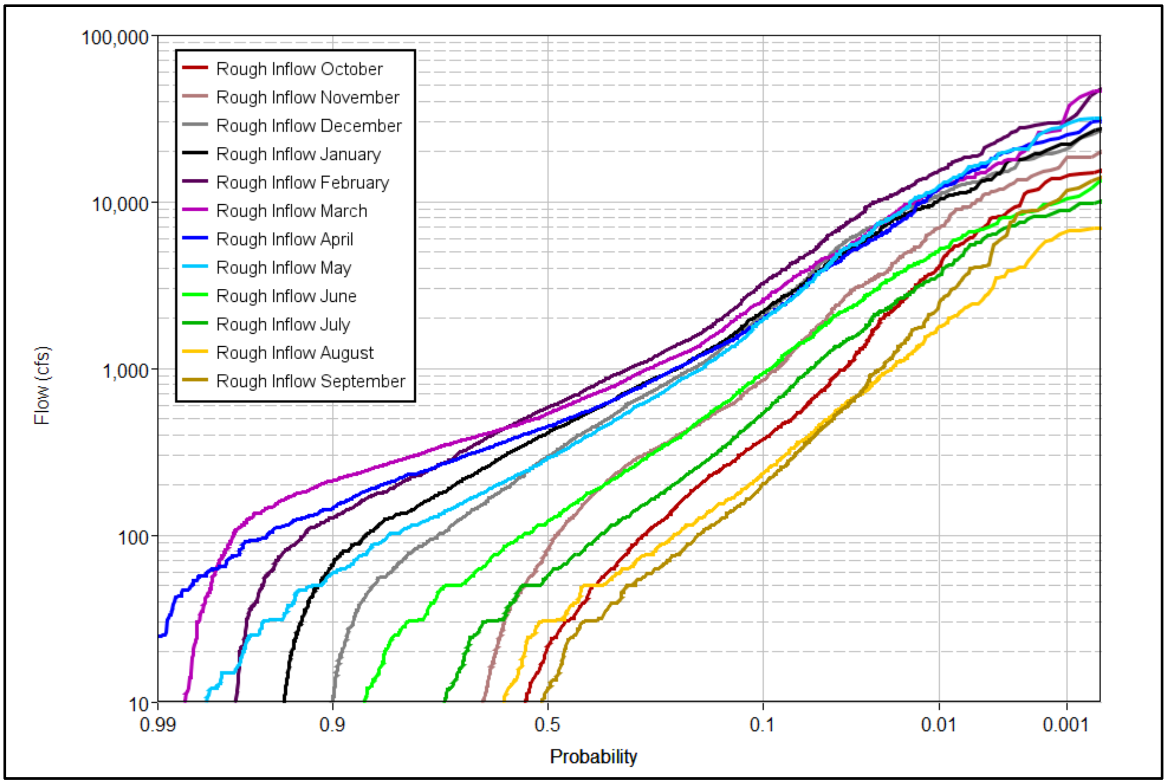

Figure 14. Flow duration curves for computed inflows, Rough River Lake, January 1, 1983 to March 1, 2025.

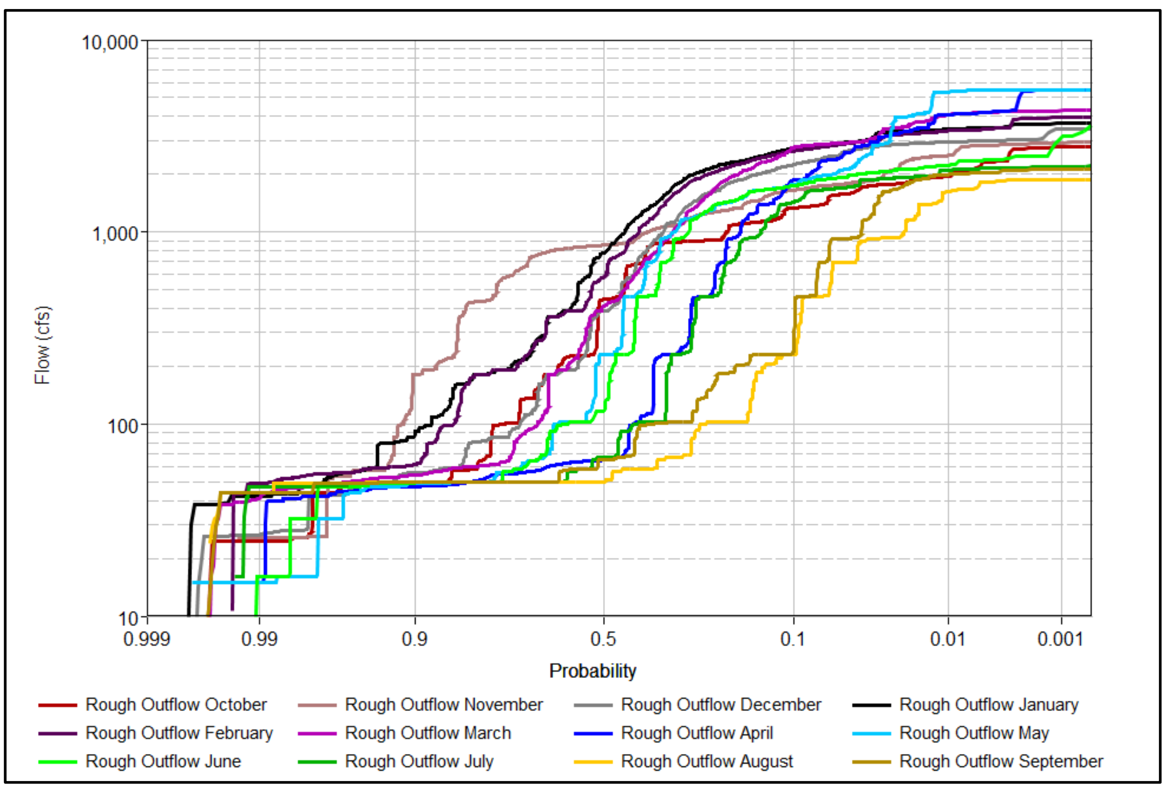

Figure 15. Flow duration curves for recorded outflows, Rough River Lake, January 1, 1983 to March 1, 2025.

Streamflow and Temperature Regime Alteration and Effects on Mussels

Life cycles and life history traits of freshwater mussels are complex. Reproduction within the mussel lifecycle is a crucial target for conservation efforts. Mussel reproduction is often limited to narrow periods of optimal conditions and reproductive adults, juveniles, and gametes can be sensitive to environmental stressors (Galbraith and Vaughn 2011). The four critical periods in mussel early life history are 1) gametogenesis and sperm release, 2) host fish attraction and infection; 3) development of glochidia on fishes, and 4) settlement and growth of juvenile mussels. The spawning strategy for freshwater mussels is unique in that males release sperm into the water column, which is collected by females during normal filter feeding. Upon fertilization, embryos are brooded by the female mussels where they develop into glochidia. Mussels may be either short-term or long-term brooders. In most short-term brooders, sperm is released, and eggs are fertilized in late spring to early summer, embryos develop within two to six weeks, and glochidia are released immediately after maturation, usually in summer, and often during one or two brief periods. In most long-term brooders, sperm is released, and eggs are fertilized in late summer or early fall, and embryos develop into glochidia by September or October. Mature glochidia are then brooded in the female over the winter and glochidia are released the following spring or early summer (Watters et al. 2009). Because of the sensitivity of breeding mussels to environmental perturbations, these periods of mussel reproduction and development need to be considered when designing and implementing flow recommendations.

Alteration of the natural temperature or flow regimes in a river can negatively affect mussel reproduction in several ways.

1. Unseasonably low temperatures can inhibit gametogenesis or release of sperm. In the Cumberland River, Kentucky, summer temperatures rarely exceed 20°C due to hypolimnetic release from an upstream dam. Mussels in the Cumberland River showed no evidence of gametogenic activity, but they resumed production of gametes when transplanted into streams where summer temperatures exceeded 20°C (Heinricher and Layzer 1999). Elimination of mussels from the Cumberland River and other rivers affected by suppressed summer water temperatures from dam release is attributed to recruitment failure due to a lack of gamete production (Layzer et al. 1993). Similarly, long-term brooders typically release sperm only when water temperature reaches 22–25°C (Jirka and Neves 1982).
2. Unseasonably high flows can dilute sperm, resulting in poor egg fertilization, or they can interfere with transmittal of glochidia to host fishes. Mussel glochidia die if they do not encounter and attach to a suitable host soon after release from the female. Most mussel species have elaborate strategies for host infection that appear to target suitable fish species (see discussion of target mussel species). For example, mussels may use modified mantle lures to attract hosts, or they may release glochidia in conglutinates that resemble host prey items. Both strategies rely on visual encounters between host fishes and glochidia. Other species may release large numbers of glochidia freely or in mucus webs that rely on chance encounters with hosts (summarized in Haag 2012). High, turbid flows can interfere with sight-feeding fishes' ability to locate lures or conglutinates and dilute glochidia that rely on chance encounters with fishes.
3. Unseasonably low temperatures can inhibit or prevent glochidial transformation on fishes. For example, glochidia of sheepnose (*Plethobasus cyphyus*) transformed robustly on suitable host fishes at 22–25°C, but most glochidia did not transform on the same fish species at 18–20°C (Hove et al. 2016).

4. Unseasonably high flows or unseasonably low temperatures can cause increased mortality of juvenile mussels. When mussels detach from a host fish, they must settle in a location with suitable, stable substrate and begin feeding. Most mussel species in the Barren, Nolin, and Rough rivers infect hosts and juveniles detach from fishes in late spring to summer. Sustained, high flows during this period can prevent juvenile mussels from settling. For most mussel species, significant juvenile growth occurs only at mean temperatures greater than about 20–22°C (Haag et al. 2019; 2021). Sustained periods of low temperatures can prevent juvenile mussels from growing and obtaining energy reserves for the coming winter.

Mussel declines or changes in assemblage structure may be due to different combinations of these factors in different parts of the river. In the tailwater reach, loss of the entire mussel community may be due primarily to unseasonably cold temperatures that may reduce gametogenesis, sperm release, glochidial growth on fishes, or juvenile growth. These factors would be expected to affect most species similarly. However, unseasonably high flows or reduced oxygen concentrations in late summer or fall also could reduce juvenile survival.

Streamflow and Temperature Regime Alteration and Effects on Fish

Dams in Kentucky have significant ecological impacts on aquatic ecosystems, especially on the fish species that inhabit the state's rivers and streams. Construction of dams disrupts natural hydrological processes, altering water flow, sediment transport, and temperature, which in turn affects the survival, migration, and reproduction of fish populations. One of the primary consequences of damming is alteration of flow regimes, which are critical for the ecological health of river systems. In Kentucky, dams regulate the flow of water in rivers like the Nolin, Barren, and Rough, preventing the natural seasonal fluctuations in discharge that many fish species rely on for spawning and migration (Jager et al. 2011). Reduction in seasonal flow variability can lead to habitat degradation (loss of stability and shifts in substrate concentration) and disrupted spawning cues (Baruch et al. 2024).

In addition to flow alterations, dams also affect water temperature, which is a crucial factor for fish survival and reproduction. Impoundment of water behind dams often leads to thermal stratification, creating a layer of warmer surface water and cooler, deeper water. When water is released downstream, it may be significantly warmer or cooler than the natural temperature, depending on the depth from which the water is drawn. Cold hypolimnetic releases of high magnitude and duration likely have the greatest negative impact on fish communities below the dam. Temperature shifts can also stress temperature-sensitive species, such as the river chub (*Nocomis micropogon*), which require cool, oxygen-rich waters to thrive (Arnot et al. 2008). Warmer water temperatures can also favor the establishment and proliferation of aggressive fish species, such as bluegill (*Lepomis macrochirus*), which can outcompete more typical assemblages of native species and further alter community dynamics (Rahel 2007).

Dams also influence sediment transport, which affects fish habitats. Sediment carried by rivers plays an important role in maintaining riverbed structure, which provides spawning sites for many fish species. Dams trap sediment in reservoirs, reducing the amount of sediment that reaches downstream areas and leading to altered riverbed conditions. This can degrade habitats for many small benthic fishes adapted to riffle habitats. Moreover, the construction of dams creates barriers to fish migration, particularly for species that require access to both upstream and downstream habitats for different life stages. Species like the freshwater drum (*Aplodinotus grunniens*) and other migratory fish are unable to bypass dams, leading to population declines in certain areas (Poff et al. 1997).

Target Species to Model Flow Restoration

Through coordination with regional mussel and fish experts, we have developed a preliminary list of target species for the GRB SRP focus. Modeling ecological flows out of a dam based on target species is an effective strategy because it tailors flow regimes to meet the specific habitat requirements of organisms that depend on stable environmental conditions for survival and reproduction (Poff et al. 1997). By focusing on key species—such as aquatic plants, invertebrates, or fish—this approach ensures that flow alterations account for critical needs, including water temperature, sediment transport, and timing of flows necessary for spawning or migration (Arthington et al. 2010). Linking flow management to the life histories of target species supports ecosystem health by maintaining ecological functions and protecting biodiversity, especially for endangered or keystone species (Helfield et al. 2007). This species-specific model enhances the resilience of the entire ecosystem while balancing both ecological and human water needs (Poff et al. 2003).

For mussels, target species were identified according to the following criteria.

1. Species that are widely distributed in the Barren, Nolin, and Rough rivers from tailwaters downstream to nearly the mouth. This criterion is desirable because it allows us to assess the effects of flow management for both the tailwater reach, which likely is affected by altered temperature and flow regimes, and middle and lower rivers, which likely are affected primarily by altered flow.
2. Species that are abundant enough to make meaningful estimates of abundance or age structure both prior to and after any flow modifications are implemented. It is nearly impossible to make rare species abundance estimates that have the precision levels necessary to detect changes over time.
3. A group of species that represents an array of life history strategies. Species with different life histories (e.g., host use, spawning or glochidial release timing) can be expected to respond differently to flow modification. Assessing species with different life history strategies allows us to evaluate effects of flow modification to mussel assemblages.
4. Species, which due to their similar life history traits, can serve as surrogates for imperiled species (which may be too rare to monitor). For each target species serving as a surrogate, we list imperiled species for which their life history is similar.

Below are the recommended target species with quick references to life history information for consideration during the Barren, Nolin, and Rough rivers e-flow workshop.

Target Mussel Species

All target mussel species occur in similar habitats. They occur most commonly in riffle or run habitats with gentle to moderate current in stable substrates composed of a mixture of gravel, sand, and silt. They occur sparingly in pools with little current or extensive areas of deep, fine sediments. Chronological timelines of important life history events for several of the targeted mussels are provided in Appendix A.

Longsolid (***Fusconaia subrotunda***)

- **Habitat**: Found in medium to large rivers and streams, the Longsolid prefers clean, slow-moving waters. Commonly found in areas with stable flow and some cover, such as submerged vegetation or rocks (NatureServe 2021, USFWS 2022a)
- **Substrate Preference**: Typically prefers firm sand or gravel substrates for burrowing and feeding (NatureServe 2021)
- **Water Temp**: Warm water streams, up to 25-30 C

- **Reproduction:** Short-term brooders, spawn in May/June/July, gravid through July
- **Host Fish**: Unknown, but most likely minnows
- **Subsistence**: Spring temperatures in June are crucial to spawning and recruitment. Fall low flow conditions provide lots of food and stable habitats for new juveniles (< 5 mm). High oxygen levels (> 95%) recommended for young mussels
- **Base Flow:** Spring and summer base flows with no abrupt changes in temperature and oxygen provide optimal conditions for growth and spawning. Time window is much shorter for short-term brooders to provide optimum conditions

<u>Mucket</u> (*Actinonaias ligamentina*)

- **Habitat**: Typically found in flowing waters of medium to large rivers in main channels over firm sand and gravel substrates. Habitat is associated with its host fish, black basses
- **Substrate Preference**: Fine sand and gravel in riffles and runs
- **Reproduction**: Long-term brooders, spawn in August, gravid from Sept to May
- **Host Fish**: Bass, shad
- **Subsistence**: Fall low flow conditions provide lots of food and stable habitats for new juveniles (< 5 mm). High oxygen levels (> 95%) recommended for young mussels
- **Base Flow**: Fall base flows with no abrupt changes in temperature and oxygen provide optimal conditions for growth and spawning (usually in August)

<u>Spike</u> (*Eurynia dilatata*)

- **Habitat**: Typically found in flowing waters of medium to large rivers in main channels over firm sand and gravel substrates. Habitat is associated with its host fish, darters
- **Substrate Preference**: Sand and gravel in riffles and runs
- **Reproduction**: Short-term brooders, spawn in May/June/July, gravid through July
- **Host Fish**: Multiple darters. Shad
- **Subsistence**: Spring temperatures in May/June are crucial to spawning and recruitment. Fall low flow conditions provide lots of food and stable habitats for new juveniles (< 5 mm). High oxygen levels (> 95%) recommended for young mussels
- **Base Flow:** Spring and summer base flows with no abrupt changes in temperature and oxygen provide optimal conditions for growth and spawning. Time window is much shorter for short-term brooders to provide optimum conditions

<u>Round Hickorynut</u> (*Obovaria subrotunda*)

- **Habitat**: Typically found in flowing waters of small, medium to large rivers (USFWS 2022b)
- **Substrate Preference**: Fine stable sand and gravel substrates. Habitat is associated with its host fishes, darters, especially sand darters
- **Reproduction**: Long-term brooders, spawn in August, gravid from Sept to May
- **Host Fish**: Eastern sand darter, variegate darter, greenside darter, emerald darter
- **Subsistence**: Fall low flow conditions provide lots of food and stable habitats for new juveniles (< 5 mm). High oxygen levels (> 95%) recommended for young mussels
- **Base Flow**: Fall base flows with no abrupt changes in temperature and oxygen provide optimal conditions for growth and spawning (usually in August)

<u>Fanshell</u> (*Cyprogenia stegaria*)

- **Habitat**: Typically found in flowing waters of medium to large rivers in main channels over firm sand and gravel substrates. Habitat is associated with its host fishes, darters, especially logperch.
- **Substrate Preference**: Fine sand and gravel in shallow runs

- **Reproduction**: Long-term brooders, spawn in August, gravid from Sept to May
- **Host Fish**: Logperch, sculpin, greenside darter
- **Subsistence**: Fall low flow conditions provide lots of food and stable habitats for new juveniles (< 5 mm). High oxygen levels (> 95%) recommended for young mussels
- **Base Flow**: Fall base flows with no abrupt changes in temperature and oxygen provide optimal conditions for growth and spawning (usually in August)

Pink Mucket (***Lampsilis abrupta***)

- **Habitat**: Pink muckets are found in large, medium, and small rivers/streams, the pink mucket prefers clean, fast-flowing waters. It can survive in some impounded rivers but won't survive lacustrine environments
- **Substrate Preference**: The species prefers rock or boulder substrates in fast moving water and silt-free, firm sand or gravel substrates in slower flows
- **Reproduction:** long-term brooders, spawn in August, gravid from Sept to June
- **Host Fish**: Black bass

Rough Pigtoe (***Pleurobema plenum***)

- **Habitat**: Found in medium to large rivers and streams, and prefers clean, slow-moving waters. Has been documented on river flats and muddy sand environments
- **Substrate Preference**: Typically prefers firm sand, gravel, or cobble, substrates for burrowing and feeding
- **Water Temp:** Warm water streams, up to 25-30 C
- **Reproduction**: short-term brooders, spawn in May/June/July, gravid through July
- **Host Fish**: Unknown

Kentucky Creekshell (***Villosa ortmanni***)

- **Habitat**: Found in large rivers with cobble/gravel substrates. The species was documented in deep flowing riffles in the Green River, but more recently, in small to medium streams (Cicerello and Hannan 1990, Cicerello and Schuster 2003)
- **Substrate Preference**: Sand or gravel substrates, but substrate conditions can be highly variable for the species
- **Reproduction**: Long-term brooder, with females becoming gravid in late summer or early fall and remaining gravid through the spring or early winter
- **Host Fish**: Johnny darter and sculpins

Target Fish species

Bigeye Chub (***Hybopsis amblops***)

- **Habitat**: Small to medium-sized streams and rivers of moderate gradient and clear water; occurs over rocky substrates in slight current above or below riffles; a benthic species sensitive to turbidity.
- **Spawning Season**: Late April to June, water temperatures 18-22°C.
- **Spawning Habitat and Behavior**: Spawns in moderate current and depths over sand and gravel.

Shoal Chub (***Macrhybopsis hyostoma***)

- **Habitat:** Small to large rivers of low to moderate gradient in turbid and clear water; occurs over coarse sand and gravel substrates immediately below riffles in deeper runs (0.5-1.5 m) with fast current; a strictly benthic species. Not known to occur in Rough River.

- **Spawning Season**: May to June, water temperatures 18-24°C.
- **Spawning Habitat and Behavior**: Spawning location unknown, but presumably similar to general habitat.

<u>Freckled Madtom</u> (*Notorus nocturnus*)

- **Habitat**: Medium to large rivers of low to moderate gradient in clear to turbid water; occurs over sand and gravel substrates with patches of woody debris and in undercut banks with tree roots in slow current.
- **Spawning Season**: May to July, water temperature around 25°C.
- **Spawning Habitat and Behavior**: Spawns in shallow riffles with reduced flow, where nests are constructed under flat rocks, cans, or other objects.

<u>Bluegrass Darter</u> (*Etheostoma jimmycarter*)

- **Habitat**: Small streams to medium-sized rivers of moderate to high gradient and clear water; occurs in pools, runs, and margins of riffles over gravel and sand substrates in slow current.
- **Spawning Season**: March to May, water temperatures 14-17°C.
- **Spawning Habitat and Behavior**: Spawns in riffles where eggs are buried in gravel or coarse sand.

<u>Channel Darter</u> (*Percina copelandi*)

- **Habitat**: Large streams to large rivers of moderate gradient in clear water; occurs over cobble, gravel, and sand substrates in pools and deep runs in slow to moderate current; a strictly benthic species. Not known to occur in Nolin River.
- **Spawning Season**: April to June, water temperatures 14-25°C.
- **Spawning Habitat and Behavior**: Spawns in moderate to fast-flowing riffles over boulder, cobble, and gravel substrates; sand is avoided.

<u>Slenderhead Darter</u> (*Percina phoxocephala*)

- **Habitat**: Small to medium-sized streams and rivers of low to moderate gradient and clear water or turbid water; occurs over gravel and cobble mixed with sand substrates in riffles, but also in pools during winter.
- **Spawning Season**: April to June, water temperatures 19-21°C.
- **Spawning Habitat and Behavior**: Spawns at the upper end of riffles over fine gravel or coarse sand, in which eggs are buried.

Conclusion

The SRP is a partnership between TNC and USACE that is focused on identifying and implementing opportunities for changes to operations at USACE infrastructure (locks and dams, dry dams, reservoirs, etc.) to create environmental benefits, while serving the infrastructure's authorized purposes.

The ecological health and biodiversity of the GRB face significant challenges due in part to the alteration of natural flow regimes caused by the impoundment of the Barren, Green, Nolin, and Rough rivers. This review highlights critical factors such as streamflow, temperature, and dissolved oxygen variations that have the potential to impact aquatic habitats and the life cycles of key species, including federally endangered mussels and fish of conservation concern. It underscores the importance of implementing targeted environmental flows to restore and sustain ecological processes, enhance habitat connectivity, and support species resilience.

The SRP provides a collaborative framework to optimize reservoir operations, balancing ecological needs with federal mandates. Continued research, stakeholder engagement, and adaptive management are essential to achieving a sustainable flow regime that preserves the ecological integrity of the major rivers of the basin while maintaining their multifaceted benefits. This report serves as a foundational step toward informed decision-making and effective conservation strategies for one of the nation's most valuable ecological resources.

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Appendix A

Supporting Materials

Figures A1 to A3 provide a visual presentation of mussel life histories and associated conditions.

Figure A1. Life histories and associated conditions for longsolid and round pigtoe mussels.

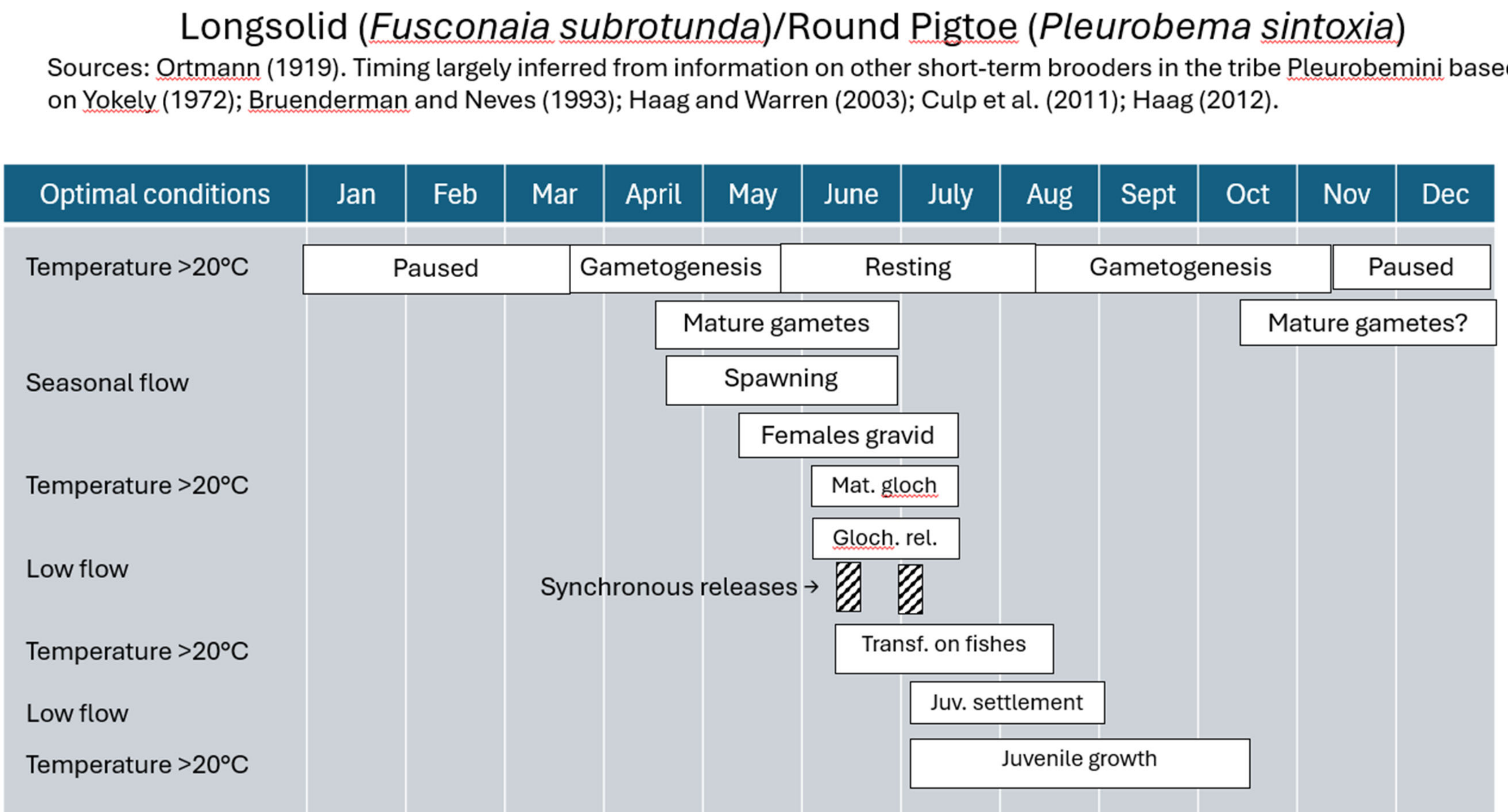

Figure A2. Life histories and associated conditions for spike mussels.

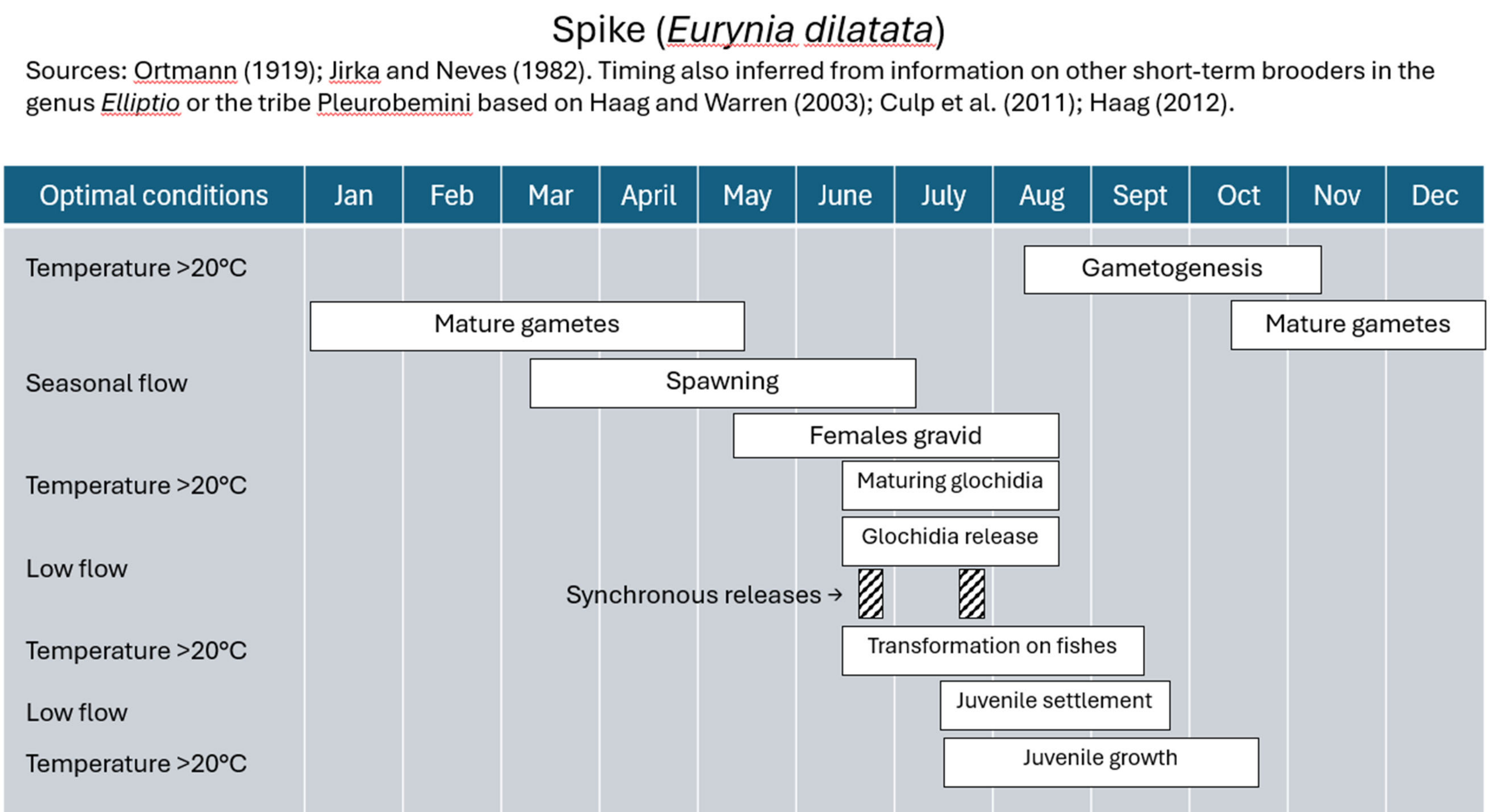

Figure A3. Life histories and associated conditions for mucket mussels.