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Modifying Cumberland River System Reservoir Operations to Improve Mussel Habitat

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Abstract. The Cumberland River and its tributaries once supported a rich and abundant mussel fauna of more than 90 species. An alarming reduction in the richness and abundance of the mussel fauna inhabiting the Cumberland River basin has occurred during the 20th century. Losses were caused in part by construction and operation of several major dams. These dams now regulate river flows, drastically modifying water quality. Releases for hydroelectric power production prevent water temperatures from rising above 22°C, which interferes with mussel reproduction and restricts the occurrence of host fish. By employing mathematical models, the Corps of Engineers has identified a 40-mile reach of the main stem Cumberland River where summer water temperatures can be raised 2-4°C by modifying release patterns from upstream dams. This reach of the Cumberland River contains at least two federally endangered mussel species, *Dromus dromas* and *Lampsilis abrupta*. There is a unique challenge to improving biotic conditions in a regulated system where competing demands are placed upon water resources for energy production, industrial and municipal water supply, navigation, flood control, and aquatic life.

Introduction

An important cause for the decline of historically rich, native mussel populations in portions of the Cumberland River basin has been the overwhelming impact of large impoundments and releases of cold, hypolimnetic water for the generation of hydroelectric power. Mussels have been completely eliminated from some areas that formerly supported rich and abundant shellfish populations. In other areas the cumulative impact of river regulation by dams has resulted in the gradual decline of mussel populations with little or no evidence of successful recruitment. The primary goal of this study is to document positive and negative impacts by modelling operational changes in release patterns from dams to improve mussel habitat. Modelling revealed the positive and negative responses within the system to operational changes in dam releases. Of greater uncertainty is the biological response to operational changes, in this case the response of native mussels.

Geographical Setting

The Cumberland River basin covers an area of approximately 18,000 square miles in Kentucky and Tennessee. Originating near Harlan, Kentucky, at the confluence of the Poor Fork and Clover Fork, the Cumberland River flows westward through rugged, mountainous terrain. The upper basin has abundant coal reserves, which have been exploited extensively. Passing over Cumberland Falls, the river continues its westward course and enters the backwaters of Lake Cumberland, the most upstream impoundment on the main stem. Lake Cumberland is formed by Wolf Creek Dam, which is operated primarily for hydropower production and flood control. It is the only storage impoundment on the mainstem, and by controlling 6,000 square miles, about one-third of the drainage basin, plays the key role in determining downstream water quality.

Below Wolf Creek Dam, the Cumberland River again occupies a well-defined stream channel, and flows approximately 70 river miles before entering Tennessee and encountering the backwaters of the next reservoir. From this point, continuing downstream for approximately 350 river miles, the Cumberland River passes through a chain of four run-of-the-river reservoirs (Cordell Hull, Old Hickory, Cheatham, and Barkley), which create a channel for commercial navigation. Typically, each of these run-of-the-river reservoirs has an upper, riverine zone with physical habitat resembling preimpoundment conditions that gradually transitions into a more lentic, depositional environment. Reentering Kentucky below Nashville, the Cumberland River emerges from Barkley Dam to flow a final 30 miles to its confluence with the Ohio River near the town of Smithland.

In addition to the five main stem dams, the U.S. Army Corps of Engineers, Nashville District, operates four storage reservoirs on major tributaries. These are Laurel River Lake on Laurel River, Dale Hollow Lake on Obey River, Center Hill Lake on Caney Fork River, and J. Percy Priest Lake on Stones River (Figure 1). All storage reservoirs operate for hydropower and provide flood control and recreation benefits. Water development projects in the Cumberland River basin operate as a system providing multiple benefits, and where possible balance the needs of conflicting demands for water resources. Selected statistical data for Cumberland River basin water development projects are provided in Table 1.

Decline of the Cumberland River Mussel Fauna

Historically, the Cumberland River basin supported a rich mussel fauna of more than 90 species (Gordon and Layzer 1989). The historic richness of the mussel fauna in the Cumberland River drainage is indicated by the results of two wide-ranging studies undertaken by Wilson and Clark (1914) and Neel and Allen (1964). Wilson and Clark documented approximately 80 species during their qualitative survey. They observed that despite the construction of locks and dams on the main stem and extensive harvesting for shells and pearls, mussels continued to prosper at most locations where suitable habitat existed.

Neel and Allen resurveyed the upper Cumberland River and some of its tributaries in Kentucky during 1947-1949. Striking changes had occurred since Wilson and Clark's survey. Although they documented 59 species, the number of mussel species had declined sharply in most of the upper Cumberland tributary streams they sampled. Perturbations from mining of abundant coal reserves were implicated for much of the decline. Only the main stem Cumberland River locations revealed high richness and abundant numbers of mussels.

The purpose of Neel and Allen's survey was to document the status of mussel populations before the closure of massive Wolf Creek Dam, which would inundate over 100 miles of excellent mussel habitat in the Cumberland River. Discharges from

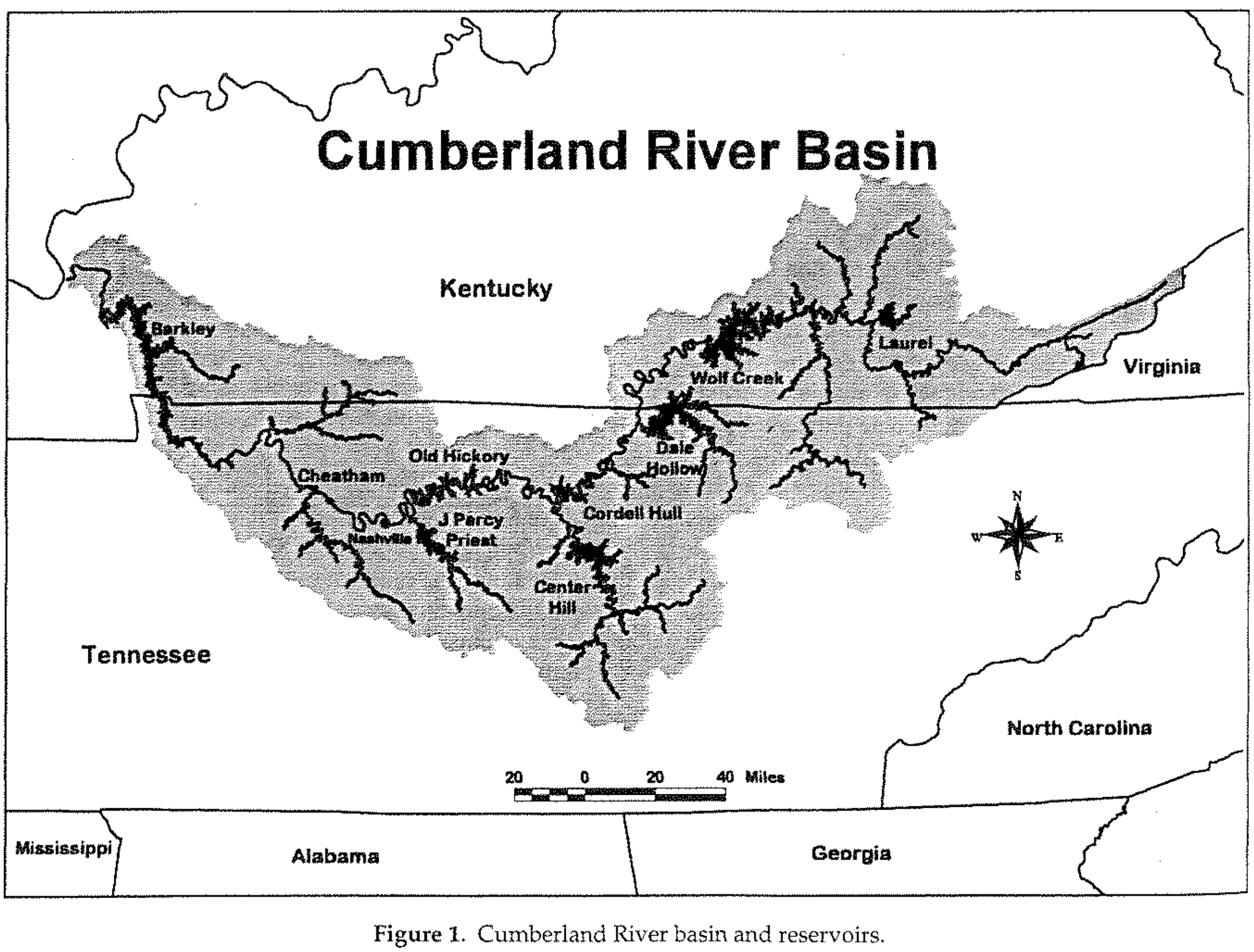

Figure 1. Cumberland River basin and reservoirs.

Wolf Creek, Dale Hollow, and Center Hill dams, which became operational in the early 1950s, would profoundly alter mussel populations in affected reaches of the Cumberland River Basin. Cold water released during the generation of hydroelectric power suddenly and drastically altered complex ecological relationships that had evolved through the millennia. Mussels with their complex life history and host fish requirements were particularly vulnerable to environmental changes brought about by dams.

The serious decline of mussel resources in the main stem Cumberland River below Wolf Creek Dam was documented in 1982 (Miller et al. 1984). This qualitative survey was conducted during a prolonged shutdown of the Wolf Creek Dam power plant, and it allowed investigators to extensively search the tailwater for the presence of mussels. Neel and Allen (1964) had noted 39 species in this reach of river during their survey. The 1982 survey found only one living individual each of two species encountered by Neel and Allen. Fluctuating water levels and cold water had prevented mussel reproduction, and over the years the populations had dwindled to just a few remaining individuals.

Likewise, the decline of mussels in a major tributary, Caney Fork River below Center Hill Dam, was documented by surveys conducted in 1983 (Miller 1984) and 1989 by Layzer (1993). Miller (1984) found 11 living species of mussels in the Center Hill tailwater; however, none were recovered in the first 11 miles below the dam. Including relics, Miller (1984) collected 27 mussel species in the Caney Fork River downstream of Center Hill Dam. Layzer found only four species alive below Center Hill Dam and none in the immediate tailwater reach. Given time, it seems the last remaining live mussels in the Caney Fork River downstream of Center Hill Dam will disappear forever.

It is in the middle reaches of the Cumberland, where the river passes through the series of run-of-the-river reservoirs, that pockets of the original riverine mussel community have been noted in recent years. This is particularly true for the upper portions of Old Hickory Lake. Old Hickory Lake reaches from Old Hickory Dam at river mile (RM) 216.6 to Cordell Hull Dam at RM 313.5, a distance of 97 river miles. The upper 40 to 50 river miles of Old Hickory Lake are somewhat riverine and retain some habitat favorable for mussels.

A study conducted by the Tennessee Valley Authority (TVA) to monitor environmental conditions in proximity to the now-cancelled Hartsville Nuclear Plant (TVA unpublished report, 1976) indicated an abundant and rich mussel fauna occupying numerous beds in RM 270-305. The TVA researchers noted many mussel boats working portions of the river. Musselers were observed to have collected representatives of two federally endangered species, *Dromus dromas* and *Lampsilis abrupta*. Using a variety of collecting techniques, TVA found 35 species still occupying the upper portion of Old Hickory Lake. *Lampsilis abrupta* was found throughout the reach surveyed, while *Dromus dromas* was found at only one location, a site having considerable current.

Table 1. Multipurpose Reservoir Data.

Parameter	Laurel	Wolf Creek	Dale Hollow	Cordell Hull	Center Hill	Old Hickory	J. Percy Priest	Cheatham	Barkley
Location	Laurel	Cumberland	Obey	Cumberland	Caney Fork	Cumberland	Stones	Cumberland	Cumberland
River Mile @ Dam	2.3	460.9	7.3	313.5	26.6	216.2	6.8	148.7	30.6
Completion Date	Oct 77	Aug 52	Nov 53	Feb 74	Apr 51	Dec 57	Feb 70	Nov 59	Mar 66
Local Drainage Area, mi²	282	5,451	935	1,372	2,174	1,404	892	1,594	3,438
Total Drainage Area, mi²	282	5,789	935	8,096	2,174	11,674	892	14,160	17,598
Conservation Pool	982.0	673.0	631.0	499.0	618.0	442.0	480.0	382.0	354.0
Power Pool	1018.5	723.0	651.0	504.0	648.0	445.0	490.0	385.0	359.0
Flood Control Pool	None	760.0	663.0	508.0	685.0	450.0	504.5	None	375.0
Total Storage, ac-ft	435,600	6,089,000	1,076,000	310,900	2,092,000	545,000	652,000	104,000	2,082,000
Total Area, ac	6,060	63,500	30,990	13,920	23,060	27,450	22,700	7,450	93,450
Backwater, mi	19.2	101.3	61.0	71.9	64.0	97.3	41.9	67.5	118.1
Maximum Depth, ft	263	179	145	78	177	68	103	41	81
Mean Depth (summer), ft	72	80	49	22	73	19	33	14	15
Mean Discharge, cfs	372	9,012	1,479	13,236	3,801	18,605	1,516	22,675	33,912
Mean Retention Time, days	511	149	341	7	138	8	98	2	6

Additional information on the state of mussel stocks in the upper portion of Old Hickory Lake can be gleaned from data collected by Parmalee during 1977-1979 (Parmalee et al. 1980). Parmalee examined piles of mussel shells taken by commercial shellers. In September 1979, collections were made by brailing three major mussel beds located between RM 291.0 and RM 296.8, using the services of a commercial sheller. This resulted in the collection of 27 species of mussels. Federally endangered species and their numbers recovered alive were *Lampsilis abrupta* (2), *Plethobasus cooperianus* (3), and *Dromus dromas* (1). To this list can be added 11 more species, including the federally endangered *Pleurobema plenum*, found in shell piles. About half of the observed fauna was judged to be rare or uncommon. A 1983 survey of potential dredge and disposal sites between RM 303.8 and 309.2 (TVA, 1983) found 22 species of mussels alive, including *Lampsilis abrupta* (10) and *Pleurobema plenum* (1). Mussels were reported not to be abundant based on the low number of specimens collected per man-hour of effort.

A 1992 survey of proposed navigation channel dredging and disposal sites between RM 304.3 and RM 308.9 (TVA 1992) found 17 species of mussels alive. Again *Lampsilis abrupta* (6) was found. Only relic specimens of *Dromus dromas* were recovered.

The Tennessee Wildlife Resources Agency (TWRA) has three mussel sanctuaries on the Cumberland River in the upper portion of Old Hickory Lake. During 1989, TWRA divers conducted a survey of various sites within two of these sanctuaries to determine how mussel populations were faring. A total of 21 species of mussels was recovered alive during the survey.

All of the studies conducted seem to indicate a general decline in the mussel fauna in the upper reach of Old Hickory Lake. Few, if any, species are reproducing and successfully recruiting because only old individuals are being found. Various factors including depressed water temperature regimes, dredging for navigation, and water level fluctuations caused by peaking hydropower generation were implicated in the decline of the mussel fauna. Further downstream the gradual transition into a more lentic environment eliminated some less tolerant species. Despite all these impacts, a portion of the riverine mussel fauna, which still contains at least one federally endangered species and perhaps others, persists in this reach. The continued survival of the fauna is in contrast to its nearly complete elimination below upstream storage impoundments.

The continued decline of the Cumberland River mussel fauna has alarmed agencies such as the U.S. Fish and Wildlife Service (FWS), which is charged with implementing laws to protect and recover populations of threatened and endangered wildlife. In early 1994, a project was initiated involving the Corps of Engineers' Nashville District and Ohio River Division offices and the FWS to examine in greater detail the causes of the decline of native mussel stocks in the middle and upper Cumberland River. This included discussion of the impacts of Corps of Engineers water management operations on native mussel habitat. Specifically, the depression of water temperatures resulting from hypolimnetic releases for the generation of hydropower was identified as the primary factor responsible for the continued decline of mussel populations. Depressed water temperatures induce physiological stress on mussels, preventing reproduction. In addition, cold water has eliminated many species of host fish required for the metamorphosis of mussel glochidia to a juvenile state.

Options for altering cold-water release patterns from Nashville District storage impoundments for the purpose of warming specific river reaches are limited to structural alteration of the release works from dams and operational changes. Because structural changes would require large capital expenditures, the first logical step was to model a series of operational changes to accomplish some warming in five different areas of the Cumberland River and tributaries affected by Nashville District project operations. The only way an operational change can accomplish warming is to significantly reduce outflows from one or more dams. A temperature criterion of reaching at least 22°C in affected reaches for a minimum of 3 consecutive weeks during June-September was set as a target.

Based on these stated needs for improving mussel spawning conditions, the Nashville District conducted a modelling study examining various operational changes at dams to improve temperature regimes in three reaches of the Cumberland River and two reaches below dams on major tributaries. A real-time reservoir system model was used to determine impacts of reservoir operations on water quality, hydropower production, intake temperatures at a fossil fuel power plant, and outflow dissolved oxygen (DO) from two dams at critical points in the system.

Evaluation of Alternatives

The first of the five segments under consideration extends from Wolf Creek Dam at RM 460.9 to the backwaters of Cordell Hull Reservoir at RM 381.0, a distance of about 80 river miles. Releases of cold water from Wolf Creek Dam have created conditions favorable for the establishment of a put-and-take trout fishery in the upper 25 miles of the tailwater. In order to maintain the trout fishery, water temperatures below 20°C had to be maintained in that reach. The operational plan for Wolf Creek Dam releases consisted of reducing daily outflows from Wolf Creek Dam to about 500 cfs for a month. Such an operation would have maintained cold water in the reach supporting the trout fishery. A transition zone would have been created downstream of the trout waters. Below the transition zone, water temperatures would warm to >22°C. The 500 cfs outflow figure, which yielded improved water temperatures in portions of the Cumberland River downstream of Wolf Creek Dam, is less than 10% of the normal release. A special operation at Wolf Creek Dam essentially shuts off most of the flow through the river system during a critical time for downstream water quality concerns, and it significantly impacts power production. The reduction in flows causes increased detention times in downstream reservoirs, causing severe DO depletion in the main stem. State water quality standards for DO (5 mg/l) in the Old Hickory Dam outflow would have been significantly violated, compromising water quality in the lower portions of the Cumberland River and negatively impacting the assimilative capacity of the river at Nashville, Tennessee. As a result of this analysis, a special operation to elevate water temperatures in a portion of the Wolf Creek Dam tailwater was eliminated from further consideration due to negative environmental impacts and the significant loss of hydropower production.

The 7.3-mile-long reach of the Obey River below Dale Hollow Dam was another segment considered for a special operation. The short length of this reach compounded the difficulties in carrying out any plan to effectively reach the target temperature of 22°C. Shutting off flows from Dale Hollow Dam would have theoretically allowed the tailwater to warm. However, cold water would have intruded into the Obey River from the Cumberland River, which receives the outflows from Wolf Creek Dam some 80 miles upstream. The only method to warm the short reach of the Obey River below Dale Hollow Dam would have been to drastically reduce outflows from both Dale Hollow and Wolf Creek dams for an extended period of time. As discussed earlier, severe reductions in outflows from Wolf Creek Dam resulted in very adverse downstream consequences for water quality. This precluded any further consideration of operations to warm the Obey River below Dale Hollow Dam.

Cordell Hull Reservoir extends from RM 313.5 to RM 381.0. The major inflows to Cordell Hull are the outflows from Wolf Creek and Dale Hollow dams. The upper reaches of Cordell Hull Reservoir retain a somewhat riverine characteristic, but are affected by the cold inflows. Under the scenario of reducing the Wolf Creek outflow to 500 cfs, the inflow coming from Dale Hollow Dam then becomes the major cold-water contributor, preventing necessary warming. It therefore becomes necessary to drastically reduce both cold water inputs. When this happens there would be insufficient warm water available to displace the colder, denser water already in the upper reaches of Cordell Hull Reservoir. Due to this phenomenon, and the adverse consequences to water quality in downstream areas, warming of the upper reaches of Cordell Hull Reservoir was not considered practicable.

The fourth area considered for a special operation to modify temperature conditions for mussels was the 26.5-mile reach of the Caney Fork River downstream of Center Hill Dam. The operational objective for the Center Hill tailwater would be to release enough water to maintain the popular trout fishery in the first 11 miles below the dam. This <20°C zone of cold water would be followed by a transition to waters approaching the mussel requirement criterion of >22°C. The reduction in flows from Center Hill Dam required to accomplish the warming would have some adverse consequences for downstream water quality. However, increasing outflows from other projects would have avoided adverse water-quality impacts. Unfortunately, though it would be possible to create a reach of warmer water meeting the minimum temperature criterion set forth, mussels are now virtually absent from this reach of the Caney Fork River. Their reestablishment in the Caney Fork River below Center Hill Dam would be extremely problematic. The return of cold water at the conclusion of the special operation would probably negate any benefits that might have been gained.

Most Feasible Alternative

The most feasible alternative for a special operation was the portion of the Cumberland River in the upper reach of Old Hickory Lake, from RM 244.5 to about RM 313.5. At the lower terminus of the reach is TVA's Gallatin Fossil Plant, which has a maximum allowable intake temperature criterion of 24.4°C. If the intake temperature rises above 24.4°C, the plant has problems meeting National Pollution Discharge Elimination System (NPDES) discharge permit limits for its cooling water. A further concern downstream is that flow reductions resulting from efforts to warm the upper portion of Old Hickory Lake might cause the outflow from Old Hickory Dam to fall below 5 mg/l for a significant period of time, violating state DO standards.

The operational objective for the Old Hickory reach would be to warm inflows enough to improve conditions for mussels in the upstream reaches of the impoundment. In some years outflow temperatures from Cordell Hull Dam reach nearly 22°C for several weeks at a time. However, this more favorable temperature regime is then negatively impacted by the influx of cold water entering the Cumberland River from the regulated Caney Fork River just 4 miles downstream of Cordell Hull Dam. The input of cold water comes at the upper end of the portion of the Cumberland River containing the remnant, riverine mussel fauna. Warming of the upper portion of Old Hickory Lake would be accomplished by drastically reducing inputs of cold water from Center Hill Dam on the Caney Fork River and modifying releases from Dale Hollow Dam on the Obey River which contributes cold water to Cordell Hull Reservoir. This combination of operational changes would extend the period of time at which the upper end of Old Hickory Lake exceeds 22°C. Additional warming could be accomplished by modifying the release patterns at Cordell Hull Dam to withdraw warmer water during afternoon.

For operational changes to accomplish a warming of the upper portion of Old Hickory Lake, a variety of conditions would have to be met including warmer-than-normal meteorological conditions and outflow temperatures from storage projects, and a relatively typical year from a hydrologic standpoint. Developing an operational plan to warm the upper reach of Old Hickory Lake would involve trial and error using mathematical models. Because antecedent meteorological conditions vary greatly from year to year, the operation would have a realistic chance of being carried out successfully an average of once every 5 years.

Summary

Of the five areas evaluated for operational changes to improve temperature regimes for mussels, only one, the upper Old Hickory Lake reach, was feasible to attempt. Although the thermal regime can be improved, it is problematic as to whether this improvement would translate into successful reproduction and recruitment of mussels into the existing population. Without an operational change to improve conditions, the continued decline of the mussel fauna seems inevitable. An improvement in conditions might also allow additional time to explore other options for conserving the remaining mussel fauna.

In a highly regulated system such as the Cumberland River, a change in operations to favor one resource, in this case mussels, may result in adverse impacts to other resources or users. In this specific case, adverse impacts may result for power production, recreation, coldwater fisheries, and downstream waste assimilative capacities. With careful manipulation and monitoring of operational changes, adverse consequences for other benefits delivered by the system can be minimized.

The complex life history requirements of freshwater mussels have made them particularly vulnerable to changes brought about by the regulation of rivers. In general, the impoundment and regulation of rivers tends to simplify ecosystems, often negatively impacting fauna that evolved with complex requirements and interrelationships with the natural riverine system. In a highly regulated system such as the Cumberland River, where dams were built before current environmental statutes were enacted, options for improving habitat conditions are somewhat limited. The decline of the mussel fauna observed in the Cumberland River basin points out the urgent need to identify and act upon measures to conserve mussel resources both in systems with and without significant hydrologic regulation.

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