Species Status Assessment Report for the Longsolid (*Fusconaia subrotunda*)

Photo credit: Dick Biggins/Service

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ACRONYMS USED

Act	Endangered Species Act
ADCNR	Alabama Department of Conservation and Natural Resources
AMD	acid mine drainage
ANHP	Alabama National Heritage Program
ANS	aquatic nuisance species
ARA	active river area
BMP	best management practices
CAFO	Concentrated Animal Feeding Operations
CBD	Center for Biological Diversity
CWA	Clean Water Act
CWP	Center for Watershed Protection
DNR	Department of Natural Resources
EPA	U.S. Environmental Protection Agency
ESI	Ecological Specialists, Inc.
FPG	Forest Practices Guidelines
FR	Federal Register
HUC	Hydrologic unit codes
INHS	Illinois Natural History Survey
KDEP	Kentucky Department for Environmental Protection
KSNPC	Kentucky State Nature Preserves Commission
KYDOW	Kentucky Division of Water
KDFW	Kentucky Department of Fish & Wildlife Resources
LEC	Lewis Environmental Consulting
MU	Management Unit
NCASI	National Council for Air and Stream Improvement
NCFA	North Carolina Forestry Association
NCNHP	North Carolina National Heritage Program
NCMNS	North Carolina Museum of Natural Sciences
NCWRC	North Carolina Wildlife Resources Commission
NGO	non-governmental organization
NHEP	New Hampshire Estuaries Project
NHP	Natural Heritage Program
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NWR	National Wildlife Refuge
ODNR	Ohio Department of Natural Resources
OWC	organic wastewater contaminants
PANHP	Pennsylvania National Heritage Program
PDEP	Pennsylvania Department of Environmental Protection
PPM	parts per million
RM	river mile
ROW	right-of-way
RRI	Reservoir Release Improvement
Service	U.S. Fish and Wildlife Service
SMCRA	Surface and Mining Control and Reclamation Act of 1977
SSA	Species Status Assessment
SWAP	State Wildlife Action Plan
TAN	total ammonia-nitrogen
TDEC	Tennessee Department of Environment and Conservation
TNC	The Nature Conservancy
TSS	total suspended solids
TVA	Tennessee Valley Authority
TWRA	Tennessee Wildlife Resources Agency
USACE	U.S. Army Corps of Engineers
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
VDGIF	Virginia Department of Game and Inland Fisheries
WVDEP	West Virginia Department of Environmental Protection
WVDNR	West Virginia Division of Natural Resources

EXECUTIVE SUMMARY

In 1831, Isaac Lea described the Longsolid, a medium-sized mussel, up to 5 inches (125 millimeters (mm) in size, which can be long-lived-potentially up to 50 years. It is found in small streams to large rivers (such as the Ohio River mainstem), and prefers a mixture of sand, gravel, and cobble substrates.

The Longsolid is historically known from 12 states, though now only occurs in nine. It is currently found in three major river basins: the Ohio (where is most prevalent), Cumberland (where it is rarest), and Tennessee, it is considered extirpated from the Great Lakes basin. Known populations have declined in number from 162 historically to 60 today. It has suffered impacts from negative influences to aquatic species commonly found in the central and eastern U.S. including habitat fragmentation from dams and other barriers; habitat loss; degraded water quality from chemical contamination and erosion from poorly managed development, agriculture, mining, and timber operations; direct mortality from dredging and harvest; and the proliferation of invasive species, such as the zebra mussel. Projections 50 to 70 years into the future indicate that the number of populations could remain at 60 or drop to as low as 16, depending on the variety of considerations built into the scenarios we evaluated. In addition, it is highly likely that the Longsolid could disappear entirely from the Cumberland River basin given current and possible future conditions in the last remaining population within that basin.

In projecting the future viability of the Longsolid, three scenarios were considered: one in which current influences remain constant 30 years into the future; one in which negative influences decrease due to elevated levels of conservation efforts over 30 years; and one in which negative influences become worse over the 30 years. Historical, current, and future population projections are summarized in Table ES-1, below. The table articulates the number of populations (redundancy), the distribution of the populations across the three river basins where the mussel is extant (representation), and the capability of the population to withstand stochastic events (resiliency).

Table ES-1. Overall summary of historical, current, and future conditions for Longsolid populations across its range.

- **High -** Resilient populations generally distributed over a generally contiguous length of stream (greater than or equal to 30 river miles), with evidence of recruitment, and multiple age classes represented. Connectivity among populations is maintained within MUs such that populations are not linearly distributed (i.e., occur in tributary streams within a management unit). These populations are expected to persist in 50 to 70 years and beyond and withstand stochastic events. *(Thriving; capable of expanding range.)*

- **Medium** - Spatially restricted populations with limited levels of recruitment or age class structure. Individuals occur in tributary streams, such that within a MU, populations are not linearly distributed. Resiliency is less than under high conditions, but the majority (approximately 75 percent) are expected to persist in 50 to 70 years. *(Stable, not necessarily thriving or expanding its range.)*

- **Low** - Small and highly restricted populations, with no evidence of recent recruitment or age class structure, and limited detectability. These populations have low resiliency, are not likely to withstand stochastic events, and potentially will no longer persist in 50 to 70 years. Populations are linearly distributed within a management unit. (*Surviving, observable; but population likely declining*.)

(FUTURE CONDITION ONLY)

- **Very Low -** Populations are expected to no longer occur in a river/stream or management unit in the future (50–70 years). A population may be below detectable levels despite consistent survey effort within its formerly occupied range. Evidence of population limited to relic or weathered dead shells. (*No survival or survival uncertain; no longer observable*.)

	Historical	Current	Future Scenario 1	Future Scenario 2	Future Scenario 3
Great Lakes Basin					
# total populations	6	0	--	--	--
# Management units	4[2]	0	--	--	--
# states	3[1]	0	--	--	--
Ohio River Basin					
# very low populations	--	--	12	0	29
# low populations	Unknown	30	21	20	9
# medium populations	Unknown	7	5	12	1
# high populations	Unknown	3	1	5	0
# total populations[2]	104[2]	39	27	39	10
# Management units	67[2]	30	20	30	9
# states	7[3]	5	5	5	3
Cumberland River Basin					
# very low populations	--	--	1	0	1
# low populations	Unknown	1	0	1	0
# medium populations	Unknown	0	0	0	0
# high populations	Unknown	0	0	0	0

[1] Accounts for states where the species currently resides and those states that the species is known to be extirpated from.

[2] Total values under the three future condition scenarios exclude the very low populations counts given these populations would likely no longer exist in the future

[3] Accounts for states where the species currently resides and those states that the species is known to be extirpated from.

	Historical	Current	Future Scenario 1	Future Scenario 2	Future Scenario 3
# total populations[1]	10[2]	1	0	1	0
# Management units	9[2]	1	0	1	0
# states	2[2]	1	0	1	0
Tennessee River Basin					
# very low populations	--	--	5	0	14
# low populations	Unknown	18	12	6	4
# medium populations	Unknown	2	3	12	2
# high populations	Unknown	1	0	2	0
# total populations[1]	46[2]	20	15	20	6
# Management units	26[2]	14	11	14	4
# states	6[2]	5	5	5	4
TOTAL					
# very low populations	--	--	18 (30%)	0	44 (73%)
# low populations	Unknown	48 (80%)	33 (55%)	27 (45%)	13 (22%)
# medium populations	Unknown	9 (15%)	8 (13%)	24 (40%)	3 (5%)
# high populations	Unknown	3 (5%)	1 (1%)	9 (15%)	0
# total populations[1]	162	60	42	60	16
# Management units	105	45	31	45	13
# states	12	9	8	9	6

This SSA Report for the Longsolid includes:

(1) An Introduction, including taxonomy (Chapter 1);
(2) A description of the SSA Framework, including Resiliency, Redundancy, and Representation (Chapter 2);
(3) A description of Longsolid's ecology (Chapter 3);
(4) The resource needs of the Longsolid as examined at the individual, and population, and rangewide scales (Chapter 4);
(5) Characterization of the historical and current distribution, abundance, and demographic conditions of the Longsolid across its range (Chapter 5);
(6) An assessment of the current factors that negatively and positively influence the Longsolid and the degree to which the various factors influence its viability (Chapter 6);

(7) Descriptions of future scenarios, including an evaluation of those factors that may influence the species in the future at the population or rangewide scale and a synopsis of resiliency, redundancy, and representation given the potential future condition scenarios (Chapter 7);
(8) An overall synthesis of this report (Chapter 8).

CHAPTER 1 - INTRODUCTION

1.1 Purpose of SSA

The Species Status Assessment (SSA) framework (Service 2016a, entire) is an in-depth review of a species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The SSA report is easily updated as new information becomes available and to support all functions of the Endangered Species Program from Candidate Assessment to Listing to Consultations to Recovery. As such, the SSA report is a living document that may be used to inform decision making under the Act.

Importantly, the SSA report is not a decisional document; rather, it provides a review of available information strictly related to the biological status of the Longsolid mussel (also referred to herein as "the Longsolid"). Any decisions regarding the legal classification of a species are made after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the *Federal Register*, with appropriate opportunities for public input.

1.2 Species Basics - Taxonomy and Evolution

The Longsolid (*Fusconaia subrotunda*; Figure 1.1) is a freshwater mussel currently found in the Ohio, Cumberland, and Tennessee River basins, overlapping within the states of Alabama, Kentucky, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia (Appendix A; Figure 1-2). It is considered extirpated from Georgia, Indiana, and Illinois. *Fusconaia subrotunda* is part of a genus that includes 11 mussel species (Williams *et al.* 2017, p. 49).

Figure 1-1. Longsolid. Photo credit: Karen Little, Illinois State Museum.

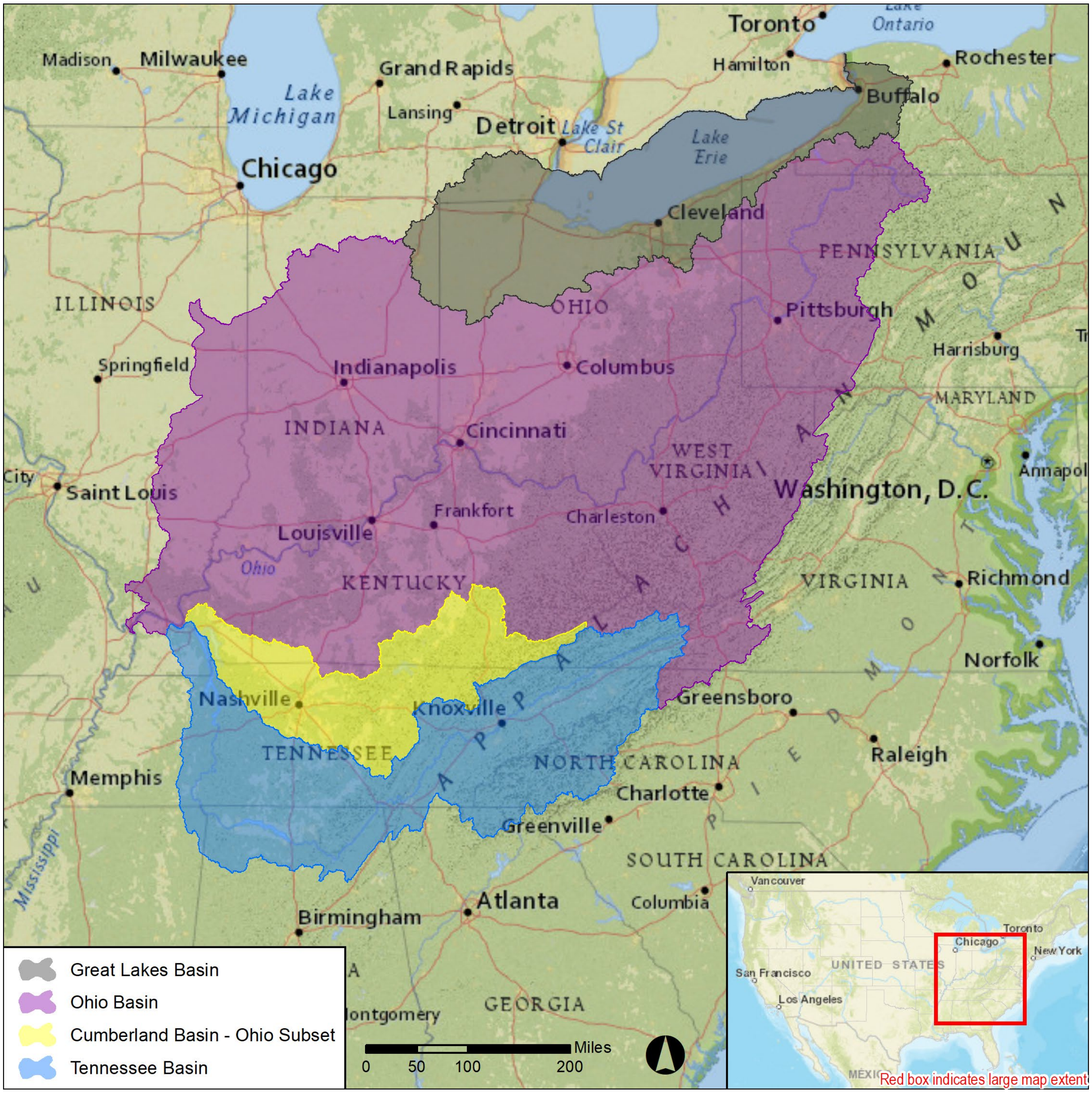

Figure 1-2. Longsolid range map indicating the Great Lakes, Ohio, Cumberland, and Tennessee River basins. The species is considered extirpated from the Great Lakes basin. (Source: Service 2018a, unpublished data).

The three major river basins that Longsolid inhabits (Figure 1.2, above) are the Ohio, Cumberland, and Tennessee. For this assessment, we used information about the species historical range to partition Longsolid into these three geographical units (basins; Figure 1-3). The Ohio basin drains portions of New York, Pennsylvania, Ohio, West Virginia, Virginia, Kentucky, Illinois, and Indiana. The Cumberland basin drains portions of Kentucky and Tennessee. The Tennessee basin drains portions of Alabama, Georgia, Kentucky, Mississippi, North Carolina, Tennessee and Virginia.

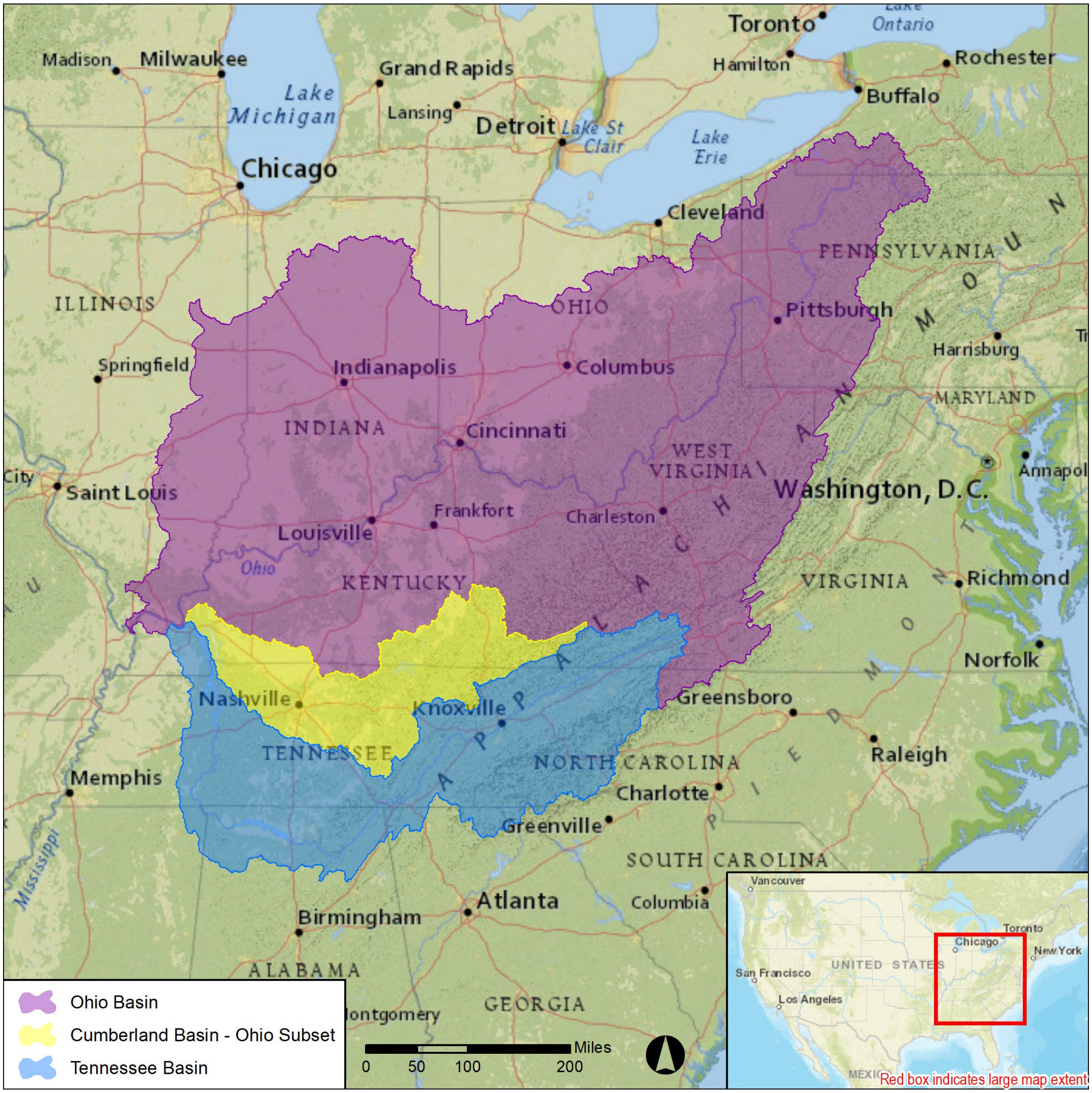

Figure 1-3. Longsolid range map illustrating the Ohio, Cumberland, and Tennessee River basins. The species currently resides within these three major river basins and the states of Alabama, Kentucky, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia. (Source: Service 2018a, unpublished data).

The Ohioan and Cumberlandian regions represent accepted patterns of faunal similarity in freshwater mussels (Haag 2009, p. 12). The Tennessee and Cumberland river systems ultimately drain into the Ohio River, and comprise the Cumberlandian Region (Ortmann 1924, p. 59). Historically, the Cumberlandian Region supported the richest freshwater mussel (Bivalvia: Unionacea) fauna in the world (Johnson 1980, p. 79). Further, although the Tennessee and Cumberland River mussel faunas are very similar, the high levels of aquatic endemism in the Cumberland River system and mussel species originating from that basin support its consideration separate from the Tennessee River system (Gordon and Layzer 1989, p. 3; Haag and Cicerello 2016, p. 38).

1.2.1 Taxonomy

The Longsolid mussel belongs to the Unionidae family, also known as the naiads and pearly mussels. This group of bivalves has been in existence for over 400 million years (Howells *et al.* 1996, p. 1), representing over 600 species worldwide and over 250 species in North America (Strayer *et al.* 2004, p. 429; Lopes-Lima *et al.* 2018, p. 3). This report on the Longsolid follows the most recently published and accepted taxonomic treatment of North American freshwater mussel as provided by Williams *et al.* (2017, entire).

The Longsolid (*Fusconaia subrotunda*) was originally described in 1831 by Isaac Lea as *Unio subrotundus* Lea 1831 (p. 117).

The currently accepted classification is (Integrated Taxonomic Information System, 2017):

- Phylum: Mollusca
- Class: Bivalvia
- Order: Unionoida
- Family: Unionidae
- Subfamily: Ambleminae
- Tribe: Pleurobemini
- Genus: *Fusconaia*
- Species: *subrotunda*

The synonymy for *Fusconaia subrotunda* is extensive, possibly due to the species' display of clinal variation, ranging from a smaller 'compressed headwater form' to a more 'inflated big river' form. The Longsolid is an example of a mussel used to describe the law of stream position (Ortmann 1920, p. 272). Additionally, several subspecies and varieties have been referred to in the literature (i.e., *F. kirtlandiana*, *F. pilaris lesueriana, F. bursa-pastoris;* see discussion in Watters *et al.* 2009, p. 130; and Parmalee and Bogan 1998, p. 120). In addition, there appears to be a unique variant in French Creek, Pennsylvania (Watters *et al.* 2009, p. 132). However, *F. subrotunda* is currently the nomenclature used to collectively refer to all of these forms.

1.3 Petition History

We, the U.S. Fish and Wildlife Service (Service), were petitioned by the Center for Biological Diversity (CBD), Alabama Rivers Alliance, Clinch Coalition, Dogwood Alliance, Gulf Restoration Network, Tennessee Forests Council, West Virginia Highlands Conservancy, Tierra Curry, and Noah Greenwald to list the Longsolid as an endangered or threatened species under the Endangered Species Act of 1973, as amended (Act). This petition was part of a 2010 petition to list 404 aquatic, riparian, and wetland species in the southeastern United States (CBD 2010, pp. 538–540). On September 27, 2011, we found that the petition presented substantial scientific or commercial information indicating that listing the Longsolid may be warranted (76 FR 59836 59862); substantial findings were made for the other species in this same *Federal Register* notice, although analyses and findings for those other species are addressed separately.

1.4 State Listing Status

Of the states where the Longsolid is known to historically or currently occur, it is only state-listed in Ohio as an endangered species (Table 1-1). This designation provides state statutory protection against taking or possession of the species in Ohio. Permits from the Ohio Division of Wildlife may be obtained for taking or possession of Longsolid for zoological, educational, or scientific purposes, or for propagation in captivity to preserve the species. The states of Pennsylvania, West Virginia, Virginia, and North Carolina have wildlife management agency protective regulatory measures for freshwater mussels prohibiting the the take or possession of freshwater mussels without a scientific collector's permit. However, landowner rights in those states supercede these regulations. A variety of additional "designations" or status descriptions are assigned to the Longsolid within other states, however, these are typically only accompanied by wildlife management agency mandates, and are not state statutory protections.

The states of Alabama, Tennessee, and Kentucky all have mussel harvest sanctuaries, or designated reaches of rivers where it is unlawful to take, catch, or kill freshwater mussels, and the degradation of aquatic habitat is prohibited. These sanctuaries provide some indirect protection to the Longsolid in these states, but since commercial harvest is no longer considered a primary threat to the species, in part due to its rarity, the actual protection afforded is limited. The Longsolid is a nongame species in Tennessee, making it unlawful for anyone to take, possess, transport, export, process, sell or offer for sale or ship, and for any contract carrier to knowingly transport or receive for shipment Longsolid mussels. In Pennsylvania and West Virginia, the take of live freshwater mussels without a scientific collector's permit is unlawful.

Table 1-1. State and NatureServe conservation status of Longsolid mussel throughout its historical range.

State Status	AL	IL	IN	KY	NC	OH	PA	TN	VA	WV	NY	GA
State Rank (Wildlife Action Plans) 2015	(S1)/ P1	X	SX	SC (S3) (Decreasing Trend)	SR	E (Decreasing Trend)	S2	S3 (SWAP Tier 1)	Tier 3	S3	NR	NR
NatureServe (as of 2009)	S1	S X	SX	S3S4	S1	SNR	S1	S3	S3	S2	NR	SH

KEY: E = endangered; P1 = highest conservation concern; SC = Special Concern; SR = Significantly Rare; NR = not recognized; T = threatened; X = extirpated. Tier 1 = Critical Conservation Need; Tier 3 = High Conservation Need; SX = Presumed Extirpated; SH = Possibly Extirpated; S1 = Critically Imperiled; S2 = Imperiled; S3 = Vulnerable; S4 = Apparently Secure; SNR = Not Ranked/Under Review

CHAPTER 2 - METHODOLOGY AND DATA

2.1 SSA Framework

This report is a summary of the SSA analysis, which entails three iterative assessment stages: species (resource) needs, current species condition, and future species condition (Figure 2-1).

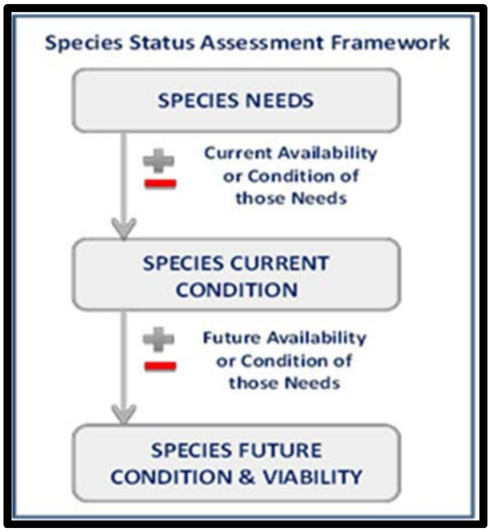

Figure 2-1. The three analysis steps in a Species Status Assessment.

2.1.1 Species Needs

The SSA includes a compilation of the best available biological information on the species and its ecological needs at the individual, population, and rangewide levels based on how environmental factors are understood to act on the species and its habitat.

- Individual level: These resource needs are those life history characteristics that influence the successful completion of each life stage. In other words, these are survival and reproduction needs that make the species sensitive or resilient to particular natural or anthropogenic influences.

- Population level: These components of the Longsolid's life history profile describe the resources, circumstances, and demographics that most influence **resiliency** of the populations.

- Rangewide level: This is an exploration of what influences **redundancy** and **representation** for the Longsolid. This requires an examination of the mussel's evolutionary history and historical distribution to understand how the species functions across its range.

To assess the biological status of the Longsolid across its range, we used the best available information, including peer-reviewed scientific literature and academic reports, and survey data provided by state and Federal agencies. Additionally, we consulted with several species experts who provided important information and comments on Longsolid distribution, life history, and habitat.

We researched and evaluated the best available scientific and commercial information on the Longsolid's life history. To identify population-level needs, we used published literature, unpublished reports, information from consultants, and data from current agency survey and taxonomic research projects. To date, no specific life history study has been conducted on the Longsolid. Arnold E. Ortmann published some information on Longsolid reproduction as part of comprehensive studies of regional mussel faunas in the early 1900s (Ortmann 1909a; 1913; 1919; 1921). Some life history information on the species was reported recently in Schilling (2015, p. 125). Where applicable, such as host fish suitability, surrogate life history information was also used from the closely related and federally endangered Fine-rayed Pigtoe (*Fusconaia cuneolus*) and Shiny Pigtoe (*F. cor*). These species are sympatric (i.e., joint occurrence of species) with the Longsolid in the Paint Rock, Clinch, and Powell River systems, and were the subject of previous life history studies in the upper Tennessee River basin (Bruenderman and Neves 1993, entire; Kitchel 1985, entire).

2.1.2 Current Species Condition

The SSA describes the current known condition of the Longsolid's habitat and demographics, and the probable explanations for past and ongoing changes in abundance and distribution within areas representative of the geographic, genetic, or life history variation across the species range.

We considered the Longsolid's distribution, abundance, and factors currently influencing the viability of the species. We identified known historical and current distribution and abundance, and examined factors that negatively and positively influence the species. Scale, intensity, and duration of threats were considered for their impacts on the populations and habitat across life history stages. The magnitude and scale of potential impacts to the Longsolid or its habitat by a given threat are described using a High/Moderate/Low category scale.

How Populations Were Evaluated For Current Conditions

For the current condition analyses, the Longsolid was considered extant if a live individual or fresh dead specimen was collected since 2000[4], or collections of the species have been made since 1990 with no available negative mussel survey data from the stream to dispute that the species still occurs there. Given the longevity of the genus *Fusconaia*, and the timing and frequency of mussel surveys conducted throughout the species' range, collections or observations of live individuals or fresh dead specimens since 2000 likely indicates the continued presence of a species within a river or stream (Stodola *et al.* 2014, p. 1). For large water bodies such as the Ohio River, or for streams that have not received consistent survey effort, it is difficult to determine whether a lack of occurrence since 1990 relative to pre-1990

[4] We used the year 2000 in this analysis for consistency, due to the longevity of the species, highly variable recent survey information across the range of the Longsolid, and available state heritage databases and information support for the likelihood of the species continued presence within this timeframe.

reflects a lack of sampling or a decline in abundance or distribution (Haag and Cicerello 2016, pp. 65–66).

Presumed extirpation was determined by documentation in literature, reports, or from communications with state malacologists and aquatic biologists. General reference texts on regional freshwater mussel fauna such as Haag and Cicerello (2016), Williams *et al.* (2008), Watters *et al.* (2009), Parmalee and Bogan (1998), and Gordon and Layzer (1989) provided substantial information on species distribution, both past and present.

There is no systematic sampling regime to monitor the Longsolid's distribution and status across its range. We gathered information from a large body of published and unpublished survey work rangewide since the early 1900s. More recent published and unpublished distribution and status information was provided by biologists from State Natural Heritage Programs (NHP), Department of Natural Resources (DNR) programs, other state and Federal agencies, academia, and museums; all information was compiled into a database for reference. Occurrence data were grouped by named stream and state, then organized by 8-digit hydrologic unit code watershed (HUC 8)[5]. All records were also added to a Geographic Information System (GIS) database to facilitate spatial analyses. Additional detail on the current condition analysis methodology is presented in Chapter 5.

Defining Management Units

The smallest measure of the Longsolid occurrence is at the river or stream reach, which varies in length. Occasional or regular interaction among individuals in different reaches not interrupted by a barrier likely occurs, but in general, interaction is strongly influenced by habitat fragmentation and distance between occupied river or stream reaches. Once released from their fish host, freshwater mussels are benthic, generally sedentary aquatic organisms and closely associated with appropriate habitat patches within a river or stream. In situations where Longsolid populations are close in proximity with little or no fragmentation, multiple river or stream reaches may constitute a single metapopulation. Examples include French and Muddy Creek in Pennsylvania, tributaries to the middle Allegheny River, and Estill Fork and Hurricane Creek, tributaries to the Paint Rock River in Alabama. Available data were organized by named river or stream that was subsequently used as the unit to delineate an individual population. In this context, "river or stream" and "population" are used synonymously herein.

In addition, the Longsolid range includes lengthy rivers such as the Ohio, Allegheny, Cumberland, and Tennessee Rivers, all of which include fragmented populations, primarily by dams. Therefore, separate populations are designated for each HUC 8 through which these

[5] Hydrologic unit codes (HUC) are two to twelve-digit codes based on the four levels of classification in a hydrologic unit system, as described in Seaber *et al.* 1987 and USGS (2018). In summary, the United States is divided into successively smaller hydrologic units arranged or nested within each other. Each successively smaller hydrologic unit/code contains successively smaller drainage areas, river reaches, tributaries, etc. HUC 8 is the fourth-level (cataloguing unit) that maps the subbasin level, which is analogous to medium-sized river basins across the U.S.

streams flow (if there was an occurrence record for the stream in that watershed). The HUC 8 watershed is termed a Management Unit (MU) in this report. For example, in the Ohio River main stem, there are occurrence records in six different HUC 8 watersheds; hence, this analysis assumes that there are six separate MUs of Longsolid populations in the Ohio River.

Management units were defined as a HUC 8, which were identified as most appropriate for assessing population-level resiliency. Range-wide species occurrence data were used to create maps indicating the historical and current distribution of Longsolid among management units for each of 60 populations currently known to be extant. Given the large range of the species within the U.S., using management units at this HUC 8 scale allowed larger rivers such as the Allegheny, Ohio, Cumberland, and Tennessee to be summarized into smaller, more manageable areas for analysis and discussion. The HUC 8 management unit approach has also been used for other wide-ranging aquatic species for the purposes of an SSA (e.g., the Eastern Hellbender (*Cryptobranchus alleganiensis*) (Service 2018b, entire)).

2.1.3 Future Species Condition

The SSA forecasts a species' response to probable future scenarios of environmental conditions and conservation efforts. As a result, the SSA characterizes the species' ability to sustain populations in the wild over time (viability) based on the best scientific understanding of current and future abundance and distribution within the species habitat.

To examine the potential future condition of the Longsolid, we developed three future scenarios that focus on a range of conditions based on projections for habitat degradation or loss, invasive or non-native species, harvest and overutilization, and genetic isolation and displacement; beneficial conservation actions were also considered. The range of what may happen in each scenario is described based on the current condition and how resilience, representation, and redundancy may change. We chose a time frame of 50 to 70 years for our analysis based on the availability of trend information, planning documents, and climate modeling that helps inform future conditions, as well as this time frame capturing at least two generations of this long-lived (25 to 35 years) species. The scenarios consider the most probable threats with the potential to influence the species at the population or rangewide scales, including potential cumulative impacts if applicable.

For this assessment, we define viability as the ability of the Longsolid to sustain resilient populations in the wild over time. Using the SSA framework (Figure 2-1, above), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Service 2016, entire; Wolf *et al.* 2015, entire).

- ***Resiliency*** is assessed at the level of populations and reflects a species' ability to withstand stochastic events (events arising from random factors). Demographic measures that reflect population health, such as fecundity, survival, and population size, are the metrics used to evaluate resiliency. Resilient populations are better able to withstand disturbances such as random fluctuations in reproductive rates and fecundity (demographic stochasticity), variations in rainfall (environmental stochasticity), and the effects of anthropogenic activities.

- ***Representation*** is assessed at the species level and characterizes the ability of a species to adapt to changing environmental conditions. Metrics that speak to a species' adaptive potential, such as genetic and ecological variability, can be used to assess representation. Representation is directly correlated to a species' ability to adapt to changes (natural or human-caused) in its environment.

- ***Redundancy*** is also assessed at the species level and reflects a species' ability to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk of such an event across multiple, resilient populations. As such, redundancy can be measured by the number and distribution of resilient populations across the range of the species.

To evaluate the current and future viability of the Longsolid, we assessed a range of conditions to characterize the species' resiliency, representation, and redundancy. Throughout this analysis, when data were lacking for the Longsolid, we used information from closely related mussel species, such as the Fine-rayed Pigtoe and Shiny Pigtoe. These two species are sympatric with the Longsolid in the Tennessee River basin in the Paint Rock, Clinch, and Powell River systems.

CHAPTER 3 - SPECIES BACKGROUND AND ECOLOGY

3.1 Physical Description

Mollusks are mostly aquatic, and are named from the Latin *molluscus*, meaning "soft." Their soft bodies are often enclosed in a hard shell made of calcium carbonate ($CaCO_3$), which functions as an exoskeleton. This shell is secreted by a thin sheet of tissue called the mantle, which encloses the internal organs (Figure 3-1).

Longsolid adult mussels are light brown in color, but darken with age. The shell is thick and medium-sized (up to 5 inches (in) (125 millimeters (mm)), and typically has a dull sheen (Williams *et al.* 2008, p. 322). There is variability in the inflation of the shell depending on population and latitudinal location (Ortmann 1920, p. 272; Watters *et al.* 2009, p. 130). Juveniles usually have a bold green ray pattern near the umbo (the raised portion of the dorsal margin of mussel shell), and the Longsolid shell becomes more elongate as it ages. The umbo cavity is wide, compressed, and typically deep, which is a key characteristic of the shell. The foot can be orange, pale orange, or white (Schilling 2015, p. 101), See Fig. 3.1.

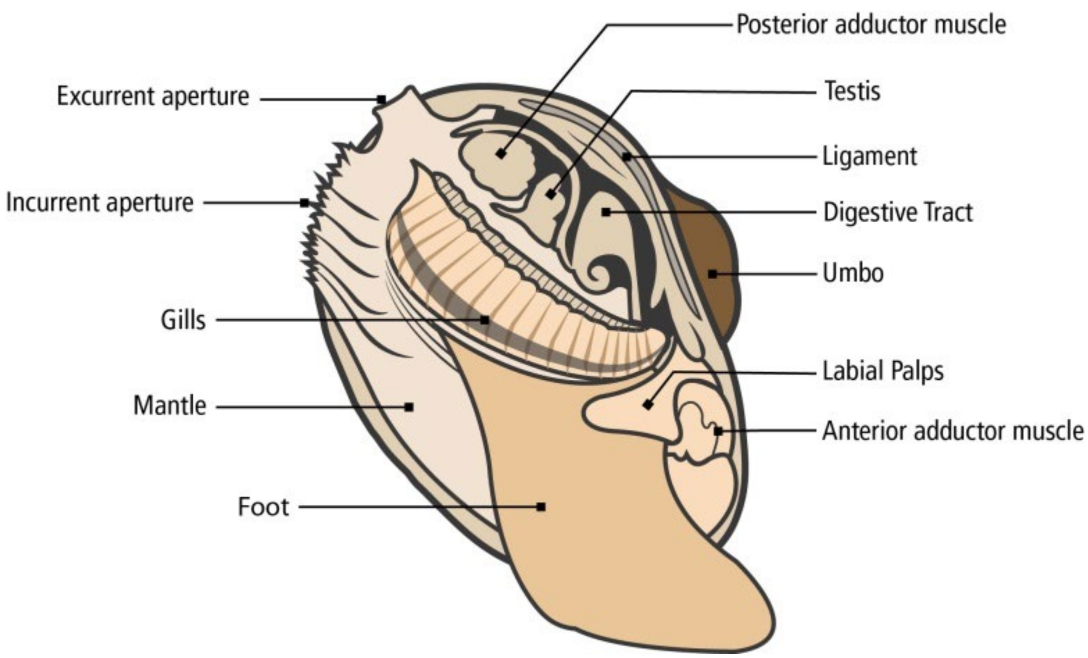

Figure 3-1. Generalized internal anatomy of a freshwater mussel. (Image courtesy of Matthew Patterson, Service).

3.2 Genetics

To our knowledge, there are no comprehensive studies that thoroughly address intraspecific divergence in genetic diversity across the range of the Longsolid. Species identification of members of the tribe Pleurobemini[6] is among the most challenging in freshwater mussels due to morphological convergence and phenotypic plasticity, particularly when similar species co-occur (Ortmann 1920, p. 272; Schilling 2015, p. 91; Inoue *et al.* 2018, p. 689).

The synonymy of the Longsolid is extensive due to the species' display of clinal variation and a smaller 'compressed headwater form' and 'inflated big river' form, to which taxonomists and malacologists often refer (Ortmann 1920, p. 272). This variation are well documented in the species. Additionally, several subspecies and varieties have been referred to in the literature (discussion in Watters *et al.* 2009, p. 130; Parmalee and Bogan 1998, p. 120); however, these are typically based on identification of this species based on morphological characters alone. Support for recognition of all forms of the Longsolid as a singular species is maintained (Williams *et al.* 2017, p. 39).

A recent examination of the phylogenetic relationships within *Fusconaia* using mitochondrial DNA found that the Longsolid does not show geographic structure despite multiple gene analyses (Schilling 2015, p. 27; Inoue *et al.* 2018, p. 690). Specimens used for these analyses were from both the Ohio basin (Green River) and the Tennessee basin (Clinch, Powell, Nolichucky, Hiwassee, French Broad, and Little rivers). While it is firmly established that the Longsolid is classified in the unionid tribe Pleurobemini, the lack of geographic constriction in the Longsolid, which is typically seen in other members of the genus *Fusconaia*, raises questions as to its origin (Campbell and Lydeard 2012, p. 9).

3.3 Life History

Little information is known or available on the life history of the Longsolid. Thus, we rely on the best available scientific and commercial information for other closely related species to help summarize life history characteristics of this species.

There are no studies on the average life expectancy of the Longsolid. Based on aging thin sections of shells, the closely related fine-rayed pigtoe was found to live at least 32 years (Bruenderman and Neves 1993, p. 88), and the shiny pigtoe was found to live to 20 years (Kitchel 1985, p. 73). Maximum age estimates for *Fusconaia* as a genus are published as 51 years (Haag and Rypel 2011, p. 230). At this time, the best available information suggests that the Longsolid is a relatively long-lived species averaging 25 to 35 years, but given the large size it can attain, possibly living up to 50 years.

Variation in mussel longevity and growth is likely related to site-specific factors and response to changes in environmental conditions such as water quality and habitat conditions present at a given location (Haag and Rypel 2011, p. 243). For example, in a Longsolid relocation study in the Elk River, West Virginia, 10 relocated individuals exhibited 100 percent survival in

[6] Pleurobemini is a diverse unionid tribe of mussels that phylogenetically has been the subject of many studies. Current classification for this subfamily includes the genera *Elliptio*, *Pleurobema*, and *Fusconaia*.

appropriate mussel habitat; surveys conducted 1 year later indicated those individuals grew 0.02 in (0.5 mm) (Dunn *et al.* 2000, p. 181). The West Virginia Division of Natural Resources (WVDNR) has long-term mark/recapture mussel monitoring sites on the Little Kanawha, Kanawha, and Elk rivers which are currently surveyed every year on a basin rotation. These sites have produced the best available information on the growth rate of the Longsolid.

On the Elk River at Queen Shoals, 78 Longsolid individuals showed an average growth of 0.67 mm/year over a five year period (Clayton 2018, pers. comm.). Similarly, at the long-term monitoring site on the Little Kanwaha River, average annual growth was 0.56 mm over a four year period for 18 individuals (Clayton 2018, pers. comm.). The long-term monitoring site on the Kanawha River at the Falls had average annual growth of 0.86 mm over a five year period for 314 individuals (Clayton 2018, pers. comm.). As would be expected the growth rate slows as individuals age. Depending on water quality and other environmental conditions negative growth is possible, or could even be expected as the individuals age and the shell erodes. In summary, the Longsolid averages 0.5-0.8 mm per year, similar to growth rates of other freshwater mussels (Haag and Rypel 2011, p. 248).

The Longsolid exhibits a preference for sand and gravel in streams and small rivers, but also may be found in coarse gravel and cobble in larger rivers (Gordon and Layzer 1989, p. 24). In streams and rivers they can be found at depths less than 2 ft (31 cm), but in large rivers can be commonly found at depths of 12 to 18 ft (3.7 to 5.5 m) (Parmalee and Bogan 1998, p. 121); but also at depths of over 20 feet (Garner 2018, pers. comm.). In a study of mussel habitat preferences in the lower Clinch River, Virginia, Longsolid were most associated with slower, deeper microhabitats with low shear stress values (Ostby 2005, p. 58), and were placed in a slow-flow tolerant guild, indicating the species has a greater tolerance for pool and run habitats. Additionally, based on this study, the Longsolid is more frequently encountered in the lower reaches of rivers such as the Clinch River (Ostby 2005, p. 40).

Adult freshwater mussels within the genus *Fusconaia* are suspension-feeders that filter water and nutrients to eat. Mussels may shift to deposit feeding, though reasons for this are poorly known and may depend on flow conditions or temperature. Ciliary tracks on the adult foot apparently facilitate this feeding behavior. Their diet consists of a mixture of algae, bacteria, detritus, and microscopic animals (Gatenby *et al.* 1996, p. 606; Strayer *et al.* 2004, p. 430). It has also been surmised that dissolved organic matter may be significant source of nutrition (Strayer *et al.* 2004, p. 431). Such an array of foods, containing essential long-chain fatty acids, sterols, amino acids, and other biochemical compounds, may be necessary to supply total nutritional needs (Strayer *et al.* 2004, p. 431). For their first several months, juvenile mussels ingest food through their foot and are thus deposit feeders, although they may also filter interstitial pore water and soft sediments (Yeager *et al.* 1994, p. 221; Haag 2012, p. 26). Due to the mechanism by which food and nutrients are taken in, freshwater mussels collect and absorb toxins (see section 6.1.2, below). Additionally, recent evidence emphasizes the importance to riverine mussels of the uptake and assimilation of detritus and bacteria over that of algae (Nichols and Garling 2000, p. 881).

3.4 Reproduction

The Longsolid is presumed to have a complex life cycle (see Figure 3-2) that relies on fish hosts for successful reproduction, similar to other mussels. In general, mussels are either male or female (Haag 2012, p. 54). Males release sperm into the water column, which is taken in by the female through the incurrent aperture, where water enters the mantle cavity. The sperm fertilizes eggs that are held within the female's gills in the marsupial chamber. The developing larvae remain in the gill chamber until they mature (called glochidia) and are ready for release.

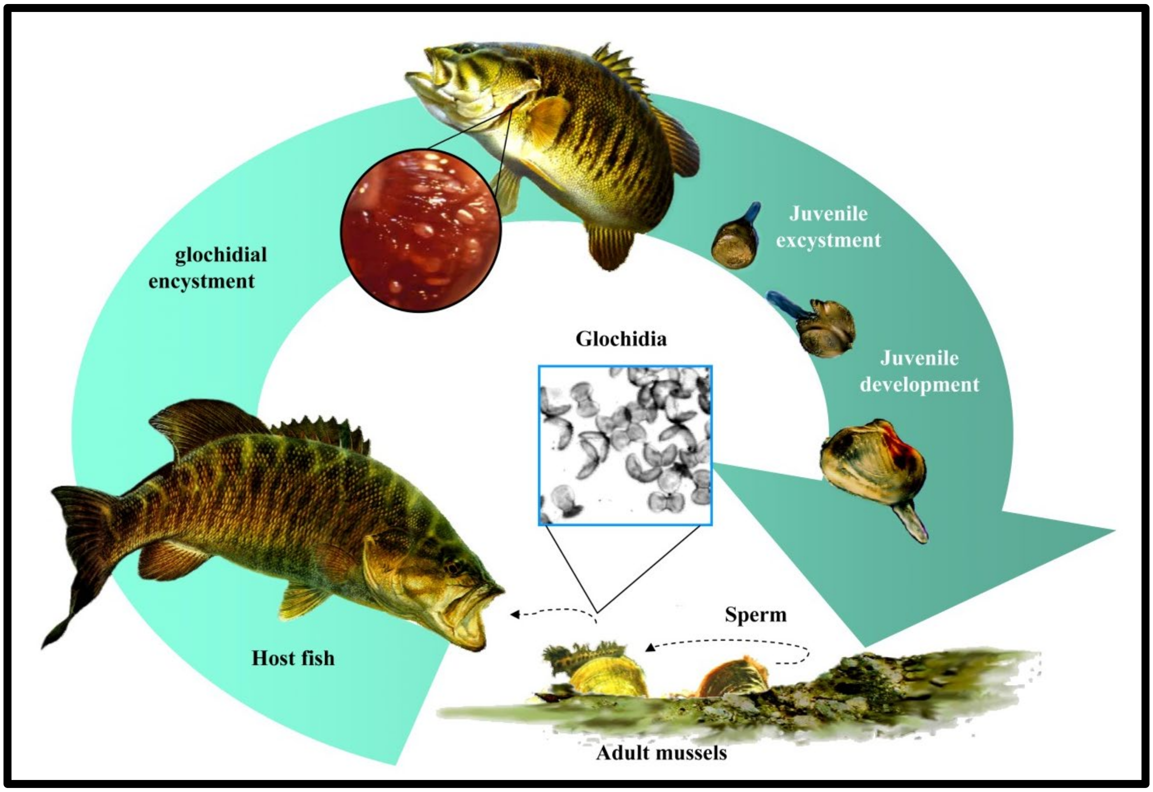

Figure 3-2. Generalized freshwater mussel life cycle. Freshwater mussels such as the Longsolid have a complex life history involving an obligate parasitic larval life stage, called glochidia, which are wholly dependent on host fish. (Image courtesy Shane Hanlon, Service).

The Longsolid is a short-term brooder, typically gravid from May-July (Gordon and Layzer 1989, p. 50). Host fish species are unknown, but based on other species of *Fusconaia*, likely hosts are minnows of the family Cyprinidae and genera *Campostoma, Cyprinella, Notropis,* and *Luxilus* as well as potentially sculpins of family Cottidae, genus *Cottus* (Bruenderman and Neves 1993, p. 87).

Similar to other species in the Pleurobemini, the Longsolid likely targets drift-feeding minnow species by releasing glochidia contained in packets called conglutinates (Haag 2012, p. 163). Following release from the female mussel, the semi-buoyant conglutinates drift in the water column where they are targeted by sight-feeding minnows (Figure 3-3). The glochidia snap shut in contact with fish and attach to the gills, head, or fins of fishes (Vaughn and Taylor 1999, p. 913). For most mussels, the glochidia will die if they do not attach to a fish within a short period. Once on the fish, the glochidia are engulfed by tissue from the host fish that forms a cyst. The cyst protects the glochidia and aids in their maturation. The larvae draw nutrients from the fish and develop into juvenile mussels, weeks to months after initial attachment.

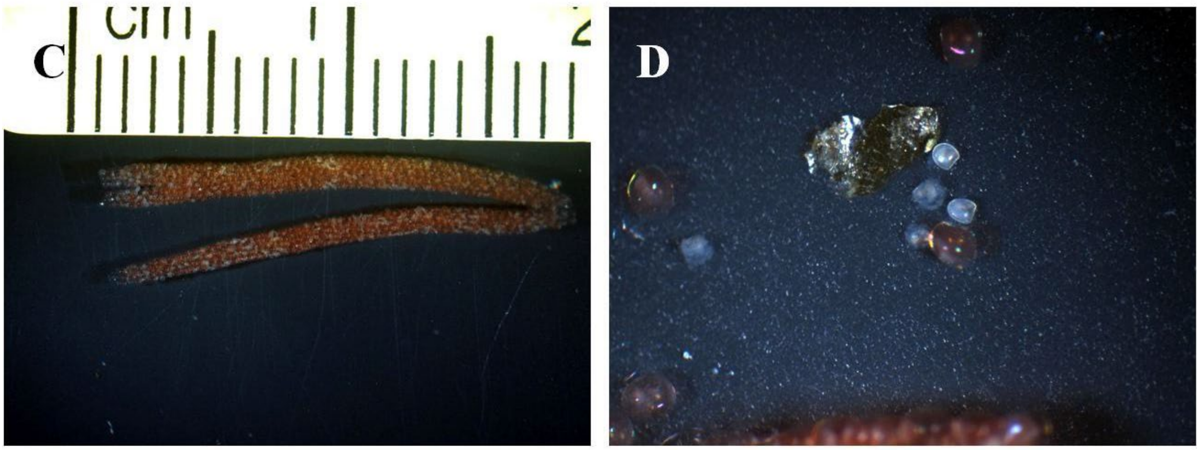

Figure 3-3. Conglutinates (C), and glochidia (D), of the Longsolid from the Clinch River (Schilling 2015, p. 125, used with permission).

In a life history study of the fine-rayed pigtoe, Bruenderman and Neves (1993, p. 87) give potential surrogate descriptive information for the shape and size of Longsolid conglutinates and fecundity: slender and subcylindrical in shape and approximately 0.24 in (6 mm) long and 0.06 in (1.5 mm) wide, with two layers of tightly aggregated glochidia about 0.03 in (0.8 mm) deep. One conglutinate from each of five females contained a mean of 236 +/- 38.1 embryos or glochidia. Fecundity was approximately 113,000 embryos for the sacrificed female. Undeveloped eggs are infrequent and conglutinates tend to break up when mature (Bruenderman and Neves 1993, p. 88).

Glochidia dimensions for the Longsolid are described from the Clinch River, Virginia, by Barnhart *et al.* 2008, (p. 393); Bruenderman and Neves 1993, (p. 85); and Schilling 2015 (p. 129). Glochidia length is 181 micrometers (µm), height is 150 µm, and hinge length is 118 µm, with a mean of 165.5 µm (Bruenderman and Neves 1993, p. 85). Height to length ratio is 1.21 (Barnhart et al. 2008, p. 393). Schilling 2015 (p. 105) reports 6.5 height, 6 length, and 4.5 hinge length for 10 Longsolid glochidia measured from the Clinch River, no units were given, but proportionally these match up with glochidial measurements previously reported. *Fusconaia* produce functional conglutinates that are usually reinforced with constitutive structural eggs dispersed throughout (Barnhart *et al.* 2008, p. 376).

CHAPTER 4 - RESOURCE NEEDS

As discussed in Chapter 3, the Longsolid has a multi-staged life cycle: fertilized eggs to glochidia to juveniles to adults. The life cycle represents several stages that have specific requirements (resource needs) that must be met (Table 4-1) for the mussel to progress to the next stage.

Table 4-1. Requirements for each life stage of the Longsolid mussel.

Life stage	Resources needed to complete life stage[7]	Source
Fertilized eggs - early spring	• Clear, flowing water. • Sexually mature males upstream from sexually mature females. • Appropriate spawning temperatures.	Berg *et al.* 2008, p. 397; Haag 2012, pp. 38–39
Glochidia - late spring to early summer	• Clear, flowing water. • Enough flow to keep glochidia or conglutinates adrift and to attract drift-feeding host fish. • Presence of host fish for attachment.	Strayer 2008, p. 65; Haag 2012, pp. 41–42
Juveniles - excystment from host fish to approx. 0.8 in (~20 mm) shell length	• Clear, flowing water. • Host fish dispersal. • Appropriate interstitial chemistry; low salinity, low ammonia, low copper and other contaminants, high dissolved oxygen. • Appropriate substrate (clean gravel/sand/cobble) for settlement.	Dimmock and Wright 1993, p. 188–190; Sparks and Strayer 1998, p. 132; Augspurger *et al.* 2003, p. 2,574; Augspurger *et al.* 2007, p. 2,025; Strayer and Malcom 2012, p. 1,787–1,788
Adults - greater than 0.8 in (20 mm) shell length	• Clear, flowing water. • Appropriate substrate (stable gravel and coarse sand free from excessive silt). • Adequate food availability (phytoplankton and detritus). • High dissolved oxygen. • Appropriate water temperature.	Yeager *et al.* 1994, p. 221; Nichols and Garling 2000, p. 881; Chen *et al.* 2001, p. 214; Spooner and Vaughn 2008, p. 308.

4.1 Individual-level Resource Needs

In the following subsections, we outline the resource needs of individuals including physical habitat and diet.

4.1.1 Clean, Flowing Water

Longsolid habitat is in rivers and streams with natural flow regimes. While mussels can survive seasonally low flows and (random) short-term, periodic drying events, intermittent stream habitats generally cannot support mussel populations.

[7] These resource needs are common among North American freshwater mussels; however, due to lack of species-specific research, parameters specific to Longsolid are unavailable.

Because a lotic (i.e., flowing water) environment is a critical need, perturbations that disrupt natural flow patterns (e.g., dams) have a potential negative influence on Longsolid resilience metrics. Longsolid habitat must have adequate flow to deliver oxygen, enable passive reproduction, and deliver food to filter-feeding mussels (see Table 4-1, above). Further, flowing water removes contaminants and fine sediments from interstitial spaces preventing mussel suffocation. Stream velocity is not static over time, and variations may be attributed to seasonal changes (with higher flows in winter/spring and lower flows in summer/fall), extreme weather events (e.g., drought or floods), or anthropogenic influence (e.g., flow regulation via impoundments). The Longsolid relies on sight-feeding fishes as part of its life cycle; therefore, turbidity during critical reproductive periods may impact glochidial attachment and ultimately decrease recruitment in any given population (McLeod et al. 2017, p. 348).

While mussels have evolved in habitats that experience seasonal fluctuations in discharge, global weather patterns can have an impact on the normal regimes (e.g., El Niño or La Niña). Even during naturally occurring low flow events, mussels can become stressed because either they exert significant energy to move to deeper waters or they may succumb to desiccation (Haag 2012, p. 109). Droughts during the late summer and early fall may be especially stress-inducing because streams are already at their naturally occurring lowest flow rate during this time.

4.1.2 Appropriate Water Quality and Temperatures

Freshwater mussels, as a group, are particularly sensitive to changes in water quality parameters, including (but not limited to): dissolved oxygen (generally below 2-3 parts per million (ppm)), salinity (generally above 2-4 ppm), ammonia (generally above 0.5 ppm total ammonia-nitrogen (TAN)), elevated temperature (generally above 86 °Fahrenheit (°F) (30 °Celsius (°C)), excessive total suspended solids (TSS), and other pollutants (see discussion in Chapter 6). Habitats with appropriate levels of these parameters are considered suitable, while those habitats with levels outside of the appropriate ranges are considered less than suitable.

Appropriate water temperature thresholds for the Longsolid are unknown; thus, we must rely on the best available information for other mussel species, which primarily focuses on temperatures necessary for reproduction. A 1986-1987 study of the Fine-rayed Pigtoe in the Clinch River suggests that glochidia are released between 69.8 and 80.6 °F (21-27 °C), and metamorphosis on fishes occurs at water temperatures between 71.6 and 77 °F (22 and 25 °C) (Bruenderman and Neves 1993, p. 86). In addition, the highest glochidial release densities were at 73.4 °F (23 °C) weekly median temperature (at Slant, Virginia; Bruenderman and Neves 1993, p. 86). Since the Fine-rayed Pigtoe is closely related and co-occurs with the Longsolid in the Clinch River, these temperature ranges are reasonable estimates of required thermal regimes for species of the genus *Fusconaia* during their reproductive cycle. These temperature ranges are also similar to those reported for the Atlantic Pigtoe (*F. masoni*) (Service 2017, p. 7).

4.1.3 In-Stream Sedimentation

Optimal substrate for the Longsolid is predominantly stable sand, gravel, and cobble without excessive accumulation of silt and detritus. Riparian condition strongly influences the composition and stability of substrates that mussels inhabit (Allan *et al.* 1997, p. 149). Streams with urbanized or agriculturally-dominated riparian corridors are subject to increased sediment-loading as soil erodes from banks that do not have a dense network of roots holding soil in place, or from the landscape in general in areas without sufficient ground cover. Streams in urban areas may be subject to excessive runoff from impervious surfaces, which can overwhelm a stream channel's capacity to carry the water, resulting in increased stream bed and bank erosion (see discussion in section 6.1.3, below). Excess sediment in streams settles to the stream bottom, filling spaces needed by juvenile mussels and host fish eggs. The result is a less suitable in-stream habitat for mussels compared to habitat with forested corridors (Allan *et al.* 1997, p. 156).

4.1.4 Food and Nutrients

Adult freshwater mussels, including the Longsolid, are filter-feeders, drawing in suspended phytoplankton, zooplankton, rotifers, protozoans, detritus, and dissolved organic matter from the water column (Strayer *et al.* 2004, p. 430) and from sediment; juvenile mussels are capable of pedal and deposit feeding to collect food items from sediments (Vaughn *et al.* 2008, pp. 409-411). Glochidia can derive what nutrition they need from their obligate fish hosts (Barnhart *et al.* 2008, p. 372). Freshwater mussels must keep their shells open, or gaped, to obtain food and facilitate gas exchange, but they often respond to water quality impairments by closing their shells (Bonner *et al.* 2018, p. 141). Food supply is not generally considered limiting in environments inhabited by Longsolid. However, food limitation may be important during times of elevated water temperature, as both metabolic demand and incidence of valve closure increases concomitantly, resulting in reduced growth and reproduction (Bonner *et al.* 2018, p. 6).

4.2 Population- and Species-level Needs

In order to assess the viability of a species, the needs of individuals are only one aspect. This section examines the larger-scale population and species-level needs of Longsolid.

4.2.1 Connectivity of Aquatic Habitat

The fragmentation of river habitat by dams and other aquatic barriers (e.g., perched or undersized culverts) is one of the primary threats to aquatic species in the U.S. (Martin and Apse 2014, p. 7). Dams (whether man-made or nature-made (e.g., from beavers (*Castor canadensis*) or wind thrown debris)) have a profound impact on in-stream habitat as they can change lotic systems (flowing water) to lentic systems (stationary or relatively still water). Moreover, fragmentation by dams or culverts generally involves loss of access to quality habitat for one or more life stages of freshwater species. In the case of mussels, fragmentation can result in barriers to host fish movement, which in turn, may influence mussel distributions. Mussels that use small host fishes such as darters, family Percidae and minnows, family Cyprinidae, are more susceptible to impacts from habitat fragmentation due to increasing distance between suitable habitat patches and low likelihood of small host fish swimming over that distance as compared to larger host fishes (Vaughn 2012, p. 7). Barriers to movement can cause isolated or patchy distributions of mussels, which may limit both genetic exchange and recolonization (e.g., after a high flow, scouring event).

4.2.2 Dispersal-Adult Abundance and Distribution

Mussel abundance in a given stream reach is a product of the number of mussel beds and the density of mussels within those beds (aggregations of freshwater mussels). For populations of Longsolid to be healthy, individuals must be numerous, with multiple age classes, and display evidence of recruitment. For Longsolid populations to be resilient, there must be multiple mussel beds of sufficient density such that local stochastic events do not necessarily eliminate the bed(s), allowing the mussel bed and the overall local population within a stream reach to recover from any one event. A non-linear distribution over a large area (occurrence in tributaries, in addition to the mainstem) also helps buffer against stochastic events that may impact populations. Mussel abundance also facilitates reproduction; mussels do not actively seek mates, rather males release sperm into the water column, where it drifts until a female hopefully takes it in (Moles and Layzer 2008, p. 212). Therefore, successful individual reproduction, and population viability, requires sufficient numbers of female mussels downstream of sufficient numbers of male mussels.

Mussel abundance is indicated by the number of individuals found during a sampling event; mussel surveys rarely are a complete census of the population; instead, density is estimated by the number found during a survey event using various statistical techniques. Because we do not have population estimates for most populations of Longsolid, nor are the techniques directly comparable (i.e., same area size searched, similar search time), we use the number of individuals captured as an index over time. While we cannot precisely determine population abundances at these sites using these numbers, we are able to determine if the species is abundant or rare at the site, and examine this over time if those data are available.

4.2.3 Host Fish

Host fish species are unknown for Longsolid. However, based on other species of *Fusconaia*, likely hosts are thought to be minnows of the family Cyprinidae and genera *Campostoma* sp., *Cyprinella* sp., *Notropis* sp., and *Luxilus* sp., as well as sculpins of the family Cottidae, genus *Cottus* (Bruenderman and Neves 1993, p. 87). There are likely some secondary hosts capable of transforming juvenile Longsolid at a low rate, potentially in large river benthic habitats where Longsolid occur but minnows and sculpins are uncommon (Garner 2018, pers. comm).

4.3 Uncertainties

Life history uncertainties include the age at maturity, patterns of age structure within populations (number within each age class or cohort in any population), and sex ratios (the species is not considered sexually dimorphic). Information on fecundity is not available. Host fish studies for the Longsolid have not been conducted and the time period to complete metamorphosis, including ranges of water temperatures at which transformation occurs, is unknown. Species-specific diet studies have not been conducted, and growth curves have not been developed.

Due to challenges associated with propagating short term brooders such as Longsolid in captive environments, information regarding their restoration potential through production is limited, which potentially limits the species' recovery potential. In many situations, abundance and precise locality information for most populations considered extirpated is lacking, therefore it is difficult to specifically attribute localized extirpation to a specific stressor or species need. The species relies on a consistent, low-level of reproductive success to maintain populations, but the actual environmental events that cue variations (increases or decreases) in reproductive success, which is indicated by recruitment in successive sampling events, is not documented.

Additionally, numeric water quality criteria specific for Longsolid threshold tolerances are unknown. The species' capability to move and disperse is acknowledged as glochidia attached to fish, but the distance that adults are capable of dispersing within appropriate habitats is unknown. Population estimates are lacking, due to inconsistent survey efforts and methodologies.

4.4 Summary of Resource Needs

As discussed in Chapter 1, for the purpose of this assessment, we define viability as the ability of the Longsolid to sustain populations in the wild over time (in this case, 40 to 50 years). The availability and quality of those resources, as well as the level of negative and beneficial influences acting upon those resources, will determine whether populations are resilient over time. Based upon the best available scientific and commercial information (summarized in Sections 4.1 and 4.2, above), and acknowledging existing ecological uncertainties (Section 4.3, above), the Longsolid's resource and demographic needs (see Figure 4-1, below) are characterized as:

- Clean flowing water with appropriate water quality and temperate conditions, such as (but not limited to) dissolved oxygen above 2-3 ppm, ammonia generally below 0.5 ppm TAN, temperatures generally below 86 °F (30 °C), and (ideally) an absence of or lack of excessive TSS and other pollutants.
- Natural flow regimes that vary with respect to the timing, magnitude, duration, and frequency of river discharge events.
- Predominantly silt-free, stable sand, gravel and cobble substrates.
- Suspended food and nutrients in the water column including (but not limited to) phytoplankton, zooplankton, protozoans, detritus, and dissolved organic matter.
- Availability of sufficient host fish numbers to provide for glochidia infestation and dispersal. Host fish species include (but may not be limited to): minnows of the family Cyprinidae and genera *Campostoma* sp., *Cyprinella* sp., *Notropis* sp., and *Luxilus* sp., as well as potentially sculpins of the genus *Cottus*.
- Connectivity among populations. Although the species' capability to disperse is evident through historical occurrence of a wide range of rivers and streams, the fragmentation of populations by small and large impoundments has resulted in isolation and only patches of what once was contiguous river and stream habitat currently occupied. Genetic exchange occurs between and among mussel beds via sperm drift, host fish movement,

and movement of mussels during high flow events. For genetic exchange to occur, connectivity must be maintained.

- Most freshwater mussels, including the Longsolid, are found in mussel beds that vary in size and are often separated by stream reaches in which mussels are absent or rare (Vaughn 2012, p. 983). The species is often a component of a large healthy mussel assemblage within optimal mussel habitats, therefore, the beds in which they occur are necessary for the species to be sustained over time.

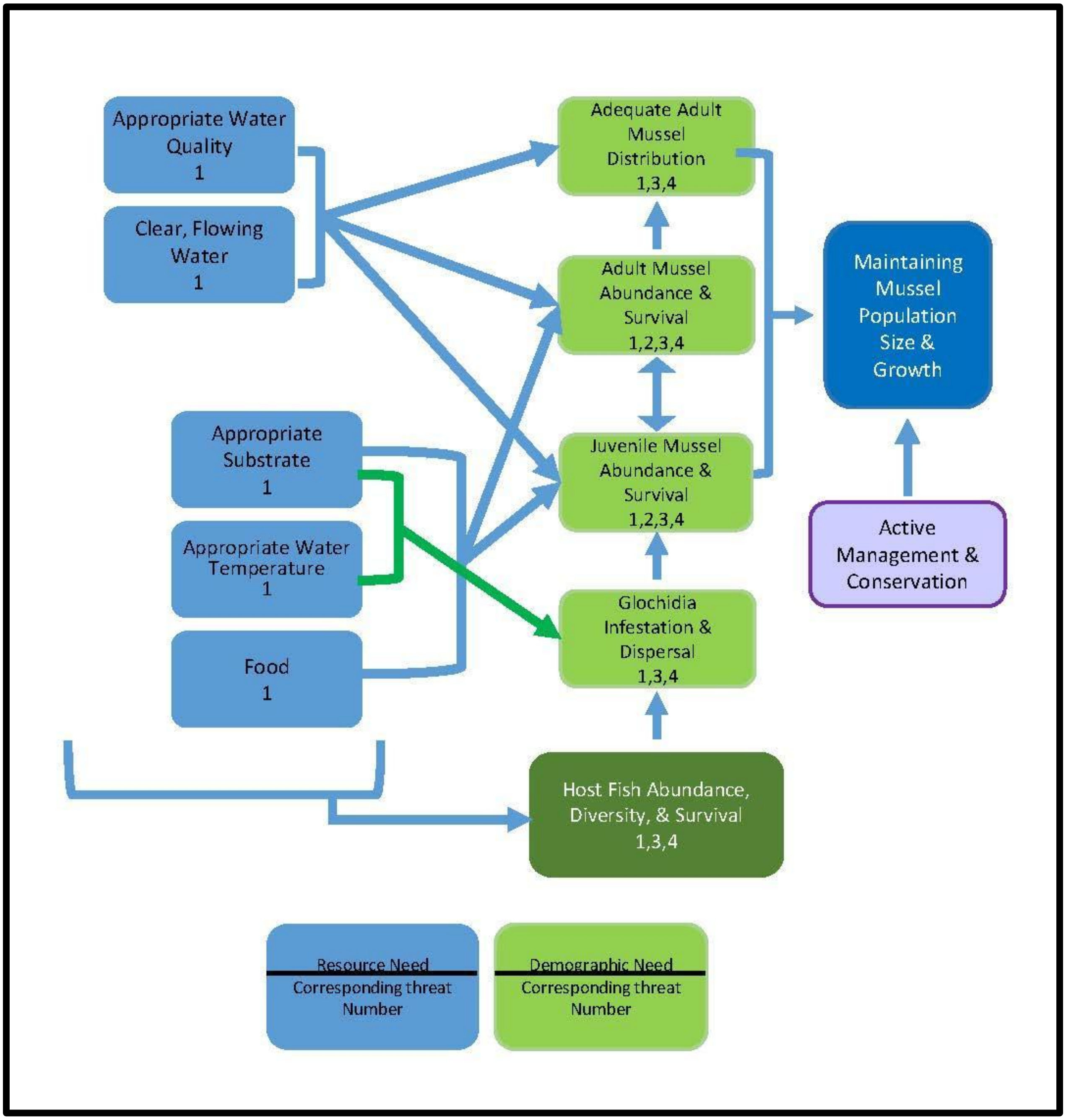

Figure 4-1. Resource and demographic needs of the Longsolid.

CHAPTER 5 - CURRENT CONDITIONS, ABUNDANCE AND DISTRIBUTION

Fundamental to our analysis of the Longsolid was the determination of scientifically sound, analytical units, at a scale useful for assessing the species (see Section 2.1.2, above). In this report, we defined Longsolid management units and populations based primarily on known occurrence locations and stream connectivity. We acknowledge that specific Longsolid demographic and genetic data with which to support this construct are sparse. However, this approach for assessing the species' condition has been used for other aquatic species in the eastern U.S., therefore, it was considered an acceptable construct for this SSA report.

After identifying the factors (i.e., stressors) likely to affect the Longsolid, we estimated the condition of each Longsolid population. The population size and extent metrics used were selected because the supporting data were relatively consistent across the range of the species and at a resolution suitable for assessing the species at the population level. The output was a condition score for each Longsolid population that was then used to assess the Longsolid across its range under the concepts of resiliency, redundancy, and representation. We acknowledge there is uncertainty regarding some of the scientific data and assumptions used to assess the biological condition of the Longsolid.

The Longsolid is wide-ranging, historically known from the Tennessee, Cumberland, and Ohio River basins, in addition to the Great Lakes basin. It is currently known from New York, Pennsylvania, West Virginia, Ohio, Kentucky, Virginia, Tennessee, North Carolina, and Alabama; while extirpated from Indiana, Illinois, and Georgia. The results of surveys conducted since 2000 indicate the currently occupied range of the Longsolid includes 60 rivers and streams, however, it no longer occurs in the Great Lakes basin. A summary of all known extant populations and their generalized estimated size is be found in Appendix A.

5.1 Historical Conditions For Context

To summarize the overall current conditions, Longsolid populations and MUs were considered extant if a live individual or fresh dead specimen was collected since 2000, or collections of the species were made since 1990 with no available negative mussel survey data of the population or MU to dispute that the species still occurs within the water body. Populations were considered extirpated based on documentation in literature, reports, or from communications with state malacologists and aquatic biologists. General reference texts on regional freshwater mussel fauna such as Haag and Cicerello (2016), Williams *et al.* (2008), Watters *et al.* (2009), Parmalee and Bogan (1998), and Gordon and Layzer (1989) provided substantial information on species distribution, both past and present.

The Longsolid is known historically from 162 populations and 105 MUs in 12 states. It occurred in the Great Lakes, Ohio, Cumberland, and Tennessee River basins. Within the Great Lakes basin, it occurred only in the US portion, not in Canada (Appendix D). The Longsolid is considered extirpated from the Great Lakes basin, which historically had at least six populations distributed across four MUs (Figure 5-1).

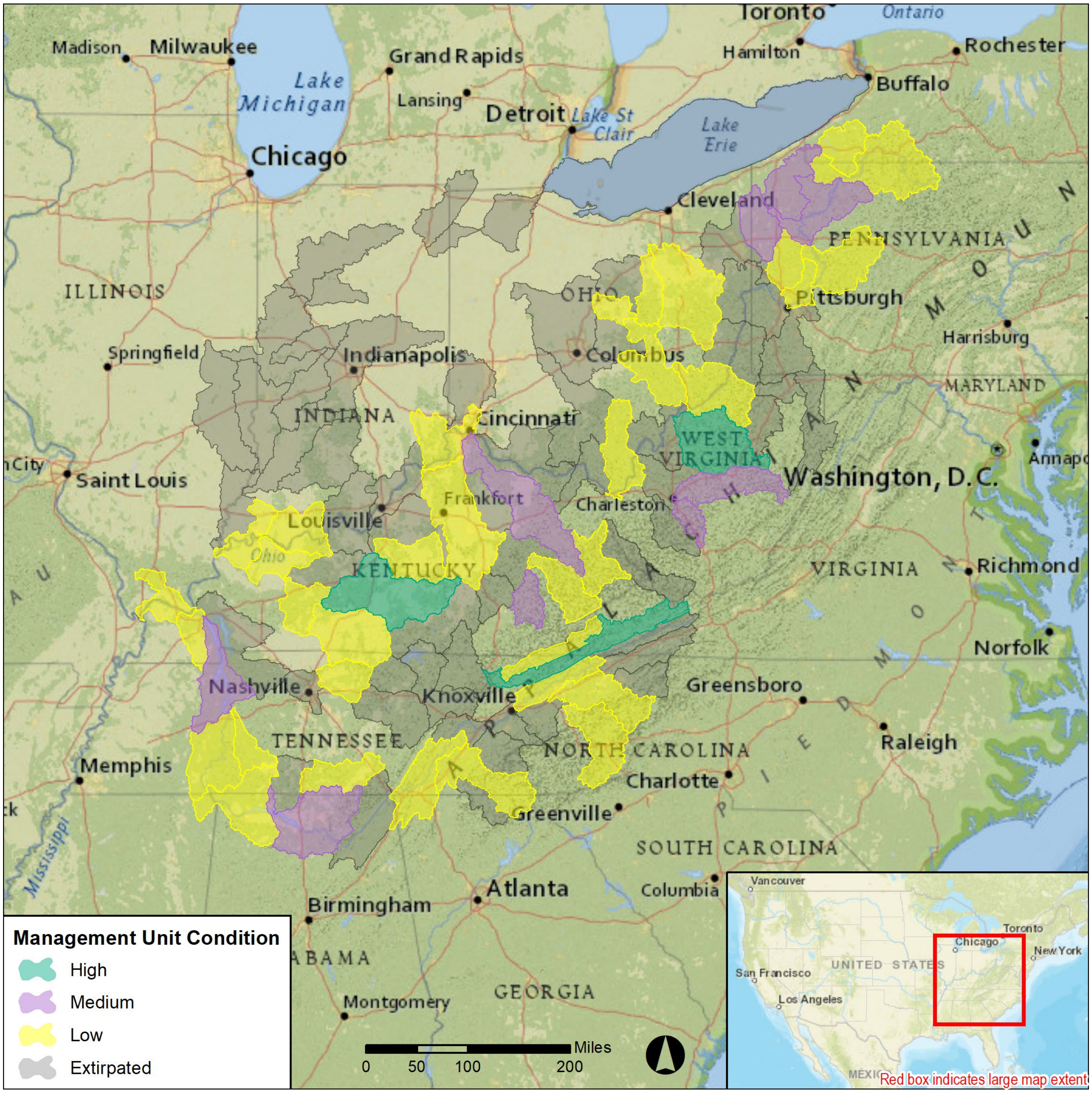

Figure 5-1. Distribution of the current and historically occupied Management Units (MUs; a.k.a. HUC8s) of Longsolid mussel in the United States. Currently occupied MUs are represented with low, medium, and high condition categories (as described in Chapters 2 and 5; Service 2018a, unpublished data).

The Longsolid is considered extirpated from the states of Georgia, Illinois, and Indiana. In total, 98 populations and 57 MUs outside of the Great Lakes basin are extirpated: 63 populations and 37 MUs in the Ohio River basin, 9 populations and 8 MUs in the Cumberland River basin, and 26 populations and 12 MUs in the Tennessee River basin. The Maumee River represented an important connection between the Ohioan and the Laurentian Great Lakes mussel faunas, because the Maumee River was once a glacial outlet into the Wabash River (Watters 1992, p.

484). The Longsolid is extirpated from the Maumee and the entired Great Lakes basin (Watters *et al.* 2009, p. 132).

Populations of the Longsolid have been lost from entire watersheds in which the species once occupied multiple tributaries, such as the Monongahela, Scioto, and Wabash River systems in the Ohio basin (Appendix B). The state of Ohio alone has lost 22 populations of Longsolid, along with 10 MUs (Watters *et al.* 2009, p.132). A table of all populations and MUs considered extirpated along with the authority of each record, and the year of the record, can be found in Appendix B.

Precipitous declines and extirpations of Longsolid populations have been observed in the Ohio, Cumberland, and Tennessee basins. Example of rivers where it is extirpated within these three basins include: Beaver River, Pennsylvania (Ortmann 1920, p. 276); Ohio River, Pennsylvania (Tolin 1987, p. 11); Mahoning River, Pennsylvania (Ortmann 1920, p. 276); Wabash River, Indiana/Illinois (Cummings *et al.* 1992, p. 46); Cumberland River, Kentucky (Haag and Cicerello 2016, p. 139); and the South Fork Holston River, Virginia/Tennessee (Parmalee and Pohemus 2004, p. 234).

In many instances, the specific cause for extirpation is unknown, and is likely attributable to a variety of compounded threats. Although no longer considered a threat, commercial harvest of Longsolid, which was associated with the button and pearl culture industries of the 19th century, likely contributed to population declines (Dennis 1984, p. 86; Danglade 1922, p. 5). Other suggested causes include habitat loss, fragmentation, and degradation due to impoundment and navigational impacts, and impaired water quality due to pollution and land use changes, as well as the introduction of nonnative species (Watters and Flaute 2010, p. 6; Watters 2000, p. 269). As early as 1909, pollution caused by coal mining and oil refineries and habitat loss due to impoundment were identified as contributors to the decline of the freshwater mussel fauna in Pennsylvania (Ortmann 1909b, p. 97).

These threats to mussels identified as early as 1909 continue into the present. In particular, mining and resource extraction impacts have been specifically identified as contributing to declines of freshwater mussel diversity and abundance in rivers that harbor some of the best remaining Longsolid populations: the Elk and Kanawha rivers in West Virginia, and the Clinch and Powell Rivers in Tennessee and Virginia (Ecological Specialists, Inc. (ESI) 2009, p. 22; Van Hassel 2007, p. 328).

All extant populations of Longsolid are affected to some extent by impoundments; which isolate populations and prevent upstream dispersal. However, tributaries that maintain connectivity to river reaches without flood control, water supply, or hydropower dam interruption are less impacted. Examples include the Allegheny River, which is not fragmented from French Creek and Muddy Creek, the Paint Rock river, which maintains connectivity to Hurricane Creek and Estill Fork, and the upper Clinch River and Indian Creek, which lack a barrier to dispersal.

5.2 Current Population Abundance, Trends, and Distribution

To assess the distribution, abundance, and (if data are available) trends of Longsolid populations, we first assigned a status category of extant or extirpated to each population. Second, for extant populations, we estimated the occupied extent of each river or stream and size of each population so each could be evaluated relative to one another (Table 5-1). Due to lack of consistency of survey efforts, population size (Table 5-2) was based on count numbers of the species summarized from inventory data. Third, we developed threat condition categories (Table 5-3) based on our qualitative assessment of the magnitude and immediacy of a potential threat within each population. Lastly, we assigned a low/moderate/high overall condition category to each population based on the combined consideration of the aforementioned population extent, size, and threat information (Table 5-4).

Population extent for each river or stream was based on available inventory data. Estimates of occupied river kilometers were derived from polygons generated by the NHP, DNR datasets, and through mapping of point occurrence data, and evaluated by examining available appropriate habitat and its connectivity relative to natural or constructed barriers such as waterfalls or dams. Additionally, if available, negative survey information on the species' extent within a river or stream reach informed the linear estimate of current occupation. Population extent was ranked as small, medium, and large, as described in Table 5-1, below.

Our estimates of the extent of each population are detailed in Appendix C. Population extent is mapped in ArcGIS v. 10.5. Data sources for population extent include NatureServe species' occurrence information sourced from states, primary literature, and gray literature; and reports and personal communications with state malacologists and aquatic biologists familiar with the extent of suitable mussel habitat within the drainage. We also used aerial imagery and topographic maps to delineate the maximum extent of the species potential occurrence (see maps in Appendix C).

Table 5-1. Population extent categories to help describe Longsolid's distribution within rivers and streams throughout its range.

Category	Description
Small	Species is estimated to continuously occur in less than 6.2 mi (10 km) of rivers/streams based on available survey information and data on the lack of detection of the species in surveys.
Medium	Species is estimated to continuously occur in more than 6.2 mi (10 km) but less than 31 mi (50 km) of rivers/streams based on available survey information and data on the lack of detection of the species in surveys.
Large	Species is estimated to continuously occur in more than 31 mi (50 km) of rivers/streams based on available survey information and data on the lack of detection of the species in surveys.

Natural barrier, such as Kanawha Falls, and artificial barriers (dams) influence the Longsolid and host fishes' capability to disperse. Additionally, when available, negative data (surveys that did not detect Longsolid) from mussel inventories conducted within the known drainages of Longsolid occurrence were used to inform extent for each population.

General references on regional mussel fauna such as Haag and Cicerello (2016), Williams *et al.* (2008), Watters *et al.* (2009), Parmalee and Bogan (1998), and Gordon and Layzer (1989) provided substantial information on species distribution. Additionally, Ecological Specialists, Inc. (2000), Watters and Flaute (2010), and Schuster (1988) were valuable references for informing the Longsolid distribution in the Ohio River.

Population size for each river or stream was based on inventory data collected for freshwater mussels since 1900 (Appendix A). Various state and Federal agencies as well as academic institutions, and non-governmental organizations conducted inventories. Population size was ranked as small (rare in collections or surveys), medium (occasional to common in collections or surveys), or large (abundant in collections or surveys) (see Table 5-2).

Table 5-2. Population size categories to help describe the Longsolid's abundance within rivers and streams throughout its range.

Category	Description*
Small (rare in collections or surveys)	Less than 100 individuals (live, fresh dead, or weathered dead/relic[8]) reported from the river/stream since 2000; usually qualitative collections of varying effort; not enough information available to generate a population estimate; population potentially represented only by older, non-reproducing individuals. These populations are not likely contributing to species resiliency.
Medium (occasional to common in collections or surveys)	100-1000 individuals (live or fresh dead) reported from the river/stream since 2000; or some quantitative information available for a population estimate that indicates detectable population density and more than one age class represented.
Large (abundant in collections or surveys)	More than 1000 individuals (live) reported from the river/stream in any given sampling event since 2000; or a population estimate is available for the population and identifies densities sufficiently high to suggest a healthy population with multiple age classes and evidence of ongoing recruitment.

* (A population may meet one or more criteria but does not have to meet all)

Our estimates of the size of each population are detailed in Appendix A. Of important note regarding these estimates: some populations are ranked as small population sizes, but data on the species occurrences in these rivers and streams are scarce. For example, 11 populations represented by collections of five or fewer individuals of Longsolid since 1990 are categorized as small population size. These include Oswayo Creek, Conewango Creek, Tionesta Creek, Middle

[8] A "fresh dead" Longsolid refers to shells that still have flesh attached to the shell, or at least retain a luster to their nacre, and may have a hinge intact and pliable, indicating relatively recent death. A "weathered dead" Longsolid shell has a loss of periostracum, which may be peeling, and faded or dull nacre. A "relic" Longsolid has a chalky nacre. A weathered dead/relic shell typically indicates the mussel died years or potentially even decades ago.

Island Creek, Meathouse Fork, Slate Creek, Rolling Fork River, Estill Fork, Hurricane Creek, Valley River, and Buffalo River. Additionally, the 6 populations in the Ohio River mainstem are represented by very few individuals since 1990. In many of these small population size examples, only fresh dead shells have been collected and no live Longsolid have been observed.

Therefore, it is difficult to make inferences about the current and future overall condition of these populations or even verify identifications without genetic confirmation. Although there is some uncertainty in the status of these populations, it was our goal to be as inclusive as possible regarding the current condition of the species, so these populations were included for the purposes of this SSA. Available negative mussel data (mussel surveys in the river or stream that failed to detect Longsolid) and information on threats to the aquatic fauna in these watersheds was also used to inform analyses.

Potential threats to the Longsolid or its habitat were categorized in terms of magnitude and immediacy based on the best available information in the literature or other sources such as State Wildlife Action Plans (SWAP), watershed planning documents, or Clean Water Act 303d lists. We ranked threat levels based on their apparent or likely magnitude of presence in the drainage (Table 5-3). Longsolid population characteristics (extent and size) were considered relative to current threats.

Table 5-3. Categories to describe the magnitude and immediacy of potential threats influencing Longsolid.

Category	Description
Low	Threats to freshwater mussels or aquatic fauna have been identified in this HUC and are in the literature or are available in State Wildlife Action Plans - threats are minimal (potential threats identified but direct tie to loss of mussels possibly lacking) compared to other occupied rivers and streams or MUs that harbor the species. Public land holdings within the river or stream where the Longsolid occurs were incorporated into this threat level.
Moderate	Threats to freshwater mussels or aquatic fauna have been identified or evaluated in this HUC and are in the literature or are available in State Wildlife Action Plans - threats are moderate (multiple threats identified but may not be imminent, or the status of the threat is unknown) compared to other occupied rivers and streams or MUs that harbor the species.
High	Threats to freshwater mussels or aquatic fauna have been identified and evaluated in this HUC and are in the literature or are available in State Wildlife Action Plans - threats are substantial (multiple threats identified and imminent) and cumulative, compared to other occupied rivers and streams or MUs that harbor the species.

Our estimates of the magnitude and immanency of potential threats to each population are detailed in Appendix D.

Mussel declines in the Ohio, Cumberland, and Tennessee basins are primarily the result of habitat and water quality loss and degradation (Neves 1993, p. 4). The chief causes of lost populations or declining populations are impoundments, channelization, chemical contaminants, mining, and sedimentation (Neves 1993, p. 4; Williams *et al.* 1993, p. 5; Watters 2000, p. 261). Expanding human populations within the range of the species (e.g., Lawler *et al.* 2014, p. 55;

Terando *et al.* 2014, p. 3) will invariably increase the likelihood that many if not all of the factors in this section will continue to impact Longsolid populations into the future.

5.3 Estimated Viability of Longsolid Mussel Based on Current Conditions

We define viability as the ability of the species to sustain healthy populations in natural river systems within a biologically meaningful timeframe. Using the SSA framework, we describe the species' current viability in terms of resiliency, redundancy, and representation.

5.3.1 Resiliency

Resiliency describes the ability of populations to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health, for example, birth versus death rates and population size. Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities. For the purpose of this SSA, with a lack of broad demographic data, each population's estimated size and extent helps provide a measure of resiliency given that larger mussel populations distributed over a larger area would be better able to rebound from stochastic events than smaller populations with limited distribution.

Populations and MUs were ranked according to the following overall condition categories: high, medium, low (Table 5-4). As discussed above under section 5.2, these categories were informed by each population's extent, size, and probable threat level, with population size weighted more heavily than extent and threat level because of more limited information on current population extent and threats to the Longsolid. Overall condition categories for each of the currently extant Longsolid populations are presented in Table 5-5, below.

Table 5-4. Categories for estimating the overall current condition of Longsolid mussel populations.

High (Stronghold) Populations	Medium Populations	Low Populations
Resilient populations generally distributed over a significant and more or less contiguous length of stream (greater than or equal to 30 river miles), with evidence of recruitment and multiple age classes represented.	Spatially restricted populations with limited levels of recruitment or age class structure. Resiliency is less than under high conditions.	Small and highly restricted populations, with no evidence of recent recruitment or age class structure, and limited detectability. These populations have low resiliency, are not likely to withstand stochastic events.

Condition category tables are a structured way to assess the current and future state of populations based on specific variables related to the resiliency of each population. Condition category tables are a transparent way to illustrate to the public which variables we are assessing and how these variable contribute to the overall status of populations. The tables allow us to weigh the different variables differently depending on the importance of that variable to the species ecology. Using condition category tables is a common FWS practice in Species Status

Assessments when further quantitative methods to assess population risk on a continuous scale may be inappropriate due to the lack of data to do so. Assigning condition or health based on multiple criteria, which is what the condition table does, is common in a variety of applications - such as, Element Occurrence rank (http://help.natureserve.org/biotics/Content/Record_Management/Element_Occurrence/EO_Rank_a_species_EO.htm), risk level in IUCN Red List criteria (http://www.iucnredlist.org/static/categories_criteria_3_1), and indices of biological integrity (https://www.pugetsoundstreambenthos.org/BIBI-Scoring-Types.aspx).

Table 5-5. Extant populations of Longsolid by major river basin, management unit (8 digit HUC), and their generalized population condition.

Major River Basin	Management Unit	State	Contiguous Population (occupied river/stream)	Overall Population Current Condition
Ohio	(1) Upper Allegheny	PA	(1) Allegheny River	Low
		PA	(2) Oswayo Creek	Low
Ohio	(2) Conewango	NY	(3) Conewango Creek	Low
Ohio	(3) Middle Allegheny-Tionesta	PA	(4) Allegheny River	Med
		PA	(5) Tionesta Creek	Low
Ohio	(4) French Creek	PA	(6) French Creek	Med
		PA	(7) Muddy Creek	Low
Ohio	(5) Middle Allegheny-Redbank	PA	(8) Allegheny River	Low
Ohio	(6) Lower Allegheny	PA	(9) Allegheny River	Low
Ohio	(7) Shenango	PA	(10) Shenango River	Med
Ohio	(8) Connoquenessing	PA	(11) Slippery Rock Creek	Low
Ohio	(9) Little Muskingum-Middle Island	OH/WV	(12) Ohio River (Willow Island Pool)	Low
		WV	(13) Middle Island Creek	Low
		WV	(14) Meathouse Fork	Low
Ohio	(10) Little Kanawha	WV	(15) Little Kanawha River	High
		WV	(16) North Fork Hughes River	Low
		WV	(17) Hughes River	Low
Ohio	(11) Tuscarawas	OH	(18) Tuscarawas River	Low
Ohio	(12) Muskingum	OH	(19) Muskingum River	Low
Ohio	(13) Walhonding	OH	(20) Walhonding River	Low
Ohio	(14) Upper Kanawha	WV	(21) Kanawha River	Med

Major River Basin	Management Unit	State	Contiguous Population (occupied river/stream)	Overall Population Current Condition
Ohio	(15) Elk River (WV)	WV	(22) Elk River	Med
Ohio	(16) Lower Levisa	KY	(23) Levisa Fork	Low
Ohio	(17) Raccoon-Symmes	OH, WV	(24) Ohio River (Gallapolis Pool, upper Greenup Pool)	Low
Ohio	(18) Middle Ohio-Laughery	IN, KY	(25) Ohio River (Markland Pool)	Low
Ohio	(19) Licking	KY	(26) Licking River	Med
		KY	(27) Slate Creek	Low
Ohio	(20) Rolling Fork	KY	(28) Rolling Fork River	Low
Ohio	(21) North Fork Kentucky	KY	(29) North Fork Kentucky River	Low
Ohio	(22) South Fork Kentucky	KY	(30) South Fork Kentucky River	Med
		KY	(31) Redbird River	Low
Ohio	(23) Lower Kentucky	KY	(32) Kentucky River	Low
Ohio	(24) Upper Green	KY	(33) Green River	High
Ohio	(25) Barren	KY	(34) Barren River	Low
Ohio	(26) Middle Green	KY	(35) Green River	Low
Ohio	(27) Lower Green	KY	(36) Green River	Low
Ohio	(28) Highland-Pigeon	KY	(37) Ohio River (Cannelton Pool)	Low
Ohio	(29) Lower Ohio-Little Pigeon	KY	(38) Ohio River (Newburgh Pool)	Low
Ohio	(30) Lower Ohio	KY	(39) Ohio River (L&D 52, 53)	Low
Cumberland	(31) Lower Cumberland-Old Hickory Lake	TN	(40) Cumberland River (Old Hickory Reservoir)	Low
Tennessee	(32) Holston	TN	(41) Holston River	Low
Tennessee	(33) Upper French Broad	NC	(42) Little River	Low
Tennessee	(34) Nolichucky	TN	(43) Nolichucky River	Low
Tennessee	(35) Upper Clinch	TN, VA	(44) Clinch River	High
		VA	(45) Indian Creek	Low
Tennessee	(36) Powell	TN, VA	(46) Powell River	Low
Tennessee	(37) Middle Tennessee-Chickamauga	TN	(47) Tennessee River	Low

Major River Basin	Management Unit	State	Contiguous Population (occupied river/stream)	Overall Population Current Condition
Tennessee	(38) Wheeler Lake	AL	(48) Paint Rock River	Med
		AL	(49) Estill Fork	Low
		AL	(50) Hurricane Creek	Low
		AL	(51) Tennessee River (Wheeler Reservoir)	Low
Tennessee	(39) Upper Elk (TN)	TN	(52) Elk River	Low
Tennessee	(40) Hiwassee	NC	(53) Hiwassee River	Low
		NC	(54) Valley River	Low
		TN	(55) Hiwassee River	Low
Tennessee	(41) Pickwick Lake	AL	(56) Tennessee River (Pickwick Reservoir)	Low
Tennessee	(42) Lower Tennessee-Beech	TN	(57) Tennessee River (Kentucky Reservoir)	Low
Tennessee	(43) Buffalo	TN	(58) Buffalo River	Low
Tennessee	(44) Kentucky Lake	TN	(59) Tennessee River (Kentucky Reservoir & 5 KM of tailwater)	Med
Tennessee	(45) Lower Tennessee	TN, KY	(60) Tennessee River	Low

Of the 39 extant populations in the Ohio basin, 30 (77 percent) currently have a low population condition. The majority of these low condition populations are small in extent and have a high magnitude of threats. The Ohio River basin has seven streams (18 percent) that are medium condition, including reaches of the Allegheny River, French Creek, Shenango, Kanawha, Elk, Licking, and South Fork Kentucky River. The Ohio River basin has two high condition streams: the Little Kanawha River in West Virginia and upper Green River in Kentucky.

There is currently only one population and MU in the Cumberland basin and it is in low condition. This population is restricted to a 12.4-mi (20-km) reach of the Cumberland River main stem below Cordell Hull Dam. Although this population is located within the Tennessee Wildlife Resources Agency (TWRA) Rome Mussel Sanctuary and is protected from mussel harvest activities, the population is threatened by hypolimnetic discharges (i.e., the perpetually cold and non-circulated water layer that lies below the thermocline) from upstream impoundments (specifically Wolf Creek Dam, Cumberland River Dam, Center Hill Dam, and Caney Fork Dam). There are no high or medium condition populations in the Cumberland basin.

Of the 20 extant populations in the Tennessee basin, 18 (90 percent) currently have a low population condition. The majority of these low condition populations have moderate or high levels of threats. The Tennessee River basin currently has two populations (10 percent) that are in medium condition, the Paint Rock and lower Tennessee River. The Tennessee River basin has one high condition population: the Clinch River in southwest Virginia and northeast Tennessee.

The overall current condition of the Longsolid indicates the species has limited resiliency: 48 of the 60 populations (80 percent) are in low condition as opposed to just 3 populations (5 percent) in high condition. Threats that are acting upon the high condition populations (Little Kanawha River in West Virginia, the upper Green River in Kentucky, and the Clinch River in Tennessee and Virginia) include habitat and water quality degradation and the introduction of contaminants resulting from wastewater treatment discharges and mining activities, as well as oil and gas exploration (Ahlstedt *et al.* 2016a, p. 10; Cicerello 1999, p. 6; Clayton 2018, pers. comm.).

Despite the abundance of Longsolid in the Elk River, WV, recruitment has not been documented, but monitoring in the Little Kanawha has indicated evidence of reproduction (ESI 2009, p. 21; Clayton 2018, pers. comm.). The mussel fauna in the Virginia portion of the Clinch River has declined, specifically at sites such as Pendleton Island where the Longsolid was once common but is now rare (Ahlstedt *et al.* 2016a, p. 11). Additionally, downstream impoundments separate these populations from others within the Ohio and Tennessee River basins, and the resulting fragmentation and lack of connectivity decreases dispersal capability and increases the potential for genetic isolation.

5.3.2 Representation

Representation refers to the breadth of genetic or environmental diversity within a species and reflects the ability of a species to adapt to changing environmental conditions. The greater the diversity, the more successfully a species should be able to respond to changing environmental conditions. In the absence of genetic data for the Longsolid, we considered environmental diversity across the species' range. The best available data indicate three representative units (i.e., three major river basins) where Longsolid is currently found: the Ohio, Cumberland, and Tennessee River basins.

Since there is very little genetic information available for the Longsolid, we considered geographic range as surrogates for geographic variation and proxies for potential local adaptation and adaptive capacity. We used hydrographic (management) units (at the HUC 8 level; see additional discussion in Chapter 2) to define representation because watershed boundaries and natural and artificial barriers constrain ecological processes, such as genetic exchange and ultimately adaptive capacity for aquatic species.

The Longsolid was last reported as weathered dead in the Great Lakes basin from St. Joseph's River (Enviroscience 2012, p. 9) and Cedar Creek (Watters 1988, pp. 11, 33), but museum records indicate that there were at least 6 populations in the basin (Appendix D). Therefore, the species has been reduced from four to three major river drainages in other basins compared to historical information. The Longsolid has a single remaining known population and MU in the Cumberland River basin, and the best available information suggests that the Longsolid has experienced significant declines in upstream and downstream sections of the Cumberland River from historical conditions (Schuster 1988, p. 392; Haag and Cicerello 2016, p. 139). It also no longer occurs in Cumberland River tributaries, and the remaining population is linear in extent with a high level of threats, primarily cold-water discharges from upstream dams. Mussels are incapable of migrating to more desirable environmental conditions (see Chapter 3, above). Therefore, the species is at immediate risk of losing another 25 percent of major river basin representation.

As evaluated by major river basin, the current distribution of the Longsolid across its range reflects a 25 percent loss from historical representation. Regardless, the species currently ranges across three major river basins. The variety of trend information available across its range (i.e., loss of populations in tributaries or major river systems, loss of populations throughout the Great Lakes river basin, declines in population extent and size in portions of the species' range) indicate that the Longsolid's overall ability to adapt to changing environmental conditions is minimal.

5.3.3 Redundancy

Redundancy refers to number of populations of a species and their distribution across the landscape, reflecting the ability of a species to survive catastrophic events. The greater the number of populations, and the more widely they are distributed, the lower the likelihood a single catastrophic event will cause a species to become extinct.

Longsolid populations are widely distributed over nine states and the redundancy metric we use in this SSA is number of populations (Table 5-5, Appendix A). The Ohio River basin contains 39 populations and 30 MUs; the Cumberland River basin has a single population and MU; and the Tennessee River basin contains 20 populations and 14 MUs. The total number of extirpated populations and MUs by river basin are: 63 populations (37 MUs) in the Ohio, 9 populations (8 MUs) in the Cumberland, and 26 populations (12 MUs) in the Tennessee. Given the current status encompasses 60 populations and 45 management units throughout its range, the species currently retains adequate redundancy for withstanding and surviving potential catastrophic events. However, it is important to note that a high percentage (80 percent; 48 of the 60 populations) are currently in low condition. Overall, the species has decreased redundancy across its range due to extirpation of 102 populations (64 percent) compared to historical levels.

5.4 Uncertainties of Current Condition

For a wide-ranging species with variable data availability across populations, there are many uncertainties, some uncertainties of of our current condition analysis include:

- Some gene flow potentially occurs among rivers, streams, and HUC 8 watersheds without barriers to connectivity, although the timing and frequency of gene flow among these watersheds is not known and may be inadequate to maintain genetic diversity among populations.

- We acknowledge that specific Longsolid demographic and genetic data which to support the approached construct are sparse. However, this approach for assessing the species' condition has been used for other aquatic species in the eastern U.S. and is based on the best available science; therefore, it was considered an acceptable construct for this SSA report.

- Many of the populations ranked as low condition have very little information available; some have had only one documented collection of the species, with no additional survey data to confirm recent presence or absence.

- Information on threats for such a large distributional range came from a wide variety of sources such as published literature and mussel survey reports. There is a paucity of information available on threats specific to the Longsolid. In most instances threats were reported to the entire mussel fauna or aquatic fauna in general.

CHAPTER 6 - FACTORS INFLUENCING VIABILITY

In this chapter, we evaluate past, current, and future factors affecting what the Longsolid needs for long-term viability. Aquatic systems face myriad natural and anthropogenic factors that influence species viability (Neves *et al.* 1997, p. 44). Generally, these factors can be categorized as either environmental stressors (e.g., development, agriculture practices, forest management, dam operation, regulatory frameworks) or systematic changes (e.g., climate change, invasive species, barriers, conservation management practices). Current and potential future effects, along with current distribution and abundance, help inform viability, and therefore vulnerability to extinction.

Negative factors influencing the viability of Longsolid are presented below. In addition to describing the potential impacts and sources of each influence (Figure 6-1, below), we present examples from within the species' range in an attempt to illustrate the scope and magnitude of the impacts based on the best available scientific and commercial information. Additionally, we present a summary of the beneficial conservation measures (regulatory and voluntary) occurring to reduce the impacts, and if those conservation measures are considered effective.

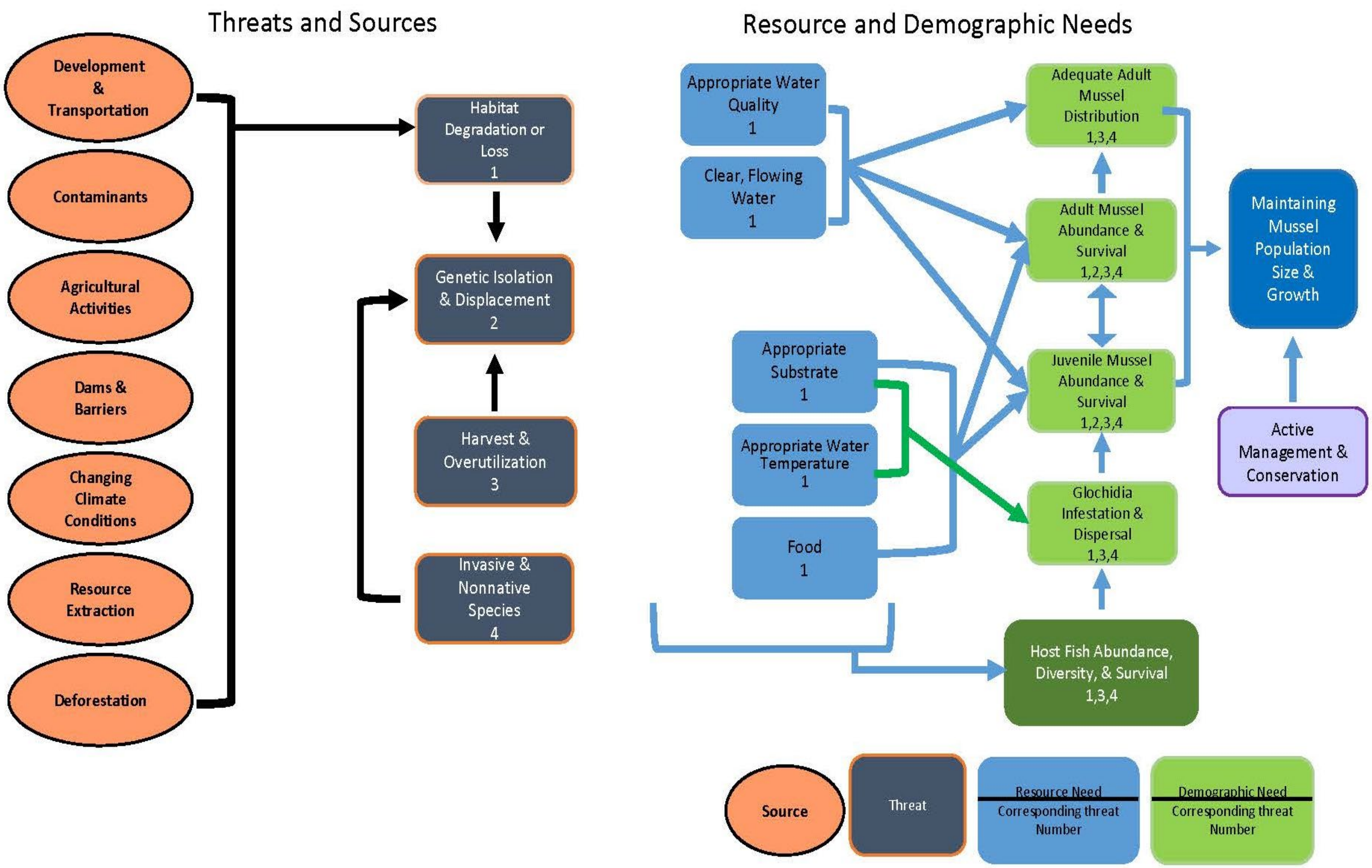

Figure 6-1. Influence diagram for Longsolid, depicting threats, sources of threats, resources needs, and demographic needs.

6.1 Habitat Degradation or Loss

6.1.1 Development/Urbanization

We use the term "development" to refer to urbanization of the landscape, including (but not limited to) land conversion for residential, commercial, and industrial uses and the accompanying infrastructure. The effects of urbanization may include alterations to water quality, water quantity, and habitat (both in-stream and streamside) (Ren *et al.* 2003, p. 649; Wilson 2015, p. 424).

Urban development can lead to increased variability in streamflow, typically increasing the extent and volume of water entering a stream after a storm and decreasing the time it takes for the water to travel over the land before entering the stream (Giddings *et al.* 2009, p. 1). An "impervious surface" refers to all hard surfaces like paved roads, parking lots, roofs, and even highly compacted soils like sports fields. Impervious surfaces prevent the natural soaking of rainwater into the ground and ultimately and gradually seeping into streams (Brabec *et al.* 2002, p. 499; New Hampshire Estuaries Project (NHEP) 2007, p. 2). Instead, rainwater accumulates and often flows rapidly into storm drains, which rapidly drain to local streams. This results in deleterious effects on streams in three important ways (USGS 2014, pp. 2–5):

(1) *Water Quantity*: Storm drains deliver large volumes of water to streams much faster than would naturally occur, often resulting in flooding and bank erosion that reshapes the channel, and causes substrate instability, resulting in destabilization of bottom sediments. Increased, high velocity discharges can cause species living in streams (including mussels) to become stressed, displaced, or killed by fast moving water and the debris and sediment carried in it.
(2) *Water Quality*: Pollutants (e.g., gasoline, oil drips, fertilizers) that accumulate on impervious surfaces may be washed directly into streams during storm events.
(3) *Water Temperature*: During warm weather, rain that falls on impervious surfaces becomes superheated and can stress or kill freshwater species when it enters streams.

Urbanization increases the amount of impervious surfaces (Center for Watershed Protection (CWP) 2003, p. 1). The resulting storm water runoff affects water quality parameters such as temperature, pH, dissolved oxygen, and salinity, which in turn alters the water chemistry potentially making it inhospitable for aquatic biota. The rapid runoff also reduces the amount of infiltration into the soil to recharge aquifers, resulting in lower sustained streamflow, especially during low flow periods (Giddings *et al.* 2009, p. 1).

Water infrastructure development, including water supply, reclamation, and wastewater treatment, results in pollution point discharges to streams. Concentrations of contaminants (including nitrogen, phosphorus, chloride, insecticides, polycyclic aromatic hydrocarbons, and personal care products) increase with urban development (Giddings *et al.* 2009, p. 2; Bringolf *et al.* 2010, p. 1,311).

Utility crossings and right-of-way (ROW) maintenance are additional aspects of development that affect stream habitats. Direct impacts from utility crossings include direct exposure or crushing of individuals, sedimentation, and flow disturbance. The most significant cumulative impact involves cleared ROWs that result in direct runoff and increased stream temperature at the crossing location, and potentially allow access of maintenance utility and all-terrain vehicles from the ROW (which destroy banks and instream habitat, leading to increased erosion). Maintenance of these utility crossings and ROWs are additional aspects of development that can influence stream habitats. Herbicides and their surfactants which used to clear ROWs also have deleterious effects to aquatic organisms (See Contaminants, Section 6.1.3, below).

The French Creek population of Longsolid is threatened by development encroaching from the City of Erie and nearby smaller urban areas (Smith and Crabtree 2010, p. 409). Regional land development and commerce are cited as threats to the integrity of the aquatic community of Muddy Creek (Mohler *et al.* 2006, p. 579). The Tuscarawas River has been severely degraded by industrial development, which continues to affect water quality in the basin (Hoggarth 1994, p. 3; Haefner and Simonson 2018, p. 1).

The aquatic fauna of the lower Elk and Kanawha rivers was directly affected by major chemical industries and commercial activity in Charleston, West Virginia, and to some extent legacy effects of these industries remain (Morris and Taylor 1978, p. 153; Taylor 1983a, p. 13; WVDNR 2012, p. 12). However, the Kanawha River downstream of the Elk River has improved in water quality from past conditions, and an abundant and diverse mussel population is recovering, indicating the Kanawaha River has potential for recovery (Clayton, 2018, pers. comm.).

Population centers along the Ohio, Cumberland, and Tennessee River main stems have a long history of human settlement and associated construction within their floodplains, and are experiencing continued development activities within the Longsolid's range in riparian areas along these rivers (ORSANCO 2016, p. 10). The Ohio River alone provides drinking water to approximately 5 million people (ORSANCO 2016, p. 15).

The Nature Conservancy (TNC) has targeted areas for conservation within some river and stream systems harboring extant populations of the Longsolid: the lower Licking River and upper Green River in Kentucky, the upper Clinch/Powell River, Tennessee and Virginia, and the Paint Rock River in Alabama. Although TNC has few riparian inholdings in these watersheds, they have carried out community-based and partner-oriented projects that are intended to address aquatic species and instream habitat conservation. TNC has worked with riparian landowners to help them restore and protect streambanks and riparian zones, and they collaborate with various other stakeholders in conserving aquatic resources.

Various small, isolated, parcels of public land (e.g., state parks, state forests, wildlife management areas) lies along rivers and streams where Longsolid occurs. However, vast tracts of riparian lands where Longsolid occurs is privately owned, and the prevalence of privately owned lands in streams with extant populations is comparatively much larger than the species' occurrence on public land. This will necessitate substantial additional voluntary conservation or maintenance of riparian vegetation for overall protection of stream health. It also somewhat diminishes the level of importance afforded by public lands that may implement various land use restrictions. In other words, activities in riparian lands that occurs outside or upstream of public lands may be pervasive and have a profound impact on the downstream mussel populations. Habitat protection benefits on public lands may therefore easily be negated by detrimental activities upstream or immediately downstream in a watershed.

The most important public land holding in the Ohio River is the Ohio River Islands NWR. The refuge includes all or parts of 21 islands and 3 mainland tracts totaling 3,220 ac (1,303 ha) in the Ohio River from RM 35 (Shippingport, Pennsylvania) downstream to RM 397 (Manchester, Ohio, and adjacent Kentucky); islands are managed in six Ohio River pools (i.e., New Cumberland, Hannibal, Willow Island, Belleville, Racine, Meldahl). The location of Mammoth Cave National Park also provides a significant level of localized watershed protection against development pressures for the Longsolid population in the upper Green River, Kentucky. Additionally, the Erie NWR protects some habitat in Pennsylvania, on lower Muddy Creek, which is particularly important for maintaining the medium condition populations in the French Creek MU.

Increased commercial and residential development is more frequently cited as a threat to Longsolid populations in the upper Ohio River basin, and may be most likely to negatively affect the species in medium condition populations such as in the Shenango and Allegheny rivers, and French Creek. However, increased human population growth projections indicate urban sprawl will also affect Longsolid populations in the Tennessee, Cumberland, and lower Ohio River basins (Terando *et al.* 2014, p. 7). A frequently cited threat to mussels is poor wastewater discharge treatments, which are generally more common in rural areas, but regardless are an indicator of anthropogenic disturbance (ESI 2009, p. 14; see section 6.1.3, Contaminants, below).

The effects of commercial and residential urbanization and development on aquatic communities at large spatial scales are poorly studied (Wheeler *et al.* 2005, p. 162). Extant populations of Longsolid are not concentrated in urban areas with large human occupation on the landscape; therefore, it is the potential rapid expansion of urban and suburban growth into rural and undeveloped areas that is most likely to affect the species' populations. It is currently unknown whether the anthropogenic effects of development and urbanization are likely to impact Longsolid at the individual or population level; however, secondary impacts such as the increased likelihood of potential contaminant introduction, stream disturbance caused by impervious surfaces, barrier construction, and forest conversion are likely to act cumulatively on Longsolid populations.

6.1.2 Transportation

A major aspect of urbanization is the resultant road development. By its nature, road development increases impervious surfaces as well as land clearing and habitat fragmentation. Roads are generally associated with negative effects on the biotic integrity of aquatic ecosystems, including changes in surface water temperatures and patterns of runoff, sedimentation, adding heavy metals (especially lead), salts, organics, and nutrients to stream systems (Trombulak and Frissell 2000, p. 18). The adding of salts through road-deicing results in high salinity runoff, which is toxic to freshwater mussels. In addition, a major impact of road development is improperly constructed culverts at stream crossings. These culverts act as barriers if flow through the culvert varies significantly from the rest of the stream, or if the culvert ends up being perched, and aquatic organisms, specifically mussel host fishes, cannot pass through them. Improperly installed culverts alter in-stream habitat, and can cause changes in stream depth, resulting in pools upstream and a destabilized channel downstream of the culvert.

Transportation also includes river commerce and river navigation impacts. Dredging and channelization activities as a means of maintaining waterways have profoundly altered riverine habitats nationwide (Ebert 1993, p. 157). Channelization affects many physical characteristics of streams through accelerated erosion, increased bedload, reduced depth, decreased habitat diversity, geomorphic instability, and riparian canopy loss (Hartfield 1993, p. 139). All of these impacts contribute to loss of habitat for the Longsolid, and alter habitats for host fish. Changes in the water velocity, and changes in deposition of sediments not only alters physical habitat but the associated increases in turbulence, suspended sediments, and turbidity affect mussel feeding and respiration (Aldridge *et al.* 1987, p. 25). Levels of high suspended solids also result in mussel reproductive failure or low fertilization rates of long-term brooders, such as species of the genus *Fusconaia* (Gascho-Landis and Stoeckel 2015, p. 229).

Channel construction for navigation is known to increase flood heights, and is partially attributed to a decrease in stream length and increase in gradient (Hubbard *et al.* 1993, p. 135).
As a result, flood events may be exacerbated, conveying into downstream reaches large quantities of sediment, potentially with adsorbed contaminants (see section 6.1.3, below), which covers suitable mussel habitat and affects water quality. Channel maintenance, such as hydraulic (suction) dredging, may result in profound impacts downstream, including increased turbidity that may impede sight-feeding host fishes and sedimentation that smothers juvenile mussels (Ellis 1936, p. 39). Longsolid populations in the Eel, Vermilion, and Embarras Rivers and Killbuck Creek are extirpated; these streams have been extensively dredged and channelized (Butler 2007, p. 63; Appendix B).

Taylor (1983a, p. 3) stated that the Kanawha River in West Virginia below RM 79 lacked habitat suitable for freshwater mussels with dredging as a primary cause. The remaining Longsolid population in the Kanawha River is limited to a reach immediately below Kanawha Falls, which is above the head of navigation (Douglas 2000, p. 5). The USACE had not conducted open channel hydraulic dredging in West Virginia recently, but continue to use clamshell dredges in the upper and lower approaches to lock chambers. Generally these activities, as well as disposal of dredged material is better managed to avoid mussel impacts (Clayton, 2018, pers. comm.).

Extensive stream channelization and snag removal was also implicated in declines of the freshwater mussel fauna and habitat in the Paint Rock River system, including the lower reaches of Estill Fork and Hurricane Creek (Ahlstedt 1995-96, p. 65). Approximately 20 RMs of Conewango Creek were channelized and straightened in the first half of the last century, and residual impacts continue based on a recent survey indicating that the resulting dredged areas continue to have no riffle or run habitat (i.e., sufficient flow and habitat as described in section 4.1.1) (Crabtree 2009, p. 19).

Channelization activities, which include channel enlargement, channel realignment, clearing and snagging, and manipulation of banks, were widespread in lowland areas and in the lower reaches of rivers and streams occupied by the Longsolid in the 1900s in the Ohio, Cumberland, and Tennessee River basins (Haag and Cicerello 2016, p. 60). Studies indicate that even if active channelization activities are not currently occurring in rivers and streams occupied by the Longsolid, impacts of these actions can have permanent effects such as habitat destabilization, which result in altered habitat that may be more suitable for nonnative species, or in some situations elimination of the mussel fauna (Haag and Cicerello 2016, p. 60; Hubbard *et al.* 1993, p. 142; Watters 2000, p. 274).

The Rivers and Harbors Act of 1946 authorized USACE to maintain a navigable channel in rivers such as the Allegheny, Kanawha, Ohio, Muskingum, Cumberland, and Tennessee to promote and facilitate river commerce. Open channel maintenance may require hydraulic or clamshell (scoop) dredging of the navigation channel and placement of the dredged material (spoil). Dredging and spoil disposal continues to impact habitat for the Longsolid in these rivers. These impacts include the reduction of suitable substrates for mussel settlement and growth, and increasing suspended sediments and siltation, which affects mussel feeding and respiration (Ebert 1993, p. 157).

In addition to dredging and channel maintenance, impacts associated with barge traffic, which includes construction of fleeting areas, mooring cells, docking facilities, and propeller wash, also destroy and disrupt mussel habitat. Currently, these navigational activities are affecting at least 15 (25 percent) Longsolid populations in the Ohio, Cumberland, and Tennessee River basins (Hubbs *et al.* 2006, p. 169; Hubbs 2012, p. 3; Smith and Meyer 2010, p. 555; Sickel and Burnett 2005, p. 7; Taylor 1983a, p. 5).

Although most prevalent on the mainstem Ohio and Tennessee rivers, commerce and commercial navigation activities currently affect Longsolid populations include the Allegheny and Muskingum rivers but also previously the lower Kanawaha and Green rivers. The impacts of past dredging and navigation affected mussel beds in the mainstem Cumberland River, which has the last remaining population of Longsolid in the Cumberland River basin (Hubbs 2012, p. 9). While direct impacts of navigation such as barge traffic are more likely to affect individuals, the scope of channel maintenance activities over extensive areas alters physical habitat and degrades water quality, which affects the species at the population level.

Currently, all of the Ohio River mainstem Longsolid populations (6) that are considered in low condition are affected by channel maintenance and navigation operations. The status of these Ohio River populations is uncertain due to challenges associated with surveying large river habitats and these populations which are highly fragmented, small in extent and density, and subject to significant threats, may already be extirpated.

Additionally, channel maintenance and navigation are affecting the low condition populations in the lower Allegheny and Tennessee rivers, due to their clustered distribution and proximity to locks and dams. These include 2 Allegheny River populations below Redbank, Pennsylvania (Smith and Meyer 2010, p. 556), and 3 low condition populations in the Tennessee River main stem above Kentucky dam. The last remaining medium condition Longsolid population in a large river, in the Tennessee River below Kentucky Dam, is also threatened by the combined impacts of dams and navigation (Hughes and Parmalee 1999, p. 38).

6.1.3 Contaminants

Contaminants contained in point and non-point discharges can degrade water and substrate quality and adversely impact mussel populations. Although chemical spills and other point sources of contaminants may directly result in mussel mortality, widespread decreases in density and diversity may result in part from the subtle, pervasive effects of chronic, low-level contamination (Naimo 1995, p. 354). The effects of heavy metals, ammonia, and other contaminants on freshwater mussels were reviewed by Mellinger (1972); Fuller (1974); Havlik and Marking (1987); Naimo (1995); Keller and Lydy (1997); and Newton *et al.* (2003) (entire).

The effects of contaminants such as metals, chlorine, and ammonia are profound on juvenile mussels (Bartsch *et al.* 2003, p. 2,566; Augspurger *et al.* 2003, p. 2,571). Juvenile mussels may readily ingest contaminants adsorbed to sediment particles while pedal feeding (Newton and Cope 2007, p. 276). These contaminants also affect mussel glochidia, which are very sensitive to some toxicants; as has been displayed on the Clinch River, which is a stronghold population for the Longsolid (Goudreau *et al.* 1993, p. 221; Jacobson *et al.* 1997, p. 2,386; Valenti *et al.* 2005, p. 1,243).

Mussels are noticeably intolerant of heavy metals (Havlik and Marking 1987, p. 4). Even at low levels, certain heavy metals may inhibit glochidial attachment to fish hosts. Cadmium appears to be the heavy metal most toxic to mussels (Havlik and Marking 1987, pp. 4–9), although chromium, copper, mercury, and zinc also negatively affect biological processes (Naimo 1995, p. 355; Jacobson *et al.* 1997, p. 2,389; Valenti *et al.* 2005, p. 1,243). Chronic mercury contamination from a chemical plant on the North Fork Holston River, Virginia, destroyed a diverse mussel fauna downstream of Saltville, Virginia, and potentially contributed to the extirpation of the species from that river (Brown *et al.* 2005, p. 1,459).

Recent improvements to remove trace metals have been made at the Appalachian Power Company's Clinch River coal-fired steam plant wastewater treatment facility, in Carbo, Virginia, which has likely resulted in improved water quality immediately downstream of the plant (Ahlstedt *et al.* 2017a, p. 221). However, the long-term declines and extirpation of mussels from the Clinch River in Virginia have been attributed to copper and zinc contamination originating from wastewater discharges at electric power plants, which emphasizes that despite localized improvements, these metals can stay bound in sediments, affecting recruitment and densities of the mussel fauna for decades (Price *et al.* 2014, p. 12; Zipper *et al.* 2014, p. 9).

To the best of our current knowledge, heavy metals and their toxicity to mussels have been documented in the Muskingum, Ohio, Powell, Clinch, and Tennessee rivers (Havlik and Marking 1987, pp. 4-9). Coal plants are also located on the Kanawha, Green, and Cumberland rivers, and the effects of these facilities on water quality and the freshwater mussel fauna, including the Longsolid, are likely similar.

Among pollutants, ammonia warrants priority attention for its effects on mussels. It has been shown to be lethal to juveniles at concentrations as low as 0.7 parts per million (ppm) total ammonia nitrogen, normalized to pH 8 (range = 0.7–19.7 ppm) and lethal to glochidia at concentrations as low as 2.4 ppm total ammonia nitrogen, normalized to pH 8 (range = 2.4–10.4 ppm) (Augspurger *et al.* 2003, p. 2,574). The un-ionized form of ammonia (NH_3) is usually attributed as being the most toxic to aquatic organisms, although the ammonium ion form (NH_4+) may contribute to toxicity under certain conditions (Newton 2003, p. 1). Documented toxic effects of ammonia on freshwater bivalves include reduced survival, reduced growth, and reduced reproduction (Augspurger *et al.* 2003, p. 2,575; Mummert *et al.* 2003, p. 2,522). Ammonia has also been shown to cause a shift in glucose metabolism and to alter the metabolic utilization of total lipids, phospholipids, and cholesterol (Chetty and Indira 1994, p. 693).

Sources of ammonia are agricultural (e.g., animal feedlots and nitrogenous fertilizers), municipal (e.g., outdated water treatment plants and industrial waste products), and from natural processes (e.g., precipitation and decomposition of organic nitrogen) (Goudreau *et al.* 1993, p. 222; Augspurger *et al.* 2003, p. 2,575; Newton 2003, p. 2,543). Toxic effects of ammonia are more pronounced at higher pH and water temperature because the level of the un-ionized form increases as a percentage of total ammonia (Mummert *et al.* 2003, p. 2,545; Newton 2003, p. 2,544). Therefore, this contaminant may become more problematic for juvenile mussels during low flow, high temperature periods (Cherry *et al.* 2005, p. 378).

In stream systems, ammonia frequently is at its highest concentrations in interstitial spaces where juvenile mussels live and feed, and may occur at levels that exceed water quality standards (Cooper *et al.* 2005, p. 392; Frazier *et al.* 1996, p. 97). U.S. Environmental Protection Agency (EPA) established ammonia water quality criteria (WQC) (EPA 1985, entire) that may not be protective of mussels (Augspurger *et al.* 2003, p. 2,571). Ammonia is considered a limiting factor for survival and recovery of some mussel populations due to its high level of toxicity and because the highest concentrations occur in their microhabitats (Augspurger *et al.* 2003, p. 2,569).

Other common contaminants associated with households and urban areas, particularly those from industrial and municipal effluents, may include heavy metals, chlorine, phosphorus, and numerous other toxic compounds. Pharmaceuticals, hormones, and other organic wastewater contaminants (OWCs) were detected downstream from urban areas and livestock production (Kolpin *et al.* 2002, p. 1,208). These OWCs (82 of the 95 tested for) originated from a wide range of residential, industrial, and agricultural sources, and some are known to have deleterious effects on aquatic organisms (Kolpin *et al.* 2002, p. 1,210). Wastewater is discharged through NPDES-permitted (and some non-permitted) sites throughout the country. In Virginia, high counts of coliform bacteria originating from wastewater treatment plants have been documented in both the Clinch and Powell rivers, and degradation of water quality is a primary threat to aquatic fauna in these systems (Neves and Angermeier 1990, p. 50).

The toxic effects of high salinity wastewater from oil and natural gas drilling on juvenile and adult freshwater mussels were observed in the Allegheny River, Pennsylvania (Patnode *et al.* 2015, p. 55). Extraction of petroleum produces water with high chlorine concentrations, to which all stages of freshwater mussels are highly sensitive (Patnode *et al.* 2015, p. 56). The degradation of water quality as a result of land-based oil and gas drilling activities is a significant adverse effect on freshwater mussels, and specifically Longsolid in the Ohio River basin and populations in the Allegheny River, as well as the Kanawha, Little Kanawha, and Elk rivers.

Chemical spills occur often and are devastating for isolated populations of rare, relatively immobile species with limited potential for recolonization, such as mussels (Wheeler *et al.* 2005, p. 155). Numerous streams throughout the range of the Longsolid have experienced mussel and fish kills from toxic chemical spills, especially in the upper Tennessee River system in Virginia (Ahlstedt *et al.* 2016a, p. 8; Neves 1987, p. 254; Jones *et al.* 2001, p. 20; Schmerfeld 2006, p. 12). Catastrophic pollution events, coupled with pervasive sources of contaminants from municipal and industrial pollution and coal-processing wastes have contributed to the decline of the Longsolid and other species in the Clinch River (Neves 1991, p. 260). An alkaline fly ash pond spill in 1967 and a sulfuric acid spill in 1970 on the Clinch River at Carbo, Virginia, caused massive mussel kills for up to 12 RMs downstream from a power plant (Ahlstedt *et al.* 2016a, p. 8). Sediment from the upper Clinch River was found to be toxic to juvenile mussels, which has contributed to the decline and lack of recruitment of mussels in the Virginia portion of the river (Ahlstedt and Tuberville 1997, p. 74; Price *et al.* 2014, p. 855).

In 1998, a major spill of rubber accelerant in the upper Clinch River, Virginia, eliminated approximately 18,000 individuals of several mussel species (Jones *et al.* 2001, p. 20; Schmerfeld 2006, p. 12). The death toll also included approximately 750 individuals of three federally listed species (Schmerfeld 2006, p. 12). A catastrophic spill in 1999 affected approximately 10 RMs of the Ohio River and resulted in the loss of an estimated one million mussels, including two federally listed species (Butler 2005 p. 24). In August 2014, an inadvertent discharge of diesel fuel was released on land and drained into Markland Pool of the Ohio River at Duke Energy's W.C. Beckjord Station in Clermont County, Ohio. It is estimated that 9,000 gallons were released during a transfer of fluids near RM 452.6 (ESI 2015, p. 1). Chemical spills will invariably continue to occur and have the potential to reduce or eliminate Longsolid populations.

Spills of hazardous or toxic materials are an ongoing problem associated with commercial navigation and river-oriented industry, and a threat to freshwater mussels. Activities and areas of particular concern include vessel fueling operations (including midstream), barge loading/off-loading operations, queuing areas, and river reaches with heavy debris (Miller *et al.* 1989, p. 15). Spills also may damage or contaminate nearshore and depth-transitional areas where mussel beds are common (Miller and Payne 1998, p. 184).

Section 401 of the Federal Clean Water Act (CWA) requires that an applicant for a Federal license or permit provide a certification that any discharges from the facility will not degrade water quality or violate water-quality standards, including those established by states. Section 404 of the CWA establishes a program to regulate the discharge of dredged and fill material into waters of the United States.

Permits to fill wetlands and fill, culvert, bridge, or re-align streams or water features are issued by the USACE under Nationwide Permits, Regional General Permits, or Individual Permits.

- *Nationwide Permits* are for "minor" impacts to streams and wetlands, and do not require an intense review process. These impacts usually include stream impacts under 150 ft (45.7 m), and wetland fill projects up to 0.50 ac (0.2 ha). Mitigation is usually provided for the same type of wetland or stream affected, and is usually at a 2:1 ratio to offset losses and make the "no net loss" closer to reality.
- *Regional General Permits* are for various specific types of impacts that are common to a particular region; these permits will vary based on location in a certain region/state.
- *Individual Permit*s are for the larger, higher impact and more complex projects. These require a complex permit process with multi-agency input and involvement. Impacts in these types of permits are reviewed individually and the compensatory mitigation chosen may vary depending on project and types of impacts.

State and Federal Water Quality Programs

Current State regulations regarding pollutants are designed to be protective of aquatic organisms; however, unionids may be more susceptible to some pollutants than the test organisms commonly used in bioassays. Additionally, water quality criteria may not incorporate data available for freshwater mussels (March *et al.* 2007, pp. 2,066–2,067). A multitude of bioassays conducted on 16 mussel species (summarized by Augspurger *et al.* 2007, pp. 2,025–2,028) show that freshwater mollusks are more sensitive than previously known to some chemical pollutants, including chlorine, ammonia, copper, fungicides, and herbicide surfactants. Another study found that nickel and chlorine were toxic to a federally threatened mussel species at levels below the current criteria (Gibson 2015, p. 90). The study also found mussels are sensitive to sodium dodecyl sulfate (SDS), a surfactant commonly used in household detergents, for which water quality criteria do not currently exist.

Several studies have demonstrated that the criteria for ammonia developed by EPA in 1999 were not protective of freshwater mussels (Augspurger *et al.* 2003, p. 2,571; Newton *et al.* 2003, pp. 2,559–2,560; Mummert *et al.* 2003, pp. 2,548–2,552). However, in 2013 EPA revised its recommended criteria for ammonia after having considered newer toxicity data on sensitive freshwater mollusks (EPA, 2013; 78 FR 52192). All of the states in the range of the Longsolid have not yet adopted the new ammonia criteria. NPDES permits are valid for 5 years; thus, even after the new criteria are adopted, it could take several years before facilities must comply with the new limits.

Despite existing authorities such as the Clean Water Act, pollutants continue to impair the water quality in portions of the Longsolid. State and Federal regulatory mechanisms have helped reduce the negative effects of point source discharges since the 1970s, yet these regulations are difficult to implement and regulate. Although new water quality criteria are under development that will take into account more sensitive aquatic species, most current criteria do not. It is expected that several years will be needed to implement new water quality criteria throughout the range.

6.1.4 Agricultural Activities

6.1.4.1 Nutrient Pollution

Farming operations, including Concentrated Animal Feeding Operations (CAFOs), can contribute to nutrient pollution when not properly managed (EPA 2016, entire). Fertilizers and animal manure, which are both rich in nitrogen and phosphorus, are the primary sources of nutrient pollution from agricultural sources. If fertilizers are not applied properly, at the right time of the year and with the right application method, water quality in the stream systems can be affected. Excess nutrients affect water quality when it rains or when water and soil containing nitrogen and phosphorus wash into nearby waters or leach into groundwater. Excess nitrogen and phosphorus may cause algal blooms in surface waters (Carpenter *et al.* 1998, entire). Fertilized soils and livestock can be significant sources of nitrogen-based compounds like ammonia and nitrogen oxides (Carpenter *et al.* 1998, entire). Ammonia can be harmful to aquatic life if large amounts are deposited to surface waters (see section 6.1.3, Contaminants, above). The lack of stable stream bank slopes from agricultural clearing or the lack of stable cover crops between rotations on farmed lands can increase the amount of nutrients that enter nearby streams by way of increased soil erosion (cover crops and other vegetation will use excess nutrients and increase soil stability) (Barling and Moore 1994, p. 543). Livestock often use streams or artificial in-line ponds as a water source, this degrades water quality and stream bank stability and reduces water quantity available for aquatic fauna, like the Longsolid, that may occur downstream from these agricultural activities.

6.1.4.2 Pumping for Irrigation

Irrigation is the controlled application of water for agricultural purposes through manmade systems to supply water requirements not satisfied by rainfall. It is common practice to pump water for irrigation from adjacent streams or rivers into a reservoir pond, or spray it directly onto crops. If the water withdrawal is excessive, this may cause impacts to the amount of water available to downstream sensitive areas during low flow months, resulting in dewatering of channels and stranding of mussels. Some water withdrawal is done illegally (without permit if needed, or during dry time of year, or in areas where sensitive aquatic species occur without consultation).

6.1.4.3 Agriculture Exemptions from Permit Requirements

Normal farming (practices consistent with proper, acceptable customs and standards), silviculture, and ranching activities are exempt from the section 404 permitting process under the CWA. This includes activities such as construction and maintenance of farm ponds, irrigation ditches, and farm roads. If the activity might affect rare aquatic species, the USACE does require farmers to ensure that any “discharge shall not take, or jeopardize the continued existence of, a threatened or endangered species, or adversely modify or destroy the critical habitat of such species,” and to ensure that “adverse impacts to the aquatic environment are minimized.” However, the USACE does not require the farmer to consult with appropriate State or Federal Agencies regarding these sensitive species.

Agricultural impacts have been documented in streams where Longsolid occurs. Sedimentation and other non-point source pollution, primarily of agricultural origin, are identified as a primary threat to aquatic fauna of the Nolichucky River (The Tennessee Valley Authority (TVA) 2006 p. 11). Agricultural erosion is listed among the factors affecting the Clinch and Powell Rivers (Ahlstedt *et al.* 2016a, p. 8). Agriculture is identified as a threat to Clinch River health (Zipper *et al.* 2014, p. 810). Agricultural impacts have been noted to take a toll on mussel fauna in the Goose Creek watershed on the South Fork Kentucky River (Evans 2010, p. 15). The Elk River in Tennessee, which has a low condition, but recruiting population of Longsolid, is a watershed with significant agricultural activity (Woodside *et al.* 2004, p. 10).

Hanlon *et al.* (2009, p. 11) give multiple factors for the likely extirpation of Longsolid and other mussel species in Copper Creek, a tributary to the Clinch River in Virginia, and hypothesize that land use legacies resulting from conversion of forest to row crop and pasture agricultural practices were a primary factor in freshwater mussel decline. The specific impacts identified include removal of riparian vegetation, agricultural water quality and erosion problems, siltation and pathogens related to poor agricultural and silvicultural practices, and potentially high levels of nitrogenous wastes (Hanlon *et al.* 2009, p. 12). Agricultural Best Management Practices (BMP) generally are not required unless the applicant is receiving federal grant funds, therefore compliance is sporadic.

6.1.4.4 Agricultural Activities Summary

The advent of intensive row crop agricultural practices has been cited as a potential factor in freshwater mussel decline, and species extirpation, in the eastern United States (Peacock *et al.* 2005, p. 550). Nutrient enrichment and water withdrawals, threats commonly associated with agricultural activities, may be localized and limited in scope, and have the potential to affect individual Longsolid mussels. However, chemical control using pesticides; including herbicides, fungicides, and insecticides as well as their surfactants and adjuvants, are highly toxic to juvenile and adult freshwater mussels (Bringolf *et al.* 2007, p. 2,092). Waste from confined animal feeding and commercial livestock operations is another potential source of contaminants that come from agricultural runoff. The concentrations of these contaminants that emanate from fields or pastures may be at levels that can affect an entire population, especially given the highly fragmented distribution of the Longsolid (also see section 6.1.3).

Agencies such as the Natural Resources Conservation Service (NRCS), and the Soil and Water Conservation Districts, provide technical and financial assistance to farmers and private landowners. Additionally, county resource development councils and university agricultural extension services disseminate information on the importance of minimizing land use impacts, specifically agriculture, on aquatic resources. These programs help identify opportunities for conservation through projects such as exclusion fencing and alternate water supply sources, which help decrease nutrient inputs and water withdrawals and help keep livestock off of stream banks and shorelines, reducing erosion. However, the overall effectiveness of these programs over a large scale, such as that of the Longsolid distribution in 9 states, with varying agricultural intensities, is unknown.

Impacts from agricultural runoff and cultivation activities are a threat to the Longsolid populations in the Ohio and Tennessee basins. In the Tennessee River below Pickwick Dam agricultural activities in the floodplain, combined with hydropeaking releases from the dam, have resulted in extensive bank loss and soil erosion (Hubbs et al. 2006, p. 173). Specifically, agricultural impacts have affected and continue to affect high, medium, and low condition Longsolid populations within these basins, including:

- French Creek (Pennsylvania)
- Allegheny River (Pennsylvania)
- Shenango River (Pennsylvania)
- Elk River (West Virginia)
- Little Kanawha River (West Virginia)
- Hughes River (West Virginia)
- North Fork Hughes River (West Virginia)
- Tuscawaras River (Ohio)
- Licking River (Kentucky)
- Rolling Fork River (Kentucky)
- Kentucky River (Kentucky)
- Little River (North Carolina)
- Nolichucky River (Tennessee)
- Elk River (Tennessee)
- Clinch River (Tennessee & Virginia)
- Powell River (Tennessee & Virginia)
- Paint Rock River (Alabama)
- Estill Fork (Alabama)
- Valley River (North Carolina)
- Buffalo River (Tennessee)

Given the large extent of private land and agricultural activities within the range of the Longsolid, the effects of agricultural activities that degrade water quality and result in habitat deterioration are not frequently detected until after the event(s) occur. In summary, agricultural activities are pervasive across the range of the Longsolid. Populations are located in areas across nine states that have varying levels of agricultural activity. The effects of agricultural activities on the Longsolid is widespread and have been attributed as a factor in its decline and localized extirpation.

6.1.5 Dams and Barriers

The effects of impoundments and barriers on aquatic habitats and freshwater mussels are relatively well-documented (Watters 2000, p. 261). This section is intended to be summary of the effects, as opposed to a comprehensive overview, dams and other barriers have on the Longsolid.

Extinction/extirpation of North American freshwater mussels can be traced to impoundment and inundation of riffle habitats in all major river basins of the central and eastern U.S. (Haag 2009, p. 107; North Carolina Wildlife Resources Commission (NCWRC) 2015, p. 109). Humans have constructed dams for a variety of reasons: flood prevention, water storage, electricity generation, irrigation, recreation, and navigation (Eissa and Zaki 2011, p. 253). Dams, either natural (by beavers or by aggregations of woody debris) or man-made, have many impacts on stream ecosystems. Reductions in the diversity and abundance of mussels are primarily attributed to habitat shifts caused by impoundments (Neves *et al.* 1997, p. 63). The survival of mussels and their overall reproductive success are influenced:

- *Upstream of dams* – the change from flowing to impounded waters, increased depths, increased buildup of sediments, decreased dissolved oxygen, and the drastic alteration in resident fish populations.
- *Downstream of dams* – fluctuations in flow regimes, minimal releases and scouring flows, seasonal dissolved oxygen depletion, reduced or increased water temperatures, and changes in fish assemblages.

Interestingly, recent studies have shown that some mussel populations may be more temporally persistent immediately downstream of small dams, more abundant and diverse, and attain larger sizes and grow faster than do conspecifics in populations further upstream or downstream (Gangloff 2013, p. 476, and references therein). In today's rapidly changing landscape, it is possible that these small dams and their impoundments may perform some key ecological functions including filtration and detoxification of anthropogenically elevated nutrient loads, oxygenating low-gradient streams during low-water periods, and stabilizing portions of the stream beds that are needed for the persistence of fish and mollusk taxa (Gangloff 2013, pp. 478–479). Additional benefits of impoundments may include retention of fine sediments and associated toxicants, impediments to the spread of invasive species, and attenuation of floods from urban or highly agrarian watersheds (Gangloff 2013, p. 476). The population of the Longsolid in the Little River, North Carolina, below Cascade Lake Dam likely receives some of these direct and indirect benefits.

As mentioned above in section 6.1.2, Transportation, improperly constructed culverts at stream crossings may act as significant barriers, and have some similar effects as dams on stream systems. Fluctuating flows through the culvert can vary significantly from the rest of the stream, preventing fish passage and scouring downstream habitats. For example, if a culvert sits above the streambed, aquatic organisms cannot pass through them. These barriers not only fragment habitats along a stream course, they also contribute to genetic isolation of the aquatic species inhabiting the streams.

Over 20 of the rivers and streams currently occupied by the Longsolid in the Ohio, Cumberland, and Tennessee River basins are directly affected by dams, thus directly influencing the species' distribution rangewide, perhaps more so than any other factors influencing the species. Impacts of these dams to the Longsolid include population isolation, hydrological instability, high shear stress, scour, and cold water releases, which suppresses mussel recruitment (Hardison and Layzer 2001, p. 79; Smith and Meyer 2010, p. 543; Hubbs 2012, p. 8). A list of some of the dams currently directly influencing populations and the distribution of the Longsolid include:

- Kinzua Dam - Allegheny River (Pennsylvania and New York)
- Pymatuning and Shenango Dams - Shenango River (Pennsylvania)

- North Bend Dam - North Fork Hughes River (West Virginia)
- Burnsville Dam & Wells Lock and Dam - Little Kanawha River (West Virginia)
- Sutton Dam - Elk River (West Virginia)
- Dover Dam - Tuscarawas River (Ohio)
- Six Mile Dam - Walhonding River (Ohio)
- Cave Run Dam - Licking River (Kentucky)
- Green River Dam and 4 Locks and Dams - Green River (Kentucky)
- Barren River Dam & Lock & Dam 1 - Barren River (Kentucky)
- Old Hickory and Cordell Hull Dam Cumberland River (Tennessee)
- Norris Dam - Clinch/Powell rivers (Tennessee and Virginia)
- Cherokee Dam - Holston River (Tennessee)
- Nolichucky Dam - Nolichucky River (Tennessee)
- Apalachia, Chatuge, and Mission Dams - Hiwassee River (Tennessee and North Carolina)
- Cascade Lake Dam - Little River (North Carolina)
- Tims Ford and Harms Mill Dams - Elk River (Tennessee)
- Kentucky, Pickwick, Wilson, Guntersville, Chickamauga, Watts Bar Dams - Tennessee River (Kentucky, Alabama, and Tennessee)

Additionally, 11 Locks & Dams have been constructed on the Muskingum River in Ohio from Zanesville downstream to the Ohio River. Operational changes to incorporate hydropower in addition to flood control and navigation at six existing dams are underway. These changes increase the potential for negative impacts to the Longsolid and other rare mussels in the Muskingum River through changes in shear velocity potentially affecting the substrate and unionid communities through alteration of habitat (ESI 2012, p. 26). Additionally, Furedi (2013, p. 43) indicates that potential hydropower development is a threat to populations of the Longsolid in Pennsylvania.

The construction and continued operation of dams have historically resulted in extirpation of the Longsolid in portions of its range. In the Caney Fork River, Tennessee, many adverse effects of impoundments are contributing to habitat loss for mussels, including altered temperature regimes, silt deposition, unstable substrates, sedimentation, oxygen depletion, altered river morphology, dewatering, and reservoir fluctuation (Layzer *et al.* 1993, p. 68). In the South Fork Holston River, impoundment was identified as the biggest contributor to extirpation of a diverse and abundant native mussel fauna (Parmalee and Polhemus 2004, p. 231); this river harbored a significant population of Longsolid, which was one of the most common species prior to construction of TVA's Fort Patrick Henry, Boone, and South Holston dams (Parmalee and Polhemus 2004, p. 239). Although a population currently persists in the lower main stem Holston River, Tennessee, construction of Cherokee Dam in 1941 has resulted in extirpation of approximately 75 percent of the native mussel fauna downstream of the dam (Parmalee and Faust 2006, pp. 74-77), and large fluctuation in flow rates, water temperatures, and water depth hinder recolonization potential (Parmalee and Faust 2006, p. 73).

Another dramatic example of dam impacts within Longsolid's range is within the Ohio River, where there are 19 Locks & Dams on the mainstem between Pennsylvania and Illinois (Watters and Flaute 2010, p. 2). A net loss of 18.6 linear mi (30 km) of mussel beds has occurred between

RM 317 and RM 981 since 1967 (Williams and Schuster 1989, p. 3; whose studies geographically overlap ESI 2000, p. 9). The most drastic change was the complete absence of mussel beds in 51.8 mi (83 km) of the Ohio River above McAlpine Lock & Dam (Williams and Schuster 1989, p. 10). In the interval between 1967 and 1982, within the same study area above the McAlpine Lock & Dam, four high-lift dams (Cannelton, Newburgh, John T. Myers, and Smithland) replaced wicket dams (non-modern dams that helped regulate the river for boat passage); subsequently, between 1982 and 1994, eight mussel beds were lost entirely in tailwaters between RM 438 and RM 981 (Clarke 1995, p. 13).

Six Mile Dam on the Walhonding River in Ohio is slated for removal within the next few years (Boyer 2018, pers. comm.). The only remaining population of Longsolid known from the Walhonding River is below Six Mile Dam. Six Mile Dam has a strong influence on the numbers and distribution of freshwater fish and mussel species in the Walhonding River (Enviroscience 2010, p. 5). Habitat below the dam is currently considered unsuitable for mussels due to inappropriate substrates and areas of localized scour, but dam removal will allow for the reestablishment of undivided fish and mussel communities, improved habitat connectivity, and natural sediment transport (Enviroscience 2010, p. 6).

Green River Lock and Dam 6 in the Ohio basin in central Kentucky was removed in 2017 through a collaborative effort between state and federal agencies and non-governmental partners. This dam removal expanded free flowing hydrological conditions of the Green River approximately 9.9 RM (16 km) downstream, as well as provided river habitat connectivity with the Nolin River. The Longsolid was collected in post dam removal surveys in free-flowing reaches of the Green (Compton *et al.* 2017, p. 28). The anticipated future removal of Lock and Dam 5 downstream will continue to open up riverine habitats for freshwater mussels in the middle and lower Green River, which harbors a stronghold Longsolid population in and around Mammoth Cave National Park.

The Reservoir Release Improvement (RRI) Program, initiated by TVA in 1988, focuses on improvements in dissolved oxygen concentrations below dams, including initiating minimum flows at dams in the Tennessee River drainage (Higgins and Brock 1999, p. 4). The RRI program has resulted in improved oxygen, stable water temperatures, decreased bank erosion, and stabilization of habitat in several river systems (Scott *et al.* 1996, p. 5). Additionally, TVA has changed operations at Tims Ford Dam on the Elk River in Tennessee, which appears to have resulted in improved mussel recruitment (Howard 2017, pers. comm.). However, impacts to mussels continue to limit distribution, specifically affecting the remaining riverine habitat for the Longsolid at other Tennessee dams, including lack of seasonal variability in flow releases at Apalachia Dam, thermal regimes that are unsuitable for mussels at Cherokee Dam, and significant bank erosion and riverbed scour below Pickwick dam.

Whether constructed for purposes such as flood control, navigation, hydropower, water supply or multi-purpose uses, the construction and continued operation of dams is a pervasive negative influence on the Longsolid and its habitat throughout the range of the species. Although there have been recent efforts to remove older, failing dams such as Lock and Dam 6 on the Green River, and current plans to remove others, such as Six Mile Dam on the Walhonding River, dams and their effects on Longsolid population distribution have had perhaps the greatest documented negative influence on the species (Hardison and Layzer 2001, p. 79; Layzer *et al.* 1993, p. 68; Parmalee and Polhemus 2004, p. 239; Smith and Meyer 2010, p. 543; Hubbs 2012, p. 8; Watters and Flaute 2010, p. 2).

Dams destroy habitat, alter and disrupt connectivity, and alter water quality, all of which affect Longsolid species needs at the individual and population levels. The three stronghold populations of Longsolid are located either below (Burnsville Lake Dam, Little Kanawha River, West Virginia), above (Norris Dam, Clinch River, Tennessee and Virginia) or below and above (Lock & Dam 5, Green River Dam, Green River, Kentucky) dams. While few new dams are likely to be constructed in the 21st century, Federal mandates issued to the USACE and TVA for the maintenance and continued operation of dams (such as Sutton, Norris, and Green River Dam) make this a persistent population, basin, and rangewide threat to the Longsolid.

6.1.6 Changing Climate Conditions

Changing conditions that can influence freshwater mussels include changing water temperature and changes in precipitation patterns that increase flooding, prolong droughts, or reduce stream flows, as well as changes in salinity levels (Nobles and Zhang, 2011 pp. 147–148). An increase in the number of days with heavy precipitation over the next 25-35 years over the range of the Longsolid is expected (https://science2017.globalchange.gov/chapter/7/). Although the effects of climate change have potentially affected the Longsolid, the timing, frequency, and extent of these effects is currently unknown.

It is important to consider possible climate change impacts to Longsolid and its habitat. As mentioned in the Poff *et al.* (2002, pp. ii-v) report on Aquatic Ecosystems and Global Climate Change, impacts of climate change on aquatic systems can potentially include:

- Increases in water temperatures that may alter fundamental ecological processes, thermal suitability of aquatic habitats for resident species, and their geographic distribution, thus increasing the likelihood of species extinction and loss of biodiversity.
- Changes and shifts in seasonal patterns of precipitation and runoff which can alter the hydrology of stream systems, affecting species composition and ecosystem productivity. Aquatic organisms are sensitive to changes in frequency, duration, and timing of extreme precipitation events such as floods or droughts, potentially resulting in interference of reproduction. Further, increased water temperatures and seasonally reduced streamflow can alter many ecosystem processes, including increases in nuisance algal blooms.
- Cumulative or synergistic impacts that can occur when considering how climate change may be an additional stressor to sensitive freshwater systems, which are already adversely affected by a variety of other human impacts, such as altered flow regimes and deterioration of water quality.
- Adapting to climate change may be limited for some aquatic species depending on their life history characteristics and resource needs. Reducing the likelihood of significant impacts would largely depend on human activities that reduce other sources of ecosystem stress to ultimately enhance adaptive capacity, which could include, but not be limited to: maintaining riparian forests, reducing nutrient loading, restoring damaged ecosystems, minimizing groundwater and stream withdrawal, and strategically locating any new

reservoirs to minimize adverse effects.

- Changes in presence or combinations of native and nonnative, invasive species could result in specific ecological responses to changing climate conditions that cannot be easily predicted at this time. These types of changes (e.g., increased temperatures that are more favorable to a non-native, invasive species compared to a native species) can result in novel interactions or situations that may necessitate adaptive management strategies.
- Shifts in mussel community structure which can stem from climate-induced changes in water temperatures since sedentary freshwater mussels have limited refugia from disturbances such as droughts and floods, and since they are thermo-conformers whose physiological processes are constrained by water temperature within species-specific thermal preferences (Galbraith *et al.* 2010, p. 1,176).

Our review of the best available information indicates that the only state within the Longsolid's range to specifically identify climate change as a potential impact to the species is Pennsylvania. Within Pennsylvania, Furedi (2013, p. 14), concluded it to be extremely vulnerable to climate change using the Climate Change Vulnerability Index developed by NatureServe. This index assessed the abundance or geographic extent of the Longsolid within Pennsylvania to be extremely likely to substantially decrease or disappear by 2050 (Furedi 2013, p. 14).

Regardless of this assessment, small populations in Pennsylvania are already at an increased risk for extinction given the biological restrictions associated with small populations and reduced distribution (Furedi 2013, p. 3). Additionally, populations in Pennsylvania are near the northern and easternmost extent of the Longsolid range, and while it is likely that climate change may further magnify the factors contributing to the decline of the species (e.g., barriers and associated fragmentation), the precise locations and extent of these magnifications that may be influenced specifically by changing climate conditions are difficult to predict.

Within the range of the species, shifts in the Longsolid's species-specific physiological thresholds in response to altered precipitation patterns and resulting thermal regimes are possible. Additionally, nonnative, invasive species expansion because of climatic changes have the potential for long-term detriment to the Longsolid and its habitat. The influences of these changes on the Longsolid are possible under future condition (see scenario 3, section 7.5, below). However, the effects of landscape-level changes on long-lived sedentary species such as freshwater mussels may be difficult to observe and quantify, requiring systematic collection of data over an extended time period (Ahlstedt *et al.* 2016a, p. 4).

The best available information does not indicate that changing climate conditions within the range of the Longsolid are likely to have significant adverse effects at the population- or rangewide scales, as compared to other mussel species that reside in the southwestern U.S. where increasing temperatures and decreasing precipitation levels are predicted to be more severe. Therefore, climate change is considered a secondary factor influencing the viability of the species and is not currently thought to be a primary factor in Longsolid occurrence and distribution.

In summary, changing climate conditions are an increasing concern across the U.S. The most significant concerns to consider for the Longsolid and its aquatic habitat include the potential for alteration of the natural flow regime and thermal changes which can contribute to reduced connectivity between populations, and increased risk of stress to individuals. Other potential impacts are associated with changes in food web dynamics and the genetic bottleneck that can occur with low effective population sizes (Nobles and Zhang 2011, p. 148). At some point in the future, with dramatic alterations of the natural flow regime, changes in habitat connectivity, and other water quality impacts, the Longsolid may be affected by climate change. However, at this time the best available information does not indicate that changing climate conditions are playing a significant role in influencing the viability of the Longsolid across its range.

6.1.7 Resource Extraction

6.1.7.1 Coal Mining

Across the Longsolid's range, the most significant resource extraction impacts come from coal mining and oil and gas exploration activities. Activities associated with coal mining and oil and gas drilling can contribute chemical pollutants to streams. Acid mine and saline drainage (AMD) is created from the the oxidation of iron-sulfide minerals such as pyrite, forming sulfuric acid (Sams and Beer 2000, pp. 3). This AMD may be associated high concentrations of aluminum, manganese, zinc, and other constituents (TDEC 2014, p. 72). These metals, and the high acidity typically associated with AMD, can be acutely and chronically toxic to aquatic life (Jones 1962, p. 196). Implementation of the Surface Mining Control and Reclamation Act of 1977 (SMCRA) has significantly reduced AMD from new coal mines; however, un-reclaimed areas mined prior to SMCRA continue to generate AMD in portions of the Longsolid's range.

Abandoned mines are the source of pollution in more than 5,600 mi (9,102 km) of impaired streams in Pennsylvania (PDEP 2016, p. 51). Mine drainage affects 17 percent of stream miles in West Virginia (WVDEP 2014, p. 20), and surface mining has been identified as a source of impairment for approximately 775 mi (1,247 km) of streams in Kentucky (KDEP 2014, p. 66). More specifically, in the upper Kentucky River watershed where the Longsolid population exhibits a lack of recruitment, historical un-reclaimed mines and active coal mines are prevalent (KDEP 2014, p. 66). The Longsolid is extirpated from the Rockcastle and Caney Fork rivers in the upper Cumberland basin (See Appendix B); these drainages have experienced water quality degradation resulting from acid mine drainage and intensive surface mining activity (Layzer and Anderson 1992, p. 97). Mining continues to impair water quality in streams in the Cumberland Plateau and Central Appalachian regions of Tennessee and Kentucky (upper Cumberland River system and upper Tennessee River system) (TDEC 2014, p. 62), and is the primary source of low pH impairment of 376 mi (605 km) of stream in Tennessee (TDEC 2014, p. 53).

Coal mining has been implicated in sediment and water chemistry impacts in the Kanawha River in West Virginia, potentially limiting the Elk River Longsolid population (Morris and Taylor 1978, p. 153). Haag and Cicerello (2016, p. 20) note that water quality throughout the Big Sandy River watershed (which includes the Levisa Fork population) is seriously and profoundly degraded by coal mining. Evans (2010, p. 15) noted that coal mining has taken a toll on the mussel fauna in the Goose Creek watershed of the South Fork Kentucky River, also noting the deposition of coal fines in the South Fork Kentucky River itself. According to Ahlstedt *et al.* (2016a, p. 8), coal mining has resulted in discharges of industrial and mine wastes, black water release events, and fly-ash spills in the Clinch and Powell Rivers. Longsolid mussels were observed dead with meat inside their shells in the Clinch River from 2001-2004 with no direct cause for mortality; however, black-water release events associated with mining activity were documented in the same drainage in 2002-2003 (Ahlstedt *et al.* 2016a, p. 9). In the Powell River, studies have shown that runoff of sediments contaminated with by-products from coal mining activities as a potential factor leading to mussel declines (McCann and Neves 1992, p. 78).

Degradation and decline of the mussel fauna in the Powell River (Tennessee and Virginia), and problems stemming from the river's long history of pollution from extensive surface and subsurface headwater mining impacts have almost eliminated the freshwater mussel populations in the river. High levels of copper, manganese, and zinc, metals toxic to freshwater mussels were found in sediment samples from both the Clinch and Powell rivers, and mining impacts close to Big Stone Gap, Virginia have almost eliminated the mussel fauna in the upper Powell River, and the Longsolid is considered extirpated from the South Fork Powell River and Cane Creek, both tributaries to the upper portion of the Powell (Ahlstedt and Tuberville 1997, p. 75; Appendix D). The Longsolid was once considered common in the Powell River, but was not collected after 1988 from four sites sampled during quantitative surveys conducted from 1979-2004 (Ahlstedt *et al.* 2016a, p. 18). The species persists in the Powell River, but is now rare, and in danger of extirpation (Johnson *et al.* 2012, p. 98).

High concentrations of zinc and copper were found in sediments below a coal processing plant in the Clinch River, Virginia, resulting in reduced survival of juvenile mussels (Ahlstedt and Tuberville 1997, p. 75). The negative influence of mined land on mussels in the Clinch River has also been demonstrated through elevated levels of tissue zinc concentrations and dissolved manganese, indicating chronic mussel exposure to contaminated runoff (Van Hassel 2007, p. 323). The concentrations of toxic metals as a result of coal processing and mining activities, in addition to water quality degradation from abandoned mines, is a population-level threat to the Longsolid in the Tennessee and Ohio basins.

6.1.7.2 Natural Gas Extraction

Natural gas extraction in the Marcellus Shale (the largest natural gas field in the U.S. that runs through northern Appalachia) region has negatively affected water quality through accidental spills and discharges, as well as increased sedimentation due to increases in impervious surface and tree removal for drill pads and pipelines (Vidic *et al.* 2013, p. 6). Disposal of insufficiently treated brine wastewater, more saline than seawater, has specifically been found to adversely affect freshwater mussels (Patnode *et al.* 2015, p. 62). Contaminant spills are also a concern.

Sediment appears to be the largest impact to mussel streams from gas extraction activities (Clayton, 2018, pers. comm.). Excessive suspended sediments can impair feeding processes, leading to acute short-term or chronic long-term stress. Both excessive sedimentation and excessive suspended sediments can lead to reduced mussel populations (Ellis 1936, p. 29; Anderson and Kreeger 2010, p. 2). This sediment is generated by construction of the well pads, access roads, and pipelines (for both gas and water). The impact of pipelines crossing mussel streams through open-trenching, the preferred industry method, increases sediment load and contributes to a loss of mussel habitat through sedimentation, and the covering of appropriate substrates.

Since 2010 nearly 250 proposed pipeline crossings have had mussel surveys conducted in West Virginia, and with the boom in the gas industry, old pipelines are also being replaced on a large scale (Clayton, 2018, pers. comm.). The release of drilling mud through fracturing is an additional potential impact to rivers and streams, as well as spill of frack fluids used in the well drilling process, which are high in chlorides and other chemicals (Patnode *et al.* 2015, p. 63). These impacts have a high potential to occur in West Virginia and Pennyslvania where Longsolid populations overlap with oil and gas exploration. Tank trucks hauling such fluids can overturn into mussel streams, which recently occurred in Meathouse Fork of Middle Island Creek (Clayton 2018, pers. comm.). It is presumed that many spills go unreported. Compressor and processing plants have also been constructed. One frack fluid processing plant and associated salt landfill has been constructed in the headwaters of the North Fork Hughes River (Clayton 2018, pers. comm.). Other significant sediment impact results from bank slippage and mudslides resulting from pipeline construction, access road construction and well pad construction in mountainous terrain (Clayton 2018, pers. comm.).

6.1.7.3 Gravel Mining/Dredging

Instream sand and alluvial gravel mining has been implicated in the destruction of mussel populations (Hartfield 1993, p. 138). Negative impacts associated with gravel mining include stream channel modifications such as altered habitat, disrupted flow patterns, and sediment transport. Additionally, water quality modifications including increased turbidity, reduced light penetration, increased temperature, and increased sedimentation result from gravel mining. These habitat and water quality degradations result in reductions in macroinvertebrate population and fish populations, which suffer impacts to spawning and nursery habitat, and food web disruptions (Brown *et al.* 1998, p. 988; Kondolf 1997, p. 541). The USACE and state water quality agencies retain regulatory oversight for sand and gravel mining, but some sand, gravel, and rock mining in rivers is unmonitored.

6.1.7.4 Resource Extraction Summary

Coal mining, AMD, and the legacy effects of abandoned mine runoff are currently affecting Longsolid populations in the Ohio and Tennessee basins. Additionally, through the recent expansion of oil and gas exploration in the Marcellus Shale region and the anticipated future development of the Ithaca region, the impacts of pipeline construction, well pad installation, access road clearing are a current and future threat to Longsolid populations especially in West Virginia and Pennsylvania (Clayton, 2018, pers. comm.; Welte, 2018, pers. comm.). The presence of a large number of mine waste ponds in the Ohio and Tennessee basins increase the risk of dam and levee failure, and blowouts, resulting in mining waste covering the substrate, could be catastrophic to Longsolid populations. Although not currently considered a threat to the last remaining population in the Cumberland basin, resource extraction and acid mine drainage have been cited as a contributor to the loss of mussel species in the Cumberland basin (Haag and Cicerello 2016, p. 15). This is specifically true in the Big South Fork Cumberland River and Rockcastle River, where the Longsolid no longer occurs, and which may limit recovery opportunities in those watersheds (Ahlstedt *et al.* 2003-2004, p. 39; Layzer and Anderson 1992, p. 97).

Abandoned AMD is cited as an imminent threat to the stronghold Longsolid populations in the Clinch River, Virginia and Tennessee (Ahlstedt *et al.* 2016a, p. 11). The density of oil and gas exploration activities in the Little Kanawaha River, including secondary impacts of water withdrawal, access road construction, and pipeline construction, are an imminent threat to the the stronghold Longsolid population within this river (Clayton, 2018, pers. comm.). Additionally, direct and indirect effects of water quality degradation, pollution, and chemical toxicity as a result of active or past mining activities have been cited as affecting freshwater mussel populations throughout much of the historical and current range of the Longsolid (Haag and Cicerello 2016, pp. 9-16).

Resource extraction, including oil and gas exploration, is also affecting low and medium condition populations in French Creek, the Allegheny River, Elk River, Kanawha River, South Fork Kentucky River, and Powell River. When combined with the legacy effects of coal mining and its associated infrastructure, this is a substantive imminent threat to the species. The Slippery Rock Creek, North Fork Hughes River, Levisa Fork, and North Fork Kentucky River low condition populations are currently affected by resource extraction activities, including water quality degradation of past or present mining and current oil and gas exploration.

Commercial sand and gravel mining and dredging are currently affecting populations of the Longsolid in the Ohio (USACE 2006, p. 3-38), Tennessee (Hubbs *et al.* 2006, p. 170), and Walhonding Rivers (Hoggarth 1995-96, p. 150). These Longsolid populations are restricted primarily to tailwater reaches below locks and dams that have periodic dredging to the lock approaches and to maintain the navigation channel. The Cumberland River has also been affected by gravel mining and dredging in the past (Sickel 1982, p. 4), which results in permanent alteration of substrates and hydraulic patterns, contributing to habitat loss for freshwater mussels. Additionally, although aggregate extraction activities are closed in the Allegheny River, the long-lasting impacts of permanent habitat alteration remain (Smith and Meyer 2010, p. 542).

6.1.8 Forest Conversion

A forested landscape provides many ideal conditions for aquatic ecosystems. Depending on the structure and function of the forest, and particularly if native, natural mixed hardwood-conifer forests comprise the active river area (ARA), rain is allowed to slowly infiltrate and percolate (as opposed to rapid surface runoff), a variety of food resources enter the stream and river via leaf litter and woody debris, banks are stabilized by tree roots, habitat is created by occasional wind throw, and riparian trees shade the stream or river and maintain thermal climate.

Silvicultural activities, when performed according to strict Forest Practices Guidelines (FPG) or BMPs, can retain adequate conditions for aquatic ecosystems; however, when FPGs or BMPs are not followed, these activities can also cause measurable impacts and contribute to the myriad of stressors facing aquatic systems throughout Eastern U.S. (Warrington *et al.* 2017, p. 8). Both small and large-scale forestry activities have been shown to have a significant impact depending on the physical, chemical, and biological characteristics of adjacent streams (Allan 1995, p. 107).

Today, forests are harvested and converted for many reasons including, but not limited to: financial gain to the property owner by timber harvest, residential and commercial development, conversion for various agricultural practices, for the manufacturing of wood and paper products, and for fuel for electricity generation (Alig *et al.* 2010, p. 2; Maestas 2013, p. 1). In many cases, natural mixed hardwood-conifer forests are clear-cut, and then either left to naturally regenerate or they are planted in rows of monoculture species such as pine, which is used for the growing need for timber building supplies and pulp products (Allen *et al.* 1996, p. 4; Wear and Greis 2012, p. 13; NCFA 2017, entire).

The clearing of large areas of forested wetlands and riparian systems eliminates shade once provided by the tree canopies, exposing streams to more sunlight and increasing the in-stream water temperature (Wenger 1999, p. 35). The increase in stream temperature and light after deforestation has been found to alter the macroinvertebrate and other aquatic species richness and abundance composition in streams to various degrees depending a species tolerance to temperature change and increased light in the aquatic system (Kishi *et al.* 2004, p. 283; Couceiro *et al.* 2007, p. 272; Caldwell *et al.* 2014, p. 2196).

Sediment runoff from cleared forested areas is a known stressor to aquatic systems (e.g., Webster *et al.* 1992, p. 232; Jones III *et al.* 1999, p. 1,455; Broadmeadow and Nisbet 2004, p. 286; Aust *et al.* 2011, p. 123). The physical characteristics of stream channels are affected when large quantities of sediment are added or removed (Watters 2000, p. 263). Mussels and fish are potentially affected by changes in suspended and bed material load, bed sediment composition associated with increased sediment production and runoff in the watershed, channel changes in form, stream crossings, and inadequately buffered clear-cut areas, all of which can be significant sources of sediment entering streams (Taylor *et al.* 1999, p. 13).

Many forestry activities are not required to obtain a CWA 404 permit, as silviculture activities such as harvesting for the production of fiber and forest products are exempted (EPA 2018, p. 1). Because forestry activities often include the construction of logging roads through the riparian zone, this can directly degrade nearby stream environments (Aust *et al.* 2011, p. 123). Logging roads constructed in wetlands adjacent to headwater drains and streams fall into this exemption category, but may affect the aquatic system for years, as these roads do not always have to be removed immediately. Roads remain as long as the silviculture operation is ongoing, thus wetlands, streams, or ditches draining into the more sensitive areas may be heavily affected by adjacent fill and runoff if BMP or FMP fail or are not maintained, causing sedimentation to travel downstream into more sensitive in-stream habitats. Stream crossings tend to have among the lowest implementation (Warrington *et al.* 2017, p. 9). Requirements maintain that flows are not to be restricted by logging roads, but culverts are only required per BMP and FMP and are not always adequately sized or spaced, or properly installed.

Forestry practices that do not follow BMP and FMP can influence natural flow regime, resulting in altered habitat connectivity. Logging staging areas, logging ruts, and not replanting are all associated impacts that are a threat to downstream aquatic species. BMP and FMP typically require foresters to ensure that discharge shall not take, or jeopardize the continued existence of, a threatened or endangered species, or adversely modify or destroy the critical habitat of such species, and to ensure that adverse impacts to the aquatic environment are minimized. However, foresters are not required to consult with appropriate state or Federal agencies regarding sensitive species, though consultation typically results in beneficial measures that best reduce potential impacts prior to moving forward with management activities.

Around the turn of the 21st century, biologists, foresters, and managers recognized the need for wholesale implementation of BMP and FMP to address many of the aforementioned issues related to forest conversion and silvicultural practices. Currently, forestry BMP and FMP manuals suggest planning road systems and harvest operations to minimize the number of stream crossings. Proper construction and maintenance of crossings reduces soil erosion and sedimentation with the added benefit of increasing harvest operation efficiency (NCASI 2015, p. 2).

Monoculture stands can influence overall water cycle dynamics (e.g., increased evapotranspiration and overall reduced stream flows) (Swank and Miner 1968, entire; Swank and Douglass 1974, entire), as well as result in a reduced biodiversity in the canopy, middle and understory vegetation, and fauna that use the area. Furthermore, the aquatic habitats of streams in these monoculture forested areas lose heterogeneity in food resources due to reduced variety in allochthonous (i.e., energy inputs derived from outside the stream system, or leaf matter that falls into stream) inputs, and this effect is mirrored among invertebrate and fish populations, including filter-feeding mussels and benthic insectivorous fish and amphibians (Webster *et al.* 1992, p. 235; Allan 1995, p. 129; Jones III *et al.* 1999, p. 1,454).

6.2 Invasive and Non-native Species

Approximately 42 percent of Federally Threatened or Endangered species are estimated to be significantly affected by nonnative, nuisance species across the nation, and nuisance species are significantly impeding recovery efforts for them in some way (NCANSMP 2015, pp. 8–9). When a nonnative species is introduced into an ecosystem, it may have many advantages over– native species, such as easy adaptation to varying environments and a high tolerance of living conditions that allow it to thrive in its new habitat. There may not be natural predators to keep the nonnative species in check; therefore, it can potentially live longer and reproduce more often, further reducing the biodiversity in the system. The native species may become an easy food source for invasive species, or the invasive species may carry diseases that extirpate populations of native species. Examples of non-native species that affect freshwater mussels like the Longsolid are the Asian Clam (*Corbicula fluminea*), Zebra Mussel (*Dreissena polymorpha*), Quagga Mussel (*Dreissena bugenis*), Black Carp (*Mylopharyngodon piceus*), Didymo (a.k.a. rock snot; *Didymosphenia geminata*), and Hydrilla (a.k.a. water-thyme; *Hydrilla verticillata*).

The Asian Clam alters benthic substrates, may filter mussel sperm or glochidia, competes with native species for limited resources, and causes ammonia spikes in surrounding water when they die off en masse (Scheller 1997, p. 2). The Asian clam is hermaphroditic, enabling fast colonization and is believed to practice self-fertilization, enabling rapid colony regeneration when populations are low (Cherry *et al.* 2005, p. 378). Reproduction and larval release occur biannually in the spring and in the late summer. A typical settlement of the Asian clam occurs with a population density ranging from 100 to 200 clams per square meter, which may not be detrimental to native unionids; however, populations can grow as large as 3,000 clams per square meter, which would influence both food resources and competition for space for the Longsolid. Asian clams are prone to have die-offs that reduce available dissolved oxygen and increase ammonia, which can cause stress and mortality to the Longsolid (Cherry *et al.* 2005, p. 377).

Dreissenid mollusks, such as the Zebra Mussel and Quagga Mussel, are a threat to native freshwater mussels. These nonnative mollusks are known to occur in the Great Lakes, Ohio, Tennessee, and the St. Lawrence River basins. Mussels, such as the Longsolid, are adversely affected by Dreissenids through direct colonization, reduction of available habitat, changes in the biotic environment, or a reduction in food sources (MacIsaac 1996, p. 292). Zebra mussels are listed by Congress by statute as Injurious Wildlife under the Lacey Act (*https://www.fws.gov/injuriouswildlife/pdf_files/Current_Listed_IW.pdf)*. Zebra mussels are also known to alter the nutrient cycle in aquatic habitats, affecting other mollusks and fish species (Strayer *et al.* 1999, p. 22).

Since its introduction in the Great Lakes in 1986, zebra mussel colonization has resulted in the decline and regional extirpation of freshwater mussel populations in lakes and river systems across North America (Schloesser *et al.* 1996, p. 303; Schloesser *et al.* 1998, p. 300). One of the direct consequences of the invasion of zebra and quagga mussels is the local extirpation of native freshwater mussel populations from: (1) attachment to the shells of native mussels, which can kill them (dreissenid mussels are sessile, and cling to hard surfaces); (2) affecting vertical and lateral movements of mussels, due to heavy infestations which can prevent valve closure; and (3) outcompeting native mussels and other filter feeding invertebrates for food. This problem has been particularly acute in some areas of the U.S. that have a very rich diversity of native freshwater mussel species, such as the Ohio and Tennessee River systems. Densities of Zebra mussels attained 17,000 per square meter in the Tennessee River below Wilson Dam in 2017, although recent survey efforts indicate a decline from that population explosion (Garner 2018, pers. comm.).

The two nonnative plant species that are most problematic for the Longsolid are hydrilla and didymo, but golden alga, (*Prymnesium parvum*), a marine algae, has spread into the upper Ohio River basin and is a potential threat to mussel populations, particularly during low-flow years and if coupled with brine discharges (Anderson and Kreeger 2010, p. 9). Hydrilla is an aquatic plant that alters stream habitat, decreases flows, and contributes to sediment buildup in streams (NCANSMP 2015, p. 61). High sedimentation can cause suffocation, reduce stream flow, and make it difficult for mussels' interactions with host fish necessary for development.

Hydrilla can quickly dominate native vegetation, forming dense mats at the surface of the water and dramatically altering the balance of the aquatic ecosystem. Hydrilla covers spawning areas for native fish and can cause significant reductions in stream oxygen levels (Colle *et al.* 1987, p. 410). Hydrilla is widespread in the Ohio, Cumberland, and Tennessee River systems. Second, didymo or "rock snot" is a nonnative alga (diatom) that can alter the habitat and change the flow dynamics of a site (Jackson 2016, p. 970). Invasive plants grow uncontrolled and can cause the habitat to fill in, they can affect flow dynamics, and cause the water to become warmer, and can even dry out completely, especially in drought situations (Colle *et al.* 1987, p. 416).

Black Carp, a molluscivore, has been reported in Arkansas, Illinois, Mississippi, and Missouri (Nico *et al.* 2005, p. 155), has been established in Louisiana since the early 1990s, and was observed most recently in 2018 in Tennessee and Kentucky (Nico and Neilson 2018, USGS Nonindigenous Aquatic Species Database). The Black Carp is listed as Injurious Wildlife under the Lacey Act. The species is present in the lower Ohio, Cumberland, and Tennessee River systems where it co-occurs with the Longsolid. There is high potential that the Black Carp will negatively impact native aquatic communities by direct predation, and thus reducing, populations of native mussels and snails, many of which are considered endangered or threatened (Nico *et al.* 2005, p. 193).

Given their size and diet preferences, Black Carp have the potential to restructure benthic communities by direct predation and removal of algae-grazing snails. Mussel beds consisting of smaller individuals and juvenile recruits are probably most vulnerable to being consumed by black carp (Nico *et al.* 2005, p. 192). Furthermore, because Black Carp attain a large size (well over 3.28 ft (1 m) long), and their life span is reportedly over 15 years, they are be expected to persist many years and therefore have the potential to cause significant harm to native molluscs by way of predation to multiple age classes (Nico *et al.* 2005, p. 77).

The Aquatic Nuisance Species (ANS) Task Force, co-chaired by the Service and the National Oceanic and Atmospheric Administration (NOAA), encourages state and interstate planning entities to develop management plans describing detection and monitoring efforts of aquatic nuisance and nonnative species, prevention efforts to stop their introduction and spread, and control efforts to reduce their impacts. Management plan approval by the ANS Task Force is required to obtain funding under Section 1204 of the ANS Prevention and Control Act. Regardless of financial incentives, plans are a valuable and effective tool for identifying and addressing ANS problems and concerns in a climate of many jurisdictions and other interested entities. Each state within the range of the Longsolid has either a plan approved by or submitted to the ANS Task Force, or a plan under development. These plans have been effective in terms of raising awareness at the state level of the severity of ecological damage that non-native and nuisance species are capable of, but many are in early stages of implementation.

Asian clams are present throughout the range of the Longsolid, and the competitive interactions and effects of their massive die-offs have been documented, but the complete impacts of these non-native bivalves on native unionids is not completely understood. The arrival and proliferation of the zebra mussel in the Ohio River in the early 1990s corresponded with a significant decline in native freshwater mussel populations (Watters and Flaute 2010, p. 1). The decline and extirpation of native freshwater mussels in the Great Lakes and its tributaries has been attributed to zebra mussel invasion (Schloesser *et al.* 2006, p. 307). Zebra and quagga mussel densities are highly variable annually, and may depend on discharge rates, water temperatures, and settlement location, as well as predator presence (Cope *et al.* 2006, p. 185).

Although there are non-native species present throughout the range of the Longsolid in the Ohio, Cumberland, and Tennessee River basins, the greatest concentration of non-native species that has the potential to affect mussels is in the lower Tennessee and lower Ohio River basin. These non-native species discussed above affect Longsolid individuals through competitive interactions, water quality degradation, predation, and habitat alteration. All low condition Longsolid populations in the lower Ohio River (6) are currently affected by the non-native vegetation, fish, and mollusks listed above. The medium condition Longsolid population in the lower Tennessee River below Kentucky Dam and the low condition population in the lowermost Tennessee River are also directly affected by established populations of these species. In summary, the presence of non-native species is a substantial threat to the Longsolid throughout its range, but the concentration of non-native species in the lower Ohio and Tennessee rivers is most problematic.

6.3 Harvest and Overutilization

Although not currently considered an imminent threat, the harvest of Longsolid, and references to the commercial value of the species are mentioned in Böpple and Coker (1912, p. 5), Coker (1919, p. 22), Danglade (1922, p. 5), Isom (1969, p. 402), Dennis (1984, p. 86), Cochran and Layzer (1993, p. 63), Cummings *et al.* (1992, p. 46), Watters and Dunn (1993-94, p. 252), and Williams *et al.* (2008, p. 54). Commercial harvest associated with the button and pearl industries of the 19th and 20th centuries, as well as the search for native pearls, likely contributed to the decline of freshwater mussels in the Ohio, Cumberland, and Tennessee basins (Anthony and Downing 2001, p. 2,072).

Native Americans harvested mussels for food. There is no documentation regarding harvest of the Longsolid in particular, but it was likely included among their catch. The species was collected by pearlers circa 1900 and other commercial interests in later times due to the extensive harvest that occurred within the species range (Anthony and Downing 2001, p. 2,073). Although not one of the most actively sought species for pearls, the Longsolid was sacrificed for this purpose (Böpple and Coker 1912, p. 5). The species was regarded as one of the best shells for buttons in the lower Cumberland River (Coker 1919, p. 22). Additionally, Wilson and Clark (1914, p. 9) documented many portions of the Cumberland River where large piles with tons of shells were left on streambanks by pearlers hoping to get rich quick. Single beds were sometimes harvested for pearls a decade or more by pearlers. Böpple and Coker (1912, p. 10) reported a particularly habitat disruptive method of harvest where “a plow drawn by a strong team” was sometimes used in shallow Clinch River shoals, enabling pearlers to pick up mussels that had been buried in the substrate. Considering that perhaps only 1 in 15,000 mussels may produce a commercially valuable pearl, it may be safe to assume that hundreds of thousands, if not millions, of mussels were needlessly sacrificed by harvesters over several decades (Anthony and Downing 2001, p. 2,073).

Despite the alarm generated over exploitation events in historical times, the collective impact from human harvest of mussels’ pales in the shadow of the impacts realized from habitat alteration. It is unlikely that exploitation activities have eliminated Longsolid populations, but rather, they have potentially contributed to the species’ historical decline. The Longsolid is not currently a commercially valuable species, but it may be inadvertently harvested as “by catch” or by inexperienced mussel collectors unfamiliar with commercial species identification. Mussel harvest is illegal in some states within the species historical and current range (e.g., Indiana, Ohio, West Virginia), and regulated in others (e.g., Pennsylvania, North Carolina). Most states with active commercial harvest allow mussel harvesters to dive for mussels. In Kentucky, mussels may legally be harvested only by brail (i.e., dragging poles with hooks drug along the bottom of a river). Most states that allow commercial harvest, such as Alabama, Kentucky, and Tennessee, have established mussel sanctuaries where harvest is prohibited. Sanctuaries are generally associated with beds that have State or federally listed mussels in them.

Watters and Dunn (1993-94, p. 252), specifically mention the Longsolid's commercial value, and attribute significant decline of the Longsolid from previous surveys to potential over-harvest in the lowermost mussel bed in the Muskingum River, which previously harbored substantial large numbers of the species. A recent survey of the lower Muskingum River by ESI reported collection of only one live Longsolid at 1 of 10 sites, and it was considered to be aged 26 to 30 years (ESI 2012, p. 127). A potential explanation of the increasing rarity of the Longsolid and other riverine mussels in the Muskingum River may be a result of years of intensive commercial activity. Although illegal harvest of protected off-limits mussel beds occurs rangewide, commercial harvest is not thought to currently have a significant impact on the Longsolid. The Muskingum River may at least in part serve as an example of the impacts of threats such as habitat fragmentation and loss combined with previous intensive collection activities on freshwater mussels. Most river and stream reaches inhabited by this species are restricted, and its populations are relatively small in density (see Appendix A). Overall, the future potential direct threat of harvest and overutilization is minimal, and a small fraction of what it was 20 years ago, and not likely to be an issue for the future long-term viability of the Longsolid.

6.4 Genetic Isolation and Displacement

Longsolid exhibit several inherent traits that influence population viability, including relatively small population size and low fecundity at many locations compared to other mussels (see Appendix A). Longsolid prefer sites with clean, flowing water and stable substrates (see sections 4.1.1-4.1.3) and are not often abundant within their occupied habitats. Smaller population size puts the species at greater risk of extirpation from stochastic events (e.g., drought) or anthropomorphic changes and management activities that affect habitat. In addition, smaller populations may have reduced genetic diversity, be less genetically fit, and more susceptible to disease during extreme environmental conditions (Frankham 1996, p. 1,505).

Genetic drift occurs in all species, but the lack of drift is more likely to negatively affect populations that have a smaller effective population size (number of breeding individuals) and populations that are geographically spread out and isolated from one another. Relatively low fecundity, commonly observed in species of *Fusconaia*, is another inherent factor that could influence population viability (Geist 2010, p. 91). Survival of juveniles in the wild is already low and females produce fewer offspring than other mussel species (Haag and Staton 2003, p. 2,125). Factors such as low effective population size, genetic isolation, relatively low levels of fecundity and recruitment, and limited juvenile survival could all affect the ability of this species to maintain current population levels and to rebound if a reduction in population occurs (e.g., predation, toxic releases or spills, poor environmental conditions that inhibit successful reproduction). Additionally, based on our presumption of fish hosts of the Longsolid, they are small-bodied fishes that have comparatively limited movement (Vaughn 2012, p. 6); therefore, natural expansion of Longsolid populations is limited.

Fragmentation and isolation contribute to the extinction risk that mussel populations face from stochastic events (see Haag 2012, pp. 336-338). Streams are naturally dynamic, frequently creating or shifting areas of quality habitat over a particular period. A number of factors, most of which interact to create stable patches of suitable and unsuitable mussel habitat, bring about habitat fragmentation (natural and human-induced) in stream systems. The definition of fragmentation is the breaking apart of habitat segments, independent of habitat loss (Fahrig 2003, p. 499). Some causes, like barriers, directly and permanently fragment habitat. Other sources, like drought, water quality, host fish movement, substrate stability, adjacent land use, etc., lead to increasing stream fragmentation in more subtle and interdependent ways.

In dendritic landscapes, such as streams and rivers, these may lead to multiple fragments of variable size (Fagan 2002, p. 3,247). In contrast to landscapes where multiple routes of movement among patches are possible, pollution or other habitat degradation at specific points in dendritic landscapes can completely isolate portions of the system (Fagan 2002, p. 3,246). Connectivity between patches (mussel beds or occupied habitat) is important in landscapes where these patches of suitable habitat are created or destroyed frequently. Where populations are small, local extinction caused by demographic stochasticity (e.g., changes in the proportion of males and females, the reproductive potential of females, survival of individuals) happens often, and populations must be re-established by colonization from other patches. Given that these conditions may apply to many lotic mussel populations, connectivity of mussel populations and their required resources is an important factor to consider for Longsolid persistence (Newton *et al.* 2008, p. 428).

Impoundments have been identified as resulting in the genetic isolation of fishes, which act as hosts, and mussel populations (Vaughn 2012, p. 6; also see section 6.1.5, above). Perched or improperly maintained culverts at stream crossings can also act as significant barriers (see section 6.1.2 and 6.1.5, above), and have similar effects as dams on stream systems. Fluctuating flows through a culvert can differ significantly from the rest of the stream, preventing fish passage and scouring downstream habitats. The likelihood is high that some Longsolid populations are below the effective population size required to maintain long-term genetic and population viability (see Chapter 5, above and Appendix A). Recruitment reduction or failure is a potential problem for many small Longsolid populations rangewide, a potential condition exacerbated by its reduced range and increasingly isolated populations.

A once extensive Longsolid population occurred through much of the Ohio, Cumberland, and Tennessee River basins, as well as the Great Lakes basin prior to its extirpation there. On a geological scale, there were limited barriers preventing genetic interchange among its tributary sub-populations. With the completion of hundreds of dams in the 1900s, many main stem Longsolid populations were lost, resulting in isolation of tributary populations. The population size of a long-lived species, such as the Longsolid, may potentially take decades to become extirpated post-impoundment, even if recruitment failure had been complete since dam construction. At best, limited post-impoundment recruitment may be occurring in many isolated Longsolid populations, indicating that these small populations are probably not viable long-term.

Without the level of genetic interchange the species experienced historically (i.e., without barriers such as reservoirs), small isolated populations that may now be comprised predominantly of adult individuals could be slowly dying out. Even given the very improbable absence of other anthropogenic threats, these disjunct populations could be lost simply due to the consequences of below-threshold effective population sizes. However, the best available information suggests that general degradation of many isolated stream reaches is continuing to result in ever decreasing patches of suitable habitat. Thus, these threats appear to be acting insidiously to contribute to the decline of Longsolid populations over time (Butler 2005, p. 114).

Because only 60 primarily disjunct streams among 162 historically occupied areas continue to harbor populations of the Longsolid, this is likely partial testimony to the principle of effective population size and its role in population loss. The rarity displayed by most Longsolid populations creates challenges for resource managers to incorporate conservation measures that address many of the genetic issues associated with maintaining a high level of genetic diversity.

6.5 Factors Currently Believed To Have Limited Effects on Longsolid Populations

At this time, our analysis of the best available scientific and commercial information suggest that impacts to host fish, disease, parasites, and predation are not likely resulting in population- or rangewide-level impacts to the Longsolid. Some of these impacts may be influencing Longsolid individuals in specific locations, and examples are given below.

6.5.1 Host Fishes

The overall distribution of mussels is, in part, a function of the dispersal of their host fish. There is limited potential for immigration between populations other than through the attached glochidia being transported to a new area or to another population (see section 4.2.3, above). The Longsolid depends on host fish for dispersal, therefore, barriers such as dams limit recolonization potential (see section 6.1.5, above). Small populations are more affected by this limited immigration potential because they are susceptible to genetic drift, resulting from random loss of genetic diversity, and inbreeding depression (Geist 2010, p. 78). Populations that are eliminated due to stochastic events cannot be recolonized naturally, leading to reduced overall redundancy and representation.

The presumed primary host fish species for the Longsolid are known to be common, widespread riverine minnow and sculpin species in the Ohio, Cumberland, and Tennessee basins. Families of host fishes known for the genus *Fusconaia* require clean flowing water over mixed substrates and are intolerant of impoundment (Bruenderman and Neves 1993, p. 89; Haag 2012, p. 347). Factors that contribute to habitat loss and water quality degradation of Longsolid such as dams, fragmentation, resource extraction, contaminants, and nonnative species are considered to act simultaneously on its host fish.

In the French Broad River, Tennessee, the continued operation of Douglas Dam limits the occurrence and abundance of mid-water column cyprinids, through reduced habitat under hydropeaking flows, limiting the restoration potential of the Longsolid below Douglas Dam (Layzer and Scott 2006, p. 489). Similar conditions likely limit host fish abundance and distribution in the Holston and Hiwassee rivers downstream of Cherokee Dam and Apalachia Dam, respectively (Parmalee and Faust 2006, p. 74; Ahlstedt *et al.* 2016b, p. 3). The greatest concentration of hydropower dam operation and its effects on host fishes for the Longsolid is within the upper Tennessee River system on the French Broad, Holston, and Hiwassee rivers. Conditions that reduce available fish hosts at Cherokee, Douglas, and Apalachia dams also likely affect Longsolid occurrence in all impounded rivers.

The threat of limited host fish availability under these conditions is influenced by impoundment and dam operations, in addition to cyprinid distributional limitations. Therefore, the best available scientific and commercial information suggests that the availability and distribution of host fish is not a limiting factor in Longsolid distribution throughout its entire range, but rather in specific locations in the Tennessee River basin. Populations of mussels and their host fish have become isolated over time following the construction of major dams and reservoirs throughout the range of the Longsolid.

6.5.2 Enigmatic Population Declines

Mussel populations occasionally experience declines in the absence of obvious severe point or non-point source pollution or severe habitat loss and destruction. These declines are termed enigmatic population declines, due to their mysterious and currently puzzling nature (Haag 2012, p. 341). The cause of these die-offs is unknown, but researchers suspect disease may be a factor (Grizzle and Brunner 2009, p. 454). Contaminants which are not easily observable, such as metals bound in sediments, a result of past land use, could also be a contributor (Price *et al.* 2014, p. 855). Such declines have occurred within rivers and streams occupied by the Longsolid (Neves 1987, p. 9). Fish and aquatic insect communities in locations where these mussel die-offs have been documented remain relatively intact; however, juvenile mussels are sensitive to the unknown factors causing the declines, and the Longsolid is likely affected (Haag 2012, p. 342).

Mussel die-offs of unknown origin have been observed since at least the 1980s and continue to occur, particularly in the eastern U.S. (Neves 1987, p. 9). They were documented in the Clinch (1986-1988) and Powell (1982-1986) rivers in past decades (Ahlstedt *et al.* 2016a, p. 9) and as recently as 2016–2017 in the Clinch River, Tennessee and Big Darby Creek, Ohio (Richard 2018, p. 2). A long-term monitoring site on the Elk River in West Virginia indicates the Longsolid has been exhibiting no recruitment and unexplained mortality since 2004 (ESI 2009, p. 19; Clayton, 2018, pers. comm.). The Longsolid is considered extirpated from the Embarras River in Illinois and Big Darby Creek in Ohio, both of which have experienced dramatic mussel population declines. Mussel abundance declined 86 percent from 1955 to 1987 in the Embarras River, and the recent die-off in Big Darby Creek remains unexplained (Cummings *et al.* 1988, p. 9; Haag 2012, p. 341; Richard 2018, p. 16).

6.5.3 Parasites

Mussel parasites include water mites, trematodes, leeches, bacteria, and some protozoa (Grizzle and Brunner 2009, p. 433). Although these organisms are generally not suspected to be a major limiting factor for mussel populations in general, reproductive output can be negatively correlated with mite abundance, and physiological condition is negatively correlated with trematode abundance Gangloff *et al.* (2008, p. 28). Trematodes live directly in mussel gonads and may negatively affect gametogenesis. It is possible mussels are more susceptible to parasites after anthropogenic factors reduce their fitness (Henley 2018, pers. comm.).

6.5.4 Predation

Native Americans extensively harvested freshwater mussels for food (Morrison 1942, p. 348; Bogan 1990, p. 112), though among mussel predators, the muskrat (*Ondatra zibethicus*) is probably cited most often (Tyrrell and Hornbach 1998, p. 301). Based on a study of muskrat predation on imperiled mussels in the upper North Fork Holston River in Virginia, Neves and Odom (1989, p. 939) concluded that this activity could limit the recovery potential of endangered mussel species or contribute to the local extirpation of already depleted mussel populations. Ninety-six specimens of Longsolid were collected from muskrat middens in the Clinch River at Slant, Virginia, 1984–1985, and 27 specimens of the species were collected from muskrat middens in Mammoth Cave National Park on the Green River in Kentucky in 2002–2003, indicating that the species is vulnerable to mammal predation in stronghold and likely other populations (Bruenderman 1989, p. 11; Hersey *et al.* 2013, p. 255).

Predation by muskrats may represent a seasonal and localized threat to the Longsolid but not a significant one unless the population is at a critically low number of individuals. Since muskrat predation is size-selective, this threat is considered to be more likely to affect individuals rather than at a population level. Although other mammals such as raccoon, mink, otter, hogs, rats, turtles, and aquatic birds occasionally feed on mussels, the threat from these species is not currently deemed significant (Tyrrell and Hornbach 1998, p. 301). Some species of native fish, such as Freshwater Drum (*Aplodinotus grunniens*) and Redear Sunfish (*Lepomis microlophus*) feed on mussels, and potentially upon young of this species; however, predation by Black Carp (*Mylopharyngodon piceus*) is considered a greater threat since they attain a greater size and live comparatively longer and have not co-evolved with Longsolid populations (see Section 6.2, above).

According to Zimmerman *et al.* (2003, p. 28), flatworms are voracious predators on newly metamorphosed juvenile mussels in culture facilities. Young juveniles may also fall prey to various other invertebrates such as *Hydra*, non-biting midge larvae (Chironomidae), dragonfly larvae (Odonata), and crayfish (*Cambarus* spp.). Based on the current available information, we determined the overall threat posed by vertebrate and invertebrate predators of the Longsolid in most instances is less significant than other threats that are currently influencing population status rangewide.

6.6 Overall Summary of Factors Affecting the Species

Factors discussed in this chapter which are currently affecting the Longsolid include those that are systemic and contribute to the greatest threats to the species throughout its range: habitat loss and alteration, water quality impairment, and more site-specific threats, such as invasive species. The topics discussed in this chapter are reflective of the best available information as it pertains to the Longsolid; there may be other factors we are unaware of, or for which data are currently lacking.

Impacts to freshwater mussels, and benthic riverine aquatic organisms in general, often involve multiple interrelated actions, involve compounded stressors, and rarely lack a single causative agent, therefore they are not easy observe and may be difficult to quantify after they occur. While factors such as climate change, host fish availability, disease, or predation may affect the species currently or in the future, we do not have sufficient data or information to suggest that these are currently contributing to Longsolid decline. Commercial harvest was likely a significant threat which previously contributed to species decline, but it is not currently directly affecting the Longsolid, and is unlikely to be a future threat.

The current resiliency, redundancy, and representation of the Longsolid is directly tied to population and habitat fragmentation by the construction of impoundments throughout the species' range. Hypolimnetic discharges downstream from dams continue to impact populations specifically in the Tennessee and Cumberland river basins. Impoundments fragment and isolate populations from one another, prevent dispersal which reduces gene flow, and compounds stressors such as the introduction of contaminants and pollution; whether the result of mining, oil and gas exploration, agricultural runoff, or untreated or poorly treated wastewater discharges.

The threats to the Longsolid are synergistic, and result in effects to individuals and populations at a more rapid rate. The combined impacts of dams and barriers, resource extraction, agricultural activities, and non-native species have led to localized extirpations of the Longsolid, and a cumulative loss of 63% of its formerly occupied range.

CHAPTER 7 - FUTURE CONDITIONS

This chapter summarizes our evaluation of what the species' likely future conditions will be, and applies these forecasts to the concepts of resiliency, representation, and redundancy to describe future Longsolid viability.

The Longsolid occurs in rivers and streams of differing widths and lengths in the Ohio, Cumberland, and Tennessee basins (Ortmann 1920, p. 275; Williams *et al.* 2008, p. 321). Early naturalists recognized mussel shape and form in the Ohio River drainage in particular was highly variable and somewhat dependent on the location and the stream where the species was found. The Longsolid is a species that has a more compressed headwater form, a more inflated, or swollen large-river form, with intergrades of these two in medium-sized rivers Ortmann (1925, p. 328). With regard to the range of stream sizes occupied by the Longsolid, the species' current condition includes populations within small streams such as Oswayo Creek in the Ohio basin and Indian and Hurricane creeks in the Tennessee basin. Mussels which attain a larger size in big rivers, such as Longsolid, in many situations, where they occur in smaller streams, usually exist near their mouths, where they have ready access to a larger parent stream.

The species has greater numbers of populations in medium rivers, such as the South Fork Kentucky River. The Longsolid was categorized as a component of a medium river mussel assemblage by Evans (2010, p. 13), who generally characterized the species as being found at locations where the drainage area was greater than 463 ac^2 (1,200 km^2). However, the Ohio River at its mouth has a drainage area of 304,845 km^2, and the lower main stem Ohio River has relatively recent records of the species, which were included in our analyses (Haag and Cicerello 2016, p. 138; Appendix A). This wide variation in river and stream occupation by Longsolid is difficult to characterize succinctly, so for the purposes of future condition scenarios, populations of the species are generalized in three categories according to drainage size & area; streams & small rivers (less than 463 square miles (1,200 km^2)), medium rivers (463–4,633 square miles (1,200–12,000 km^2)), and large rivers (greater than 4,633 square miles (12,000 km^2)).

7.1 Future Scenario Considerations

The factors influencing the viability of Longsolid include: (1) habitat alteration or loss, (2) water quality degradation, (3) invasive and non-native species (4) genetic isolation and displacement. Each of these factors are expected to continue into the future at varying degrees, depending on the populations and locations across the landscape (e.g., some sources of habitat degradation or loss are likely to be more significant in some populations than others). We attempted to discern this variance by using the best available information on proposed projects, modeling efforts (e.g., climate change/RCP models). To the best of our knowledge, commercial harvest of freshwater mussels, although a likely contributor to the decline of the Longsolid, is unlikely to occur in the future due to more strict regulation of harvest and the depressed global demand for shells.

7.2 Future Scenarios

We forecast the Longsolid's future conditions, in terms of resiliency, representation, and redundancy, under three plausible future scenarios. These three scenarios forecast the Longsolid's viability over approximately 50 to 70 years, a range representing two generations. We concentrated on this duration because: (1) The species is relatively long-lived (25 to 35 years); and has relatively low fecundity (see section 3.3, above)); and (3) long-term trend information on Longsolid abundance and threats is not available across the species' range to contribute to meaningful alternative timeframes. Given there are 60 populations and 45 MUs under consideration, we describe the threats that may occur at the scale of each within the Ohio, Cumberland, and Tennessee basins, the three major basins the species currently inhabits. Threats either remain constant from current conditions (scenario 1), conditions improve (scenario 2), or become worse (scenario 3). Additionally we provide specific population or river examples where possible to demonstrate potential impacts.

Resiliency of Longsolid populations depends on future water quality, availability of flowing water, substrate suitability, abundance and distribution of host fish species, and habitat connectivity. We expect Longsolid populations to experience changes to these resource needs in different ways under the different scenarios. We project the expected future resiliency of each population based on events likely to occur under each scenario. We did not include an assessment of reproduction for the future scenarios; rather, the abundance of the populations in the future reflects whether reproduction, and more importantly, recruitment, are occurring. We also project an overall condition for each population as either High, Medium, Low, or Very Low (see Table 7-1 for definitions).

Table 7-1. Population and Habitat condition categories used to determine the overall projected future conditions of Longsolid populations and MUs.

Future Condition Category	**Description**
High condition populations and MUs	Resilient populations generally distributed over a significant and more or less contiguous length of stream (greater than or equal to 30 river miles), with evidence of recruitment and multiple age classes represented. Likely to maintain viability and connectivity among populations. Populations are not linearly distributed (i.e., occur in tributary streams within a management unit). These populations are expected to persist in 50 to 70 years and beyond and withstand stochastic events. (*Thriving; capable of expanding range*.)
High condition habitats	Water quality meets designated uses and contiguous reaches with clean, mixed sand, gravel, and cobble substrates without excessive silt are predominant. Stable habitats available for population expansion.
Medium condition populations and MUs	Spatially restricted populations with limited levels of recruitment or age class structure. Individuals occur in tributary streams, such that within a MU, populations are not linearly distributed. Resiliency is less than under high conditions, but the majority (approximately 75 percent) are expected to persist in 50 to 70 years. (*Stable, not necessarily thriving or expanding its range.*)
Medium condition habitats	Mixed sand, gravel, and cobble substrates free of excessive silt are maintained in stable shoals, and naturally variable water levels are maintained in currently occupied rivers and streams. Lowered water quality and habitat degradation may occur but not at a level that negatively affects both the density and extent of mussel distribution.
Low condition populations and MUs	Small and highly restricted populations, with no evidence of recent recruitment or age class structure, and limited detectability. These populations have low resiliency, are not likely to withstand stochastic events, and potentially will no longer persist in 50 to 70 years. Populations are linearly distributed within a management unit. (*Surviving, observable; but population likely declining*.)
Low condition habitats	Loss of mussel habitat or water quality degradation within the formerly occupied river or stream reach has been measured or observed. Altered thermal regimes potentially limit reproduction and colonization.
Very Low condition populations and MUs *(Future Condition Only)*	Populations are expected to no longer occur in a river/stream or management unit in the future (50–70 years). A population may be below detectable levels despite consistent survey effort within its formerly occupied range. Previous evidence of population limited to relic or weathered dead shells. (*No survival or survival uncertain; no longer observable*.)
Very Low condition habitats *(Future Condition Only)*	Contiguous mussel habitat with clean, silt-free substrates have been lost or covered in sediment. Water quantity and quality limits colonization and reintroduction potential.

For each scenario, we used best judgement based on the best available scientific and commercial information to determine the likelihood that a particular condition would apply in 50 to 70 years. For example, we used state, city, and county development planning documents, peer-reviewed literature projections, mussel expert advice and input, and our best professional judgement. We used the scale in Table 7-2, below, to estimate these likelihoods.

Table 7-2. Explanation of confidence terminologies used to estimate the likelihood of a particular future condition category.

Confidence Terminology	Explanation
Highly likely	We are more than approximately 90 percent certain this condition category will occur.
Moderately likely	We are approximately 50 to 90 percent certain this condition category will occur.
Somewhat likely	We are less than approximately 50 percent certain this condition category will occur.

7.3 Scenario 1

Under this scenario, factors influencing current Longsolid populations are assumed to remain constant into the future.

Factors influencing Longsolid populations are assumed to remain constant into the future for the next 50 to 70 years, including existing habitat degradation and beneficial conservation actions, and climate and hydrological conditions. This scenario assumes the current levels of translocation and monitoring capacity are consistent (i.e., population augmentation is not currently taking place).

Scenario 1 assumes that existing patterns and rates of land use changes continues across the species' range (Lawler *et al.* 2014, p. 56), including urban growth and changes in agricultural practices (Lasier *et al.* 2016, p. 672; Newton *et al.* 2008, p. 434; Terando *et al.* 2014, p. 4). This scenario also assumes that existing regulatory mechanisms and voluntary conservation measures indirectly benefiting the species remain in place and no new/additional conservation measures are added. See Table 7-3, below, for designated condition categories into the future for Scenario 1. Also see Figure 7-1 below.

Ohio Basin

There is a small to moderate discharge reduction due to drought conditions, and negative changes in physical habitat features due to agricultural practices, human population growth, and resource extraction activities in stream tributaries that affect individuals (e.g., Oswayo Creek, Conewango Creek, Tionesta Creek, Muddy Creek, Slippery Rock Creek, Meathouse Fork, Middle Island Creek, Levisa Fork, Slate Creek). For example, diminishment of the already low flow in Oswayo Creek and Slippery Rock Creek, which makes individuals more susceptible to drought (which can expose aquatic habitat, isolate mussels during sperm and juvenile mussel dispersal, increase predation, and concentrate contaminants), more susceptible to temperature increases, and, in extreme situations, can impede delivery of sufficient dissolved oxygen. Lower flows also foster the concentration of contaminants.

Water quality declines are evident in river populations currently identified as medium condition due to untreated or poorly treated wastewater discharges, development, resource extraction, and high risk of contaminant spills (e.g., French Creek, Shenango River, North Fork Hughes River, Hughes River, Tuscarawas River, Walhonding River, Elk River, Licking River, Rolling Fork River, North and South Fork Kentucky River, Kentucky River, Green River, Barren River). The pervasive impacts of water quality degradation can affect these entire populations.

Habitat degradation continues in large-river populations due to development, navigational impacts such as dredging and increases in river commerce traffic, and extensive agriculture in riparian areas. For example, dredging below locks and dams in the Ohio River to maintain the navigation channel can be a source of direct mussel mortality. In the Allegheny River, streamside development and agriculture causes sedimentation that fills in the interstitial spaces needed by juvenile mussels and host fish eggs. This habitat degradation has the potential to affect individuals initially, but over time, results in impacts to populations.

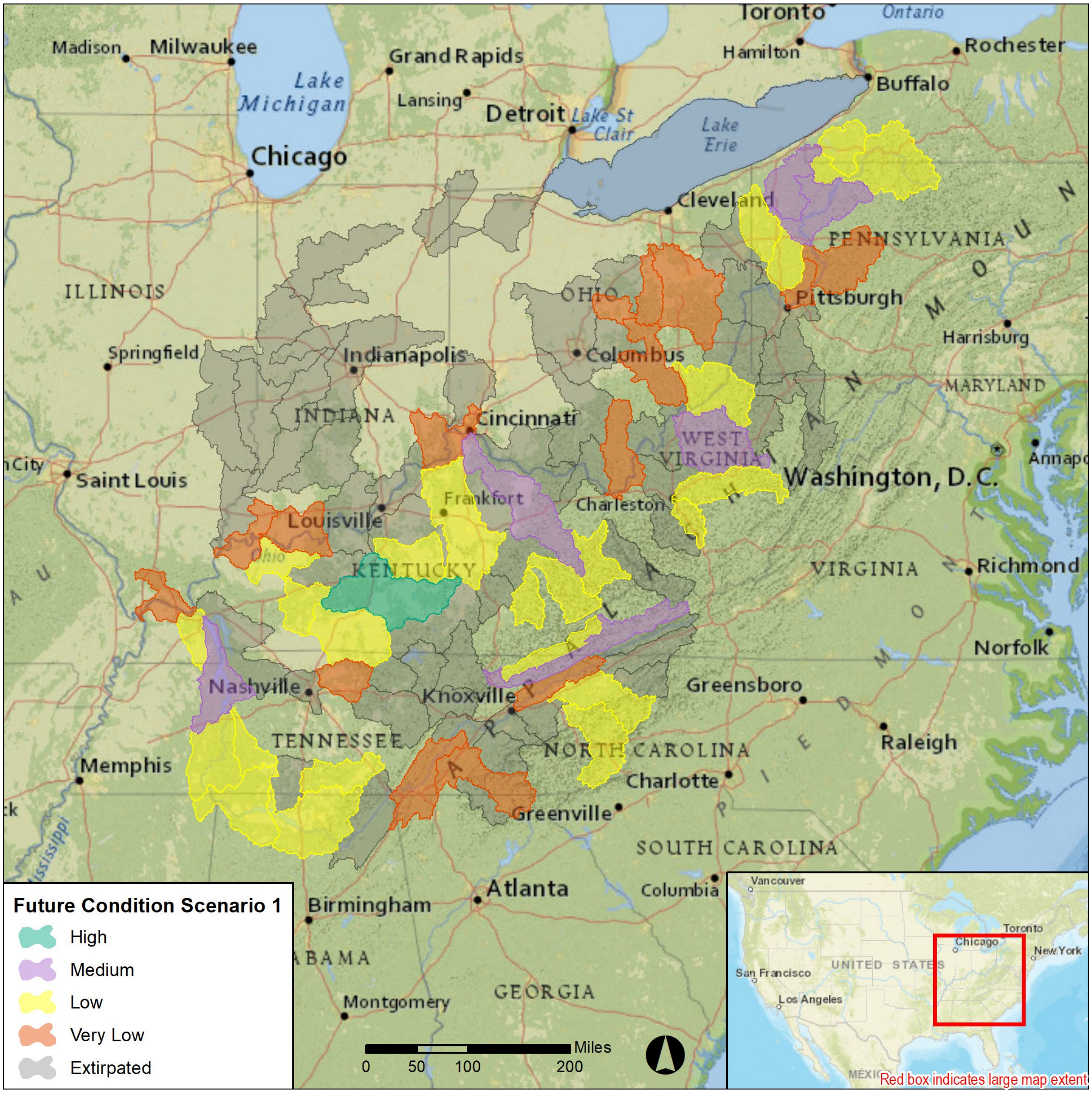

Figure 7-1. Distribution of the current and historically occupied Management Units (MUs; a.k.a. HUC8s) of Longsolid under Future Condition Scenario 1. Currently occupied MUs are represented with very low, low, medium, and high condition categories (as described in Chapter 7; Service 2018a, unpublished data).

Habitat degradation continues in large-river populations due to development, navigational impacts such as dredging and increases in river commerce traffic, and extensive agriculture in riparian areas. For example, dredging below locks and dams in the Ohio River to maintain the navigation channel can be a source of direct mussel mortality. In the Allegheny River, streamside development and agriculture causes sedimentation that fills in the interstitial spaces needed by juvenile mussels and host fish eggs. This habitat degradation has the potential to affect individuals initially, but over time, results in impacts to populations.

Nonnative species, such as Asian Clam, Zebra Mussel, Quagga Mussel, Black Carp, continue to negatively influence populations basin-wide. Asian Clam abundance and distribution is widespread within the range of the species and competes for food and nutrients needed for mussel growth and development. Black Carp are predators on mussels, and competition for space and resources from Zebra and Quagga mussels result in reduced fitness of Longsolid in the lower Ohio and Tennessee rivers.

Habitat fragmentation is a common issue for many of the Ohio River basin populations. Impoundments on the Shenango River, Tuscarawas River, and Green River, where there are dams both upstream and downstream of Longsolid populations, may limit the mussel's access to suitable habitat and isolate populations, which in turn limits the amount of genetic exchange between populations.

Cumberland Basin

Water quality degradation continues in the Cumberland River population which can result in direct mortality of mussels. The small population size and increased distance between sexually mature individuals makes it subsequently harder for females to intake sperm, affecting reproduction and recruitment. Mussel recruitment in the upper reach of Old Hickory Reservoir continues to be suppressed by cold water during the reproductive period resulting from hypolimnetic releases from upstream USACE reservoirs (e.g., Wolf Creek, Dale Hollow, and Center Hill).

Tennessee Basin

Small to moderate discharge reductions occur due to drought, and agricultural and resource extraction activities in stream tributary populations, resulting in habitat loss through increased sedimentation and siltation, which covers substrates used for settlement. Wastewater and runoff from land use activities also have increased concentrations of contaminants such as ammonia and chlorine. Discharge reductions and water extraction activities also result in periodic loss of connectivity between mussel populations (e.g., Little River, Valley River, Indian Creek, Estill Fork, Hurricane Creek). Impacts from periodic loss of connectivity can be exacerbated if it occurs during reproductively active periods of sperm distribution (limiting the ability of sperm to fertilize eggs) or juvenile mussel dispersal (limiting the distribution of the mussel in the stream).

Water quality declines are evident in rivers with medium condition populations due to untreated or poorly treated wastewater discharges, resource extraction, and high risk of contaminant spills, affecting the entire population due to predominantly linear distributions (e.g., Holston River, Nolichucky River, Clinch River, Powell River, Elk River, Hiwassee River, Buffalo River).

Habitat degradation continues in large river populations due to development, navigational impacts such as dredging and increases in river commerce traffic, and extensive agriculture in riparian areas (Tennessee River). This degradation results in direct habitat loss, increased sediment which fills substrate spaces required for juvenile mussel development and host fish eggs, and excessive storm water flows which erodes substrate habitat.

Nonnative species such as Asian Clam continue to impact populations basin-wide through competitive interactions for food and nutrients. Zebra Mussel, Quagga Mussel, and Black Carp continue to impact individuals in the lower Tennessee River through competition, suffocation, and predation.

Habitat fragmentation is a common issue for many of the Tennessee River basin populations. Impoundments on the Little River, Hiwassee River, Elk River, and Tennessee River, where there are dams both upstream and downstream of Longsolid populations, may limit the mussel's access to suitable habitat and isolate populations, which in turn limits the amount of genetic exchange between populations.

7.3.1 Resiliency

Under Scenario 1, factors currently influencing Longsolid populations remain constant into the future. In total, 22 of 60 Longsolid populations (37 percent) deteriorate in resiliency. In contrast, 38 populations (63 percent) maintain resiliency over time as some existing regulatory and voluntary conservation measures continue to be implemented to counteract existing threats. Notably, the Green River population is able to maintain its high resiliency under this scenario, largely due to the removal of Lock and Dam 6 and the potential for additional dam removals on the Green River (see Table 7-4, below). However, the effect of current levels of river and population fragmentation, sedimentation, dredging, oil and gas exploration, and increases in numbers and individuals of non-native species continue to result in habitat loss, water quality degradation, and competition for food resources and suitable substrates, which leads to reduced recruitment and low mussel abundance and survival. Genetic isolation, caused by habitat fragmentation and distance between populations, remains a concern, especially for populations in the Cumberland River and Shenango River.

Improvements in dissolved oxygen and reduction of hypolimnetic flow releases from hydropower dams continue to aid populations in some rivers (e.g. Elk-TN, Tennessee-Wilson Dam), but remain insufficient for others (e.g. Cumberland, Hiwassee, Holston). We estimate that only one out of 60 populations (1.6 percent) would be in high condition (upper Green River), 7 populations (12 percent) in medium condition, and 34 populations (57 percent) in low condition. As many as 18 populations (30 percent) are in very low condition and may no longer be detectable or are potentially extirpated.

Under this scenario, the Longsolid is potentially extirpated (very low condition) from the Tuscarawas, Walhonding, Muskingum, Cumberland, Holston and Hiwassee rivers and MUs. Six populations and MUs in the Ohio River are extirpated. Of the 42 current populations projected to persist (high, medium, or low condition), 31 MUs (69 percent) will be represented across the species range (Figure 7-1).

7.3.2 Representation

The Longsolid generally retains representation over time, but with 34 populations (57 percent) in low condition, the species is at an increased risk of extirpation, or falling into very low condition, in all but the high and medium condition populations and MUs (eight total). The watersheds with high and medium condition populations under this scenario (e.g. Allegheny, French Creek, Little Kanawha, Kanawha, Elk-WV, Licking, Green, Clinch, Paint Rock, and lower Tennessee rivers) would maintain representation in the Ohio and Tennessee basins (Table 7-3 and Table 7-4, above). However, the loss of populations from the Tuscarawas, Walhonding, Muskingum, and Ohio River mainstem results in extirpation from the state of Ohio, and the loss of the last remaining Cumberland River population results in a 50 percent loss in representation within drainage basins compared to historical conditions.

7.3.3 Redundancy

Under Scenario 1, redundancy for the Longsolid is reduced from current conditions (see Table 7-3 and 7-4, above). The loss of the population in the Cumberland River results in extirpation from the entire Cumberland River drainage, and the loss of the species from the Tuscarawas, Walhonding, Muskingum, Ohio, and Hiwassee rivers is a loss in redundancy from both the Ohio and Tennessee River systems. The best available information suggests that 18 of 60 populations (30 percent) are likely in very low condition and extirpated. The 34 low condition populations (57 percent), almost all of which are linear in extent, increases the species vulnerability to additional river and stream extirpation in both the Tennessee and Ohio river basins.

7.4 Scenario 2

Under this scenario, factors that negatively influence most of the extant populations are reduced by additional conservation, beyond the continued implementation of existing regulatory or voluntary conservation actions.

Conservation measures may include: implementation of additional BMPs, increased environmental regulations or enforcement of existing regulations improvements in aquatic connectivity, and active species management such as captive propagation or translocation efforts using brood stock from all three basins. Under Scenario 2, there is an optimistic species response to the factors influencing mussel viability, and conservation measures are implemented for targeted translocation, propagation, or augmentation. Additionally, restoration efforts using existing resources and capacity are successful, and monitoring costs decrease. See Figure 7-2, below, for MU condition under Secnario 2.

Scenario 2 presumes all populations are able to maintain or improve their current condition. This scenario assumes some reintroductions to currently unoccupied historical range or potential augmentation to populations experiencing reduced resource needs, or with limited capability to expand their range due to impoundments. Areas receiving added conservation are those that would have the greatest chance of becoming resilient in the future, potentially occurring in areas that are most likely to have land owners (such as the Service, NPS, USFS) that would maintain and improve habitat quality.

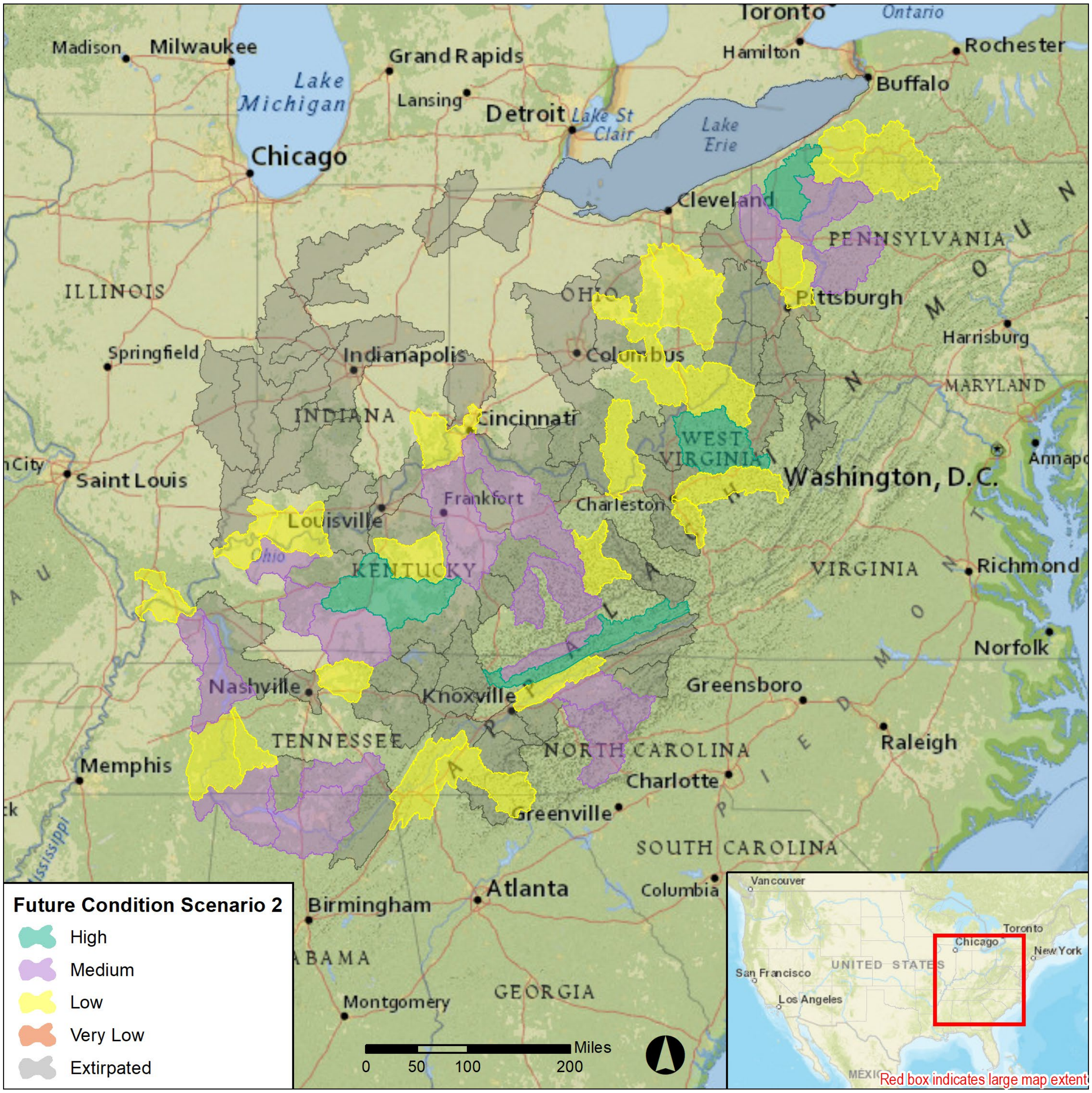

Figure 7-2. Distribution of the current and historically occupied Management Units (MUs; a.k.a. HUC8s) of Longsolid under Future Condition Scenario 2. Currently occupied MUs are represented with very low, low, medium, and high condition categories (as described in Chapter 7; Service 2018a, unpublished data).

This scenario assumes the pattern of urban growth would continue to increase to differing degrees across the species' range (Lawler *et al.* 2014, p. 56). Increased urban growth often reduces the amount of land available for agriculture (Lasier *et al.* 2016, p. 672; Newton *et al.* 2008, p. 434; Terando *et al.* 2014, p. 4). This scenario (similar to Scenario 1) also assumes that existing regulatory mechanisms and voluntary conservation measures that are indirectly benefiting the species would remain in place. However, the difference from Scenario 1 is that additional conservation is implemented across the Longsolid's range to benefit the long-term conservation of the species. See Table 7-5, below, for designated condition categories into the future for Scenario 2.

Scenario 2 assumes some actions of positive intervention are thoughtfully designed and executed as feasible and appropriate conservation plans. Such plans may be implemented by a combination of federal, state, and local governments, including river authorities, municipalities, and other "water regulators" along with NGO conservation groups, private landowners, and other stakeholders informed by biologists with expertise in the conservation of freshwater mussels and their habitats. Also, increased enforcement of environmental regulations helps address contamination issues and mitigation of resources lost due to impacts provides opportunities for conservation funds, used for translocation or propagation activities.

Ohio Basin

The natural flow regime is maintained in tributary populations to the maximum extent possible, and improvements in physical habitat are achieved due to environmental outreach and awareness, which reduces water quality degradation. The Longsolid is able to withstand impacts from climate change such as prolonged drought or flooding, due to increases in the abundance of individuals in small streams. Opportunities for improvements in habitat connectivity are achieved through barrier removal allowing for range expansion, connecting formerly periodically isolated stream populations to medium and large river populations. Population restoration/augmentation is possible (e.g., Oswayo Creek, Conewango Creek, Tionesta Creek, Muddy Creek, Slippery Rock Creek, Levisa Fork, Slate Creek).

Water quality improves in river populations that are in medium condition due to better treatment of wastewater discharges, especially in rural areas. Targeted programs are developed and implemented to improve water quality through BMPs concerning agricultural practices and development, and measurable success is achieved. Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are monitored and enforcement of violations is conducted in a timely manner, potentially reducing long-term issues. Additional protective measures are undertaken and regulations developed for oil and gas exploration in concentrated areas. Risks of population loss due to contaminant spills is lessened through the presence of non-linear populations within MUs (e.g., French Creek, Shenango River, Middle Island Creek, Tuscarawas River, Walhonding River, Licking River, Rolling Fork River, North Fork Kentucky River, Kentucky River, Green River, Barren River).

Habitat degradation in large river populations due to development, navigational impacts such as dredging and increases in river commerce traffic, and extensive agriculture in riparian areas is mitigated through use of existing funds or establishment of conservation funds for Longsolid species restoration initiatives. The costs of monitoring large river mussel populations decrease, due to advances in technology, leading to better annual estimates of mussel bed distribution (for instance, eDNA, or sonar exploration of river beds and mussel habitat), and areas that can be targeted for survey efforts. Existing public lands such as the Ohio River Island NWR and Allegheny National Forest are capable of providing refugia for brood stock to further translocation/captive propagation efforts (e.g., Allegheny River, Muskingum River, Elk River, Kanawha River, Ohio River).

Effective management of nonnative species such as Asian Clam, Zebra Mussel, Quagga Mussel, and Black Carp is implemented and studies are conducted on these species that leads to better understanding of how to reduce the impacts of their spread basin-wide, thereby reducing risk of predation, and decreasing competition for food and nutrients in mussel beds.

Cumberland Basin

Habitat degradation in large river populations due to increased development and extensive agriculture in riparian areas is mitigated through improvements in water temperatures from upstream dam releases. Or, the use of existing funds or establishment of conservation funds for Longsolid species restoration initiatives which would enable propagation of Cumberland River Longsolid for stocking into appropriate habitat within its formerly occupied range. Additional restoration efforts could address sediment and erosion issues and problems in order to increase the amount of available habitat for stocking in the Cumberland River basin.

Mussel recruitment in the upper reach of Old Hickory Reservoir improves through changes in dam releases from upstream reservoirs operated by the USACE (e.g., Wolf Creek, Dale Hollow, and Center Hill). Dissolved oxygen and temperature regimes improve as a result of these operational changes, leading to increased reproductive success. The Longsolid can be reintroduced into former portions of its range in the Cumberland River drainage through successful captive propagation efforts and partnerships (e.g. Big South Fork Cumberland National River and Recreation Area, Obed and Emory Wild & Scenic rivers).

Similar to the Ohio basin (Scenario 2, 1.c, above), the costs of monitoring large river mussel populations decrease, due to advances in technology, leading to better annual estimates of mussel bed distribution (for instance, eDNA, or sonar exploration of river beds and mussel habitat), and areas that can be targeted for survey efforts.

Tennessee Basin

Similar to the Ohio Basin (Scenario 2, 1.a., above), the natural flow regime is maintained in tributary populations to the maximum extent possible, and improvements in physical habitat are achieved due to environmental outreach and awareness. The species is able to withstand impacts from climate change such as prolonged drought or flooding. Opportunities for improvements in habitat connectivity are achieved, allowing for increases in abundance and Longsolid expansion, connecting stream and small river populations to medium and large river populations. Population restoration/augmentation is possible (e.g. Little River, Valley River, Indian Creek, Estill Fork, Hurricane Creek).

Water quality improves in river populations that are medium condition category due to better treatment of wastewater discharges, similar to the Ohio Basin (Scenario 2, 1.b, above), especially in rural areas. Targeted programs are developed to improve water quality through agricultural and development BMPs. Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are regulated, monitored, and enforcement of violations are conducted in a timely manner, potentially reducing long-term contamination issues. Additional improvements are made to raise the water temperatures of hypolimnetic

Tennessee Valley Authority dam releases. Risks of population loss from contaminant spills (resulting in suboptimal water quality conditions) are lessened through the presence of non-linear populations within MUs (e.g. Holston River, Nolichucky River, Clinch River, Powell River, Paint Rock River, Elk River, Hiwassee River, and Buffalo River).

Similar to the Ohio Basin (Scenario 2, 1.c, above), habitat degradation in large river populations due to human population growth, navigational impacts such as dredging and increases in river commerce traffic, and extensive agriculture in riparian areas is mitigated. This is potentially through use of existing funds or establishment of conservation funds for Longsolid species' restoration initiatives. The costs of monitoring large river mussel populations decrease, due to advances in technology, leading to better annual estimates of mussel bed distribution (for instance, eDNA, or sonar exploration of river beds and mussel habitat), and areas that can be targeted for survey efforts.

Management of non-native species such as Asian Clam, Zebra Mussel, Quagga Mussel, and Black Carp is implemented and studies are conducted on these species that lead to better understanding of how to reduce the effects of their spread basin-wide, thereby reducing the risk of predation, and decreasing competition for food and nutrients in mussel beds (Similar to the Ohio Basin (Scenario 2, 1.d, above)).

7.4.1 Resiliency

Under Scenario 2, factors that negatively influence most of the extant populations are reduced by additional conservation. There is an improvement in resiliency from current condition (positive change in condition category) for 25 of 60 Longsolid populations (42 percent). The other 35 populations (58 percent) maintain resiliency over time as regulatory and voluntary conservation measures continue to be implemented, and increase, to counteract existing threats (see Table 7-4, below). The effects of current levels of river and population fragmentation, sedimentation, and wastewater discharges are reduced, resulting in: increased suitable habitat conditions and population connectivity within MUs, protection of suitable substrates, and improved non-point source water treatment for maintenance of water quality standards. These overall improved conditions lead to improved recruitment and increased mussel abundance and survival.

Additionally, programs targeted to improve water quality through agricultural and development BMPs are developed and implemented. Impacts from resource extraction activities, such as gas extraction and coal mining, are monitored and violations are enforced in a timely manner, potentially reducing long-term contamination issues. Improvements in dissolved oxygen and reduction of hypolimnetic flow releases from hydropower dams continue to aid populations in some rivers (e.g. Elk-TN, Tennessee-Wilson Dam), and alternative flow-release strategies are explored and implemented by the USACE and TVA seasonally on rivers for others (Cumberland, Hiwassee, Holston).

Under this scenario, which is considered to be highly optimistic based on the current level of threats, none of the currently 60 extant populations are likely to become extirpated. However, it is important to keep in mind that some of the low current condition populations may already be not viable, especially those that are restricted by impoundments both upstream and downstream.

Populations within MUs are not linearly distributed, improving resilience to stochastic events. We estimate that 8 out of 60 populations (13 percent) would be in high condition, 22 (37 percent) in medium condition, and 30 (50 percent) in low condition. There are no very low condition populations. Additionally, the Longsolid would remain extant in all 45 MUs where it currently exists (100 percent) (Figure 7-2).

7.4.2 Representation

The Longsolid retains representation over time, with 30 high and medium populations maintained among all three remaining occupied basins (Ohio, Cumberland, and Tennessee, see Tables 7-5 and 7-6, above). The Cumberland population would also potentially increase representation through propagation efforts into the Big South Fork Cumberland River or other suitable locations. Populations within MUs are not linearly distributed, and natural or human-assisted improvements in population and habitat connectivity reduce the risk of genetic isolation. However, with 30 populations (50 percent) estimated to remain in low condition regardless of additional conservation measures being implemented, the species could potentially decline in portions of its range, particularly in the mainstem Ohio River, due to loss of individuals from the concentration of increased predation, competition, stressors resulting from the spread of non-native species.

7.4.3 Redundancy

The Longsolid maintains and potentially improves redundancy (see Table 7-5 and 7-6, above). The best available information suggests that no populations become extirpated. Natural or human-assisted population expansion into portions of its formerly occupied range occurs in all three basins. If Longsolid densities within currently occupied basins are suitable, augmentation through translocation around barriers is achieved to expand distribution. In addition, if captive propagation proves successful, as many as five populations (an increase of 8 percent) are potentially gained into rivers and streams within former portions of the species' range. This is accomplished through to reintroductions and improved conservation, including in the Cumberland River basin, which currently has very low redundancy.

7.5 Scenario 3

Under this scenario, factors that influence the current extant populations of Longsolid are likely to become worse from the implementation of known existing and projected development, resource extraction, hydroelectric projects, etc.; as well as additional risks to the species and its habitat are more challenging to predict with accuracy at this time, such as climate change.

In general, this scenario assumes that all four threats and associated sources of threats are worse in the future, leading to reductions in water quality in those areas that are already poor and increased habitat degradation of areas that are not fully supporting resource needs (i.e., appropriate food, nutrients, and water quality condition) for aquatic life. The abundance and distribution of host fishes decline. Climate change begins to affect the Longsolid at the species and population levels. Climate conditions, and variations from the natural flow regime, with periodic drought and flooding, may result in desiccation, scour, and increased sedimentation and deposition in high quality mussel habitats. This scenario assumes that existing regulatory mechanisms and voluntary conservation measures that are benefiting the species would remain in place, although funding and staffing constraints likely prohibit significant additional protections. See Table 7-7, below, for designated condition categories into the future for Scenario 3, and Figure 7-3, below for the Longsolid MU condition under Scenario 3.

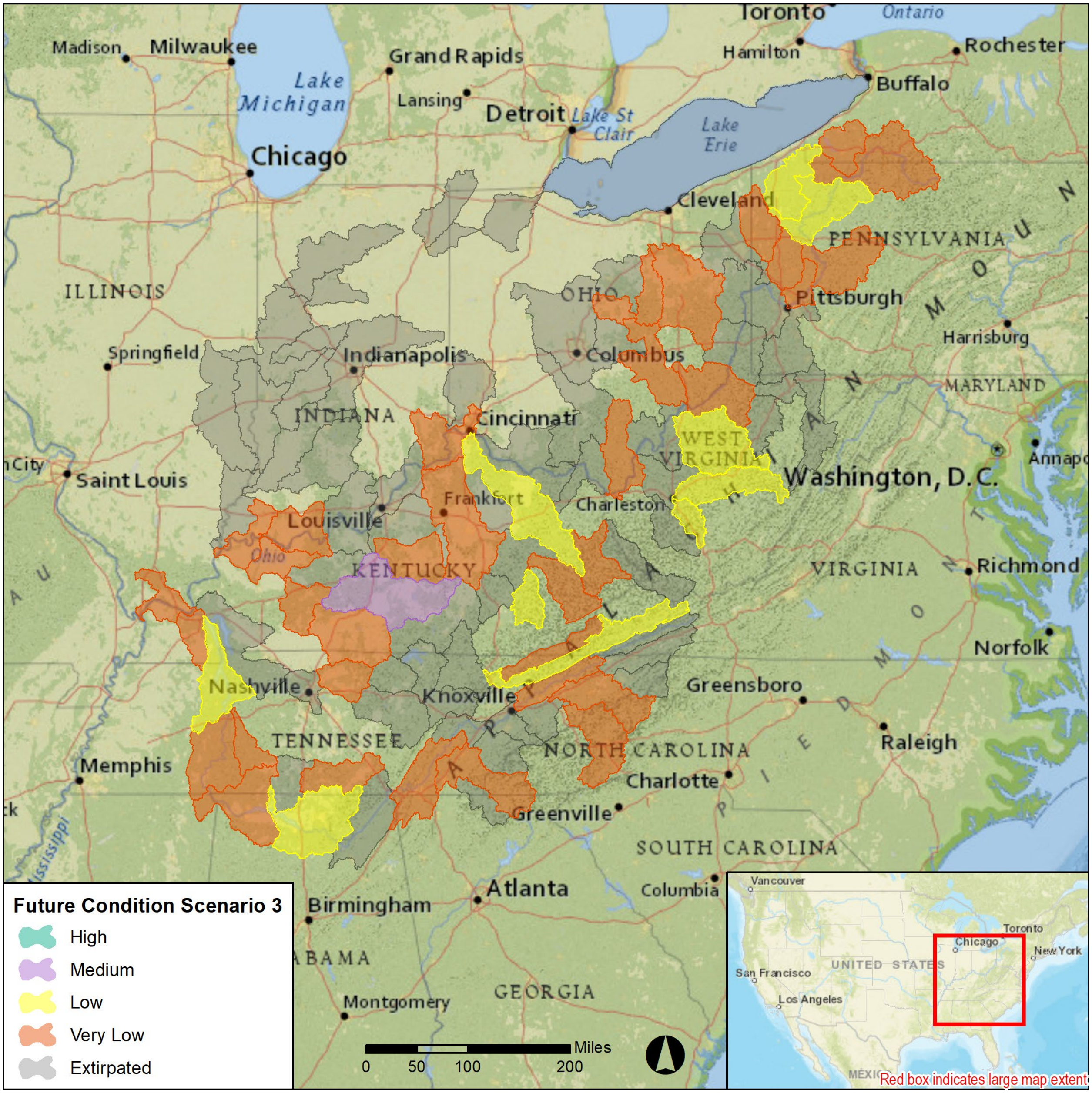

Figure 7-3. Distribution of the current and historically occupied Management Units (MUs; a.k.a. HUC8s) of Longsolid under Future Condition Scenario 3. Currently occupied MUs are represented with very low, low, medium, and high condition categories (as described in Chapter 7; Service 2018a, unpublished data).

Under Scenario 3, the Longsolid's response to multiple impacts acting synergistically on the landscape result in significant declines coupled with limited propagation capacity and/or limited capacity for reintroductions and/or augmentations. Monitoring capabilities also decrease due to cost and time. In general, this scenario considers a future where conditions are worse for the species across its entire range compared to Current Conditions (Chapter 5). In this scenario, there is some reduction or negative effects to all of the species' resource and demographic needs (flow reduction, decline in water quality, reduced connectivity between populations, etc.), but not necessarily significant or "worst case scenario" in those populations/rivers where significant impacts would be unlikely.

Ohio Basin

There are discharge reductions in tributaries that lead to alterations in the natural flow regime and changes to the physical habitat requirements of the species (i.e., reduced frequency of flow events that help keep clean-swept substrates), which lead to reduced connectivity and Longsolid recruitment affecting the entire populations in small streams. The species is unable to withstand impacts from some changing climate conditions, such as prolonged drought or periodic flooding, which results in desiccation, scour, and increased sedimentation and deposition in shoal habitats occupied by the Longsolid. Habitat fragmentation increases, reducing connectivity more than what would occur under Scenario 1, further reducing opportunities for Longsolid expansion. If stream and all populations in small streams and rivers persist, they become more restricted and genetically isolated from medium and large river populations. Population restoration through augmentation is not possible due to lack of sufficient available brood stock (e.g., Oswayo Creek, Conewango Creek, Tionesta Creek, Muddy Creek, Slippery Rock Creek, Levisa Fork, Slate Creek).

Water quality deteriorates for the populations currently classified as medium condition due to lack of treatment of wastewater discharges, especially in rural areas; however, the degree of water quality decline is substantially worse than that experienced under Scenario 1. There is little to no water quality improvement through BMPs concerning agricultural practices and development. Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are exacerbated by increased localized concentrations of abandoned mines and oil and gas exploration, increasing long-term water contamination issues that have significant influence on the survival of the Longsolid. Risks of population losses due to contaminant spills are increased compared to Scenario 1 through the presence of linear populations within MUs (e.g., Shenango River, Middle Island Creek, Elk River, Tuscarawas River, Walhonding River, Licking River, Rolling Fork River, North Fork Kentucky River, Kentucky River, Barren River).

Habitat degradation continues and worsens in large river populations due to human population growth and associated land-use changes, and navigational impacts such as dredging and increases in river commerce traffic. There is an increase in the extent of habitat degradation in riparian areas due to increased agricultural activities without adequate BMPs. The costs of monitoring large river mussel populations increases, reducing the capabilities of gathering annual estimates of species abundance and distribution (e.g., Allegheny River, Muskingum River, Elk River, Kanawha River, Ohio River).

Nonnative species such as Asian Clam, Zebra Mussel, Quagga Mussel, and Black Carp spread significantly across the basin, invading new streams and rivers within the Longsolid's range, increasing competition for Longsolid resource needs and predation on the species.

Cumberland Basin

Habitat degradation worsens in the Cumberland River due to development and increased concentrated agricultural activities. This results in additional sedimentation and water contamination, and direct mussel mortality in a population that is already isolated and very rare. Mussel recruitment in the upper reach of Old Hickory Reservoir fails through lack of changes in dam releases from upstream reservoirs operated by the USACE (e.g., Wolf Creek, Dale Hollow, and Center Hill). The costs of monitoring large river mussel populations increases beyond costs incurred under Scenario 1, and staff and budget reductions significantly reduce the capabilities of gathering annual estimates of species abundance and distribution.

Tennessee Basin

Significant decreases discharge variability occurs in tributaries, leading to alterations in the natural flow regime and changes in physical habitat, resulting in reduced connectivity of aquatic habitat and, in turn, Longsolid recruitment. Due to small population sizes, the species is unable to withstand minor impacts from climate change, such as drought or periodic flooding, which result in desiccation, scour, and increased sedimentation and deposition in shoal habitats occupied by the Longsolid. Habitat fragmentation increases significantly compared to current conditions and Scenario 1, reducing connectivity more than status quo, further reducing opportunities for Longsolid expansion. If stream and small river populations persist (noting many would likely be lost), they become more restricted and genetically isolated from medium and large river populations. Population restoration/augmentation is not possible due to lack of sufficient available broodstock (e.g., Little River, Valley River, Indian Creek, Estill Fork, Hurricane Creek).

Water quality deteriorates in rivers with populations that are currently medium condition due to untreated wastewater discharges, especially in rural areas. There is no initiative to improve water quality through BMPs concerning agricultural practices and human population growth and development. Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are exacerbated by greater localized concentrations of abandoned mines, increasing long-term water contamination issues that have a significant influence on the survival of the Longsolid. Water temperature effects below hydropower dams are exacerbated by climatic changes in rainfall. The lack of consistent seasonal rainfall (drought) reduces river flow into upstream reservoirs, resulting in alteration of seasonal dam release schedules by TVA, which not longer provides minimum flows and dissolved oxygen addition. Risks of contaminant spills remain high and elevate the likelihood of water quality contamination and direct effects to mussels due to the presence of only linear populations within MUs (e.g., Holston River, Nolichucky River, Powell River, Elk River, Hiwassee River, and Buffalo River).

Habitat degradation continues and worsens in large river populations due to human population growth, sedimentation, and navigational impacts such as dredging and increases in river commerce traffic. Activities that formerly only affected individuals, such as barge traffic and fleeting, are now affecting entire populations, due to increasing rarity of the species. There is an increase in the magnitude of agricultural activities in riparian areas to accommodate population growth. This results in loss of appropriate habitat patches and habitat heterogeneity, increasing the likelihood of Longsolid isolation and extirpation from large rivers. The costs of monitoring large river mussel populations increase due to reductions in staffing of agency partners and reliance on private industry for data and survey information, reducing the capabilities of gathering annual estimates of species abundance and distribution (Tennessee River).

Nonnative species such as Asian Clam, Zebra Mussel, Quagga Mussel, and Black Carp spread throughout the basin, invading new streams and rivers within the Longsolid range, increasing competition for Longsolid resource needs and predation on the species.

7.5.1 Resiliency

Under Scenario 3, where conditions become worse, 55 of 60 Longsolid populations (92 percent) deteriorate in resiliency (negative change in condition category from current condition), and only 5 populations (8 percent) maintain some low resiliency over time. Current threats continue along with elevated (compared to Scenario 1) impacts to populations and MUs from changing climate conditions (see Table 7-4, below). Significant changes may not be observed at first due to continued implementation of existing regulatory and voluntary conservation measures that help reduce (but not eliminate) threats (see Table 7-8, below). Increased levels of river and population fragmentation through isolation and sedimentation result in decreased habitat and/or population connectivity within MUs, and deposition of fine sediments into suitable substrates. The magnitude and scale of wastewater discharges and oil and gas exploration result in lack of non-point source water treatment, which leads to recruitment failure and decreased mussel abundance and survival throughout a significant proportion of Longsolid's range.

Targeted programs to improve water quality through BMPs concerning agricultural practices and anthropogenic land uses are not developed. There is an increase of impacts from resource extraction activities, such as oil and gas drilling in the Ohio River basin, which contributes to long-term water contamination issues. Decreases in dissolved oxygen and changes to thermal regimes such as the increased potential of hypolimnetic flow releases from hydropower dams suppress populations in some rivers already affected. Additional hydropower development at dams currently used for flood control results in localized scouring in existing downstream Longsolid habitat (e.g., Elk-TN, Tennessee-Wilson Dam, Muskingum River, North Fork Hughes River, Little Kanawha River, Elk River).

Regardless of ongoing regulatory and voluntary conservation measures, 44 of 60 populations that deteriorate in resiliency (73 percent) have the potential to drop below detectable levels or become extirpated (very low condition). Genetic isolation is a significant concern due to fragmentation and populations within MUs becoming more linearly distributed, decreasing resilience to stochastic events. We estimate that none of the 60 populations would be in high condition, only 3 (5 percent) in medium condition, and 13 (22 percent) in low condition. The number of populations (16) and MUs (13) that continue to be represented across the species' range is dependent on public lands or watersheds with aquatic species conservation incorporated into long-term planning strategies. Rivers such as the Clinch, Green, Allegheny, which are biodiversity hotspots and have resource protection measures such as BMPs, offer the only refugia from threats and limited conservation opportunities.

7.5.2 Representation

The Longsolid loses representation over time, with no high condition populations in any of the three remaining occupied basins (Ohio, Cumberland, and Tennessee; see Tables 7-5 and 7-6, above), and the complete loss of representation in the Cumberland basin. Populations within MUs in the Ohio and Tennessee basins are linearly distributed due to reductions in population and habitat connectivity, thus resulting in substantial fragmentation and a high likelihood of genetic isolation. With 13 populations (22 percent) in low condition and the potential extirpation (very low condition) of 44 populations (73 percent), the species is in significant decline in the majority of its range; all but 3 populations are in low or very low condition. Additionally, the loss of stream and small river populations and the resulting lack of metapopulations significantly increases the species' extinction risk.

7.5.3 Redundancy

The Longsolid loses redundancy compared to current conditions (see Tables 7-5 and 7-6, above). The best available information suggests that up to 44 populations (73 percent) would become extirpated. Loss of populations in all portions of its currently occupied range occurs in all three basins, and there are no longer any high condition populations which can be used for brood stock for translocation or captive propagation efforts.

CHAPTER 8 - OVERALL SYNTHESIS

The goal of this assessment is to describe the viability of the Longsolid in terms of resiliency, representation, and redundancy by using the best available commercial and scientific information at the time of the analysis. We described both current and potential future conditions regarding the Longsolid's viability within the context of these three parameters. To capture the uncertainty associated with the degree and extent of potential future risks and their impacts on the species' needs, we assessed potential future conditions using three plausible scenarios. These scenarios were based on a variety of negative and positive influences on the species across its current 9-state range, allowing us to predict potential changes in habitat used by the Longsolid. The results of our analysis described a range of possible conditions in terms of the number and distribution of Longsolid populations (Table ES-1).

Historical Range and Abundance - The historical range of the Longsolid included streams and rivers across 12 states, including New York, Pennsylvania, West Virginia, Indiana, Illinois, Ohio, Kentucky, Virginia, Tennessee, Georgia, North Carolina, and Alabama. This range encompassed four major basins: the Great Lakes, Ohio, Cumberland, and Tennessee. The best available information suggests that at least 162 populations and 105 MUs occurred over this range; however, it is also likely that more populations were undetected, prior to the use of more intensive contemporary survey methods.

Current Viability Summary - The current range extends over nine states; the species is now considered extirpated in Georgia, Illinois, and Indiana. This range encompasses three major river basins; the species now no longer exists in the Great Lakes basin (loss of six historical populations and four MUs). In addition, its representation in the Cumberland River basin is currently within a single population & MU (loss of nine historical populations and eight MUs). Overall, the Longsolid is presumed extirpated from 63 percent (102 of 162 populations) of its historically occupied populations, including six populations (the entirety) of the Great Lakes basin, 65 populations in the Ohio basin, nine populations in the Cumberland basin, and 26 populations in the Tennessee basin (Appendix B). Of the current populations, three (5 percent) are estimated to be in highly resilient, nine (15 percent) are moderately resilient, and 48 (80percent) have low resiliency.

A cautionary emphasis should be placed on the fact that the Longsolid was once a common, occasionally abundant component of the mussel assemblage in rivers and streams where it is now extirpated. Examples include the Beaver River, Pennsylvania (Ortmann 1920, p. 276); Ohio River; Pennsylvania (Tolin 1987, p. 11), Mahoning River; Pennsylvania (Ortmann 1920 p. 276), Wabash River; Indiana/Illinois (Cummings *et al.* 1992, p. 46), Nolin River; Kentucky (Taylor 1983b, p. 111), and the South Fork Holston River, Virginia/Tennessee (Parmalee and Pohemus 2004, p. 234). Significant declines of the Longsolid have been observed and documented in the Ohio and Cumberland rivers; and in the Muskingum River system, which harbors the last remaining populations (Muskingum, Tuscarawas, & Walhonding) in the state of Ohio (Neel and Allen 1964, p. 434; Watters and Dunn 1993-94, p. 252; Watters *et al.* 2009, p. 131; and Haag and Cicerello 2016, p. 139).

Future Condition Scenarios - An important assumption of the predictive analysis is that future population resiliency is largely dependent on water quality, water flow, instream habitat conditions and condition of riparian vegetation (see Resource Needs, Chapter 4). Our assessment predicts that if conditions remain the same or worsen into the future, a range of all 60 populations would experience negative changes to these important habitat requisites, including the loss of the single remaining population in the Cumberland basin, and potentially resulting in no highly resilient populations (Scenario 3). Alternatively, the scenario that suggests additive conservation measures beyond those currently implemented (Scenario 2) could result in the continued persistence of all 60 populations in the future. However, it is important to note that approximately 30 of 60 (50 percent) of these are currently low condition populations based on either surveys that pre-date 2000 or have been collected only as five or fewer older, non-reproducing individuals. Some of these populations may already be extirpated. Predicted viability varied among scenarios and is summarized below (see also Table 8-1 and Table ES-1).

Given Scenario 1, loss of resiliency, representation, and redundancy is expected. Under this scenario, we predict that one population of the current three high condition populations would remain in high condition, eight populations (13 percent) in medium condition, and 33 populations (55 percent) in low condition. Redundancy would be reduced with likely extirpation of 18 out of 60 (30 percent) currently extant populations; only the Ohio basin (one of the three basins currently occupied by the species) would retain one highly resilient population (i.e., the Green River population in the Upper Green MU). Representation would be reduced, with two of the three currently occupied river basins continuing to harbor Longsolid populations.

Given Scenario 2, we predicted higher levels of resiliency in some portions of the Longsolid's range than was estimated for Scenario 1; representation and redundancy would remain the same level as current conditions with the species continuing to occur within all currently occupied MUs and States across the species range. Nine populations (15 percent) are predicted to be high condition, compared to the current four populations in high condition. Scenario 2 also predicts 24 populations (40 percent) in medium condition and 27 populations (45 percent) in low condition; no populations would become extirpated. In addition, all three currently occupied major river basins would remain occupied, and the existing levels of redundancy and representation would improve. It is possible that this scenario is the least likely to occur in the future as compared to Scenario 1 or 3 only because it will take many years (potentially beyond the 50- to 70-year time frame analyzed in this report) for all of the beneficial effects of management actions that are necessary to be implemented and realized on the landscape.

Given Scenario 3, we predicted a significant decrease in resiliency, representation, and redundancy across the species range. Redundancy would be reduced from three major river basins to 2 basins with no high condition populations remaining, and the likely extirpation of 44 (73 percent) of the currently extant populations. The resiliency of the remaining 16 populations is expected to be reduced to three populations (5 percent) in medium condition and 13 (22 percent) in low condition. In addition to the loss of 44 populations, 32 (29 percent) of MUs are predicted to become extirpated. Representation would be reduced to thirteen MUs, two major river basins and three states (as compared to the current nine states) occupied by the species.

Overall Summary - Estimates of current and future resiliency for the Longsolid (Table 8-1, below) are low given that only three (5 percent) of the populations are estimated to be highly resilient and nine (15 percent) are moderately resilient. The Longsolid faces a variety of threats including habitat degradation or loss (i.e., declines in water quality, loss of stream flow, riparian and instream fragmentation, and genetic isolation/displacement from development, urbanization, contaminants, agricultural activities, impoundments, changing climate conditions, resource extraction, and forest conversion), as well as impacts associated with invasive and non-native species and legacy impacts from past commercial harvest and overutilization.

These negative influences, which are expected to be exacerbated by continued growing human populations that demand associated development, energy, infrastructure, and water needs, as well as (but to a lesser degree than the former) climate change, were important factors in our assessment of the future viability of the Longsolid. Given current and future decreases in resiliency, populations become more vulnerable to extirpation from stochastic events (particularly the small populations that are linearly distributed), in turn, resulting in concurrent losses in representation and redundancy. Predictions of the Longsolid's habitat conditions and population factors in the future suggest possible extirpation of between 18 (3 percent) and 44 (73 percent) currently extant populations unless additional conservation is implemented and effective.

Table 8-1. Summary of Longsolid mussel population size, extent, threat level, current conditions, and potential future conditions.

Management Unit	Contiguous Population (occupied river/stream)	Population Size	Population Extent	Threat Level	Current Condition	Future Condition		
						Scenario 1	Scenario 2	Scenario 3
OHIO RIVER BASIN								
Upper Allegheny	(1) Allegheny River	Small	Small	Moderate	Low	Low	Low	Very Low
	(2) Oswayo Creek	Small	Small	Moderate	Low	Low	Low	Very Low
Conewango	(3) Conewango Creek	Small	Small	Moderate	Low	Low	Low	Very Low
Middle Allegheny - Tionesta	(4) Allegheny River	Medium	Large	Moderate	Medium	Medium	High	Low
	(5) Tionesta Creek	Small	Small	Low	Low	Low	Low	Very Low
French Creek	(6) French Creek	Med	Large	Low	Medium	Medium	High	Low
	(7) Muddy Creek	Small	Small	Low	Low	Low	Medium	Low
Middle Allegheny - Redbank	(8) Allegheny River	Small	Small	High	Low	Very Low	Medium	Very Low
Lower Allegheny	(9) Allegheny River	Small	Small	High	Low	Very Low	Low	Very Low
Shenango	(10) Shenango River	Medium	Small	Moderate	Medium	Low	Medium	Low
Connoquenessing	(11) Slippery Rock Creek	Small	Small	High	Low	Low	Low	Very Low
Little Muskingum-Middle Island	(12) Ohio River	Small	Small	High	Low	Very Low	Low	Very Low
	(13) Middle Island Creek	Small	Small	Moderate	Low	Low	Low	Very Low
	(14) Meathouse Fork	Small	Small	High	Low	Very Low	Low	Very Low
Little Kanawha	(15) Little Kanawha River	Large	Large	Moderate	High (Stronghold)	Medium	High	Low
	(16) North Fork Hughes River	Small	Small	High	Low	Low	Medium	Very Low
	(17) Hughes River	Small	Small	Moderate	Low	Low	Medium	Very Low
Tuscawaras	(18) Tuscawaras River	Small	Small	High	Low	Very Low	Low	Very Low
Muskingum	(19) Muskingum River	Small	Medium	High	Low	Very Low	Low	Very Low
Walhonding	(20) Walhonding River	Small	Small	High	Low	Very Low	Low	Very Low
Upper Kanawha	(21) Kanawha River	Medium	Small	Moderate	Medium	Medium	High	Low

Management Unit	Contiguous Population (occupied river/stream)	Population Size	Population Extent	Threat Level	Current Condition	Future Condition		
						Scenario 1	Scenario 2	Scenario 3
Elk River (WV)	(22) Elk River	Large	Large	Moderate	Medium	Low	Medium	Low
Lower Levisa	(23) Levisa Fork	Small	Small	High	Low	Low	Medium	Very Low
Raccoon-Symmes	(24) Ohio River (lower Gallapolis Pool, upper Greenup Pool)	Small	Small	High	Low	Very Low	Low	Very Low
Middle Ohio-Laughery	(25) Ohio River (Markland Pool)	Small	Small	High	Low	Very Low	Low	Very Low
Licking	(26) Licking River	Medium	Large	Moderate	Medium	Medium	High	Low
	(27) Slate Creek	Small	Small	Moderate	Low	Low	Low	Very Low
Rolling Fork	(28) Rolling Fork River	Small	Small	Moderate	Low	Low	Low	Very Low
North Fork Kentucky	(29) North Fork Kentucky River	Small	Medium	Moderate	Low	Low	Medium	Very Low
South Fork Kentucky	(30) South Fork Kentucky River	Small	Medium	Moderate	Medium	Low	High	Low
	(31) Redbird River	Small	Small	Low	Low	Low	Low	Very Low
Lower Kentucky	(32) Kentucky River	Small	Small	Moderate	Low	Low	Medium	Very Low
Upper Green	(33) Green River	Large	Large	Low	High (Stronghold)	High	High	Medium
Barren	(34) Barren River	Small	Medium	Moderate	Low	Low	Medium	Very Low
Middle Green	(35) Green River	Small	Large	Moderate	Low	Low	Medium	Very Low
Lower Green	(36) Green River	Small	Small	Moderate	Low	Low	Medium	Very Low
Highland - Pigeon	(37) Ohio River (Cannelton Pool)	Small	Small	High	Low	Very Low	Low	Very Low
Lower Ohio-Little Pigeon	(38) Ohio River (Newburgh Pool)	Small	Small	High	Low	Very Low	Low	Very Low
Lower Ohio	(39) Ohio River (Olmstead Pool)	Small	Small	High	Low	Very Low	Low	Very Low
CUMBERLAND RIVER BASIN								
Lower Cumberland-Old Hickory Lake (Cordell Hull Tailwater)	(40) Cumberland River (Old Hickory Reservoir)	Small	Medium	High	Low	Very Low	Low	Very Low
TENNESSEE RIVER BASIN								

Management Unit	**Contiguous Population (occupied river/stream)**	**Population Size**	**Population Extent**	**Threat Level**	**Current Condition**	**Future Condition**		
						Scenario 1	**Scenario 2**	**Scenario 3**
Holston	(41) Holston River	Small	Medium	High	Low	Very Low	Medium	Very Low
Upper French Broad	(42) Little River	Small	Small	Moderate	Low	Low	Medium	Very Low
Nolichucky	(43) Nolichucky River	Small	Medium	High	Low	Low	Medium	Very Low
Upper Clinch	(44) Clinch River	Large	Large	Moderate	High (Stronghold)	Medium	High	Medium
	(45) Indian Creek	Small	Small	High	Low	Low	Medium	Very Low
Powell	(46) Powell River	Medium	Medium	High	Low	Low	Medium	Very Low
Middle Tennessee-Chickamauga	(47) Tennessee River (Chickamauga Reservoir) Watts Bar Tailwater	Small	Small	High	Low	Very Low	Low	Very Low
Wheeler Lake	(48) Paint Rock River	Medium	Large	Low	Medium	Medium	High	Medium
	(49) Estill Fork	Small	Small	Low	Low	Low	Medium	Low
	(50) Hurricane Creek	Small	Small	Low	Low	Low	Medium	Low
	(51) Tennessee River (Wheeler Reservoir) Guntersville Tailwater	Small	Medium	High	Low	Low	Medium	Very Low
Upper Elk (TN)	(52) Elk River	Small	Medium	Moderate	Low	Low	Medium	Very Low
Hiwassee	(53) Hiwassee River	Small	Small	High	Low	Very Low	Low	Very Low
	(54) Valley River	Small	Small	Moderate	Low	Very Low	Low	Very Low
	(55) Hiwassee River	Small	Small	Moderate	Low	Very Low	Low	Very Low
Pickwick Lake	(56) Tennessee River (Pickwick Reservoir) Wilson Tailwater	Small	Medium	High	Low	Low	Medium	Very Low
Lower Tennessee-Beech	(57) Tennessee River (Kentucky Reservoir) Pickwick Tailwater	Small	Medium	High	Low	Low	Low	Very Low
Buffalo	(58) Buffalo River	Small	Small	Moderate	Low	Low	Low	Very Low
Kentucky Lake	(59) Tennessee River (Kentucky Reservoir & 5 KM of tailwater)	Medium	Medium	High	Medium	Medium	Medium	Low
Lower Tennessee	(60) Tennessee River (lowermost reach before connecting to Ohio River)	Medium	Medium	High	Low	Low	Medium	Low

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APPENDIX A—SUMMARY OF EXTANT POPULATIONS AND THEIR ESTIMATED SIZE.

Within this appendix, the authority of each record is presented, the year of the record, and the shell condition (i.e., live/fresh dead, relic). This information has been gathered from a large body of published and unpublished survey work rangewide since the 1800s. More current, unpublished distribution and status information has been obtained from biologists with State Heritage Programs, Department of Natural Resources programs, other state and federal agencies, academia, and museums.

When referring to shell condition, fresh dead shells still have flesh attached to the shell, or at least retain a luster to their nacre, and may have a hinge intact and pliable, indicating relatively recent death. Relic shells may have been reported as either weathered or subfossil. Weathered dead or relic shells often have a loss of or peeling periostracum and faded or dull nacre (Ohio Mussel Survey Protocol, 2018, p. 47). Fresh dead shells probably indicate the continued presence of the species at a site, while weathered relic shells only probably indicate that the population in question is extirpated (Butler 2007, p. 17). QLTOT = qualitative total of all mussels all species, encountered live, QNTOT = quantitative total of all mussels, all species encountered live, RA = relative abundance of Longsolid in survey.

OHIO RIVER BASIN

Management Unit: Upper Allegheny
State: Pennsylvania
(1) Contiguous population: Allegheny River
Year of last live or fresh dead observation: 2005, PABFC
Estimated occupied length: Unknown; 164-246 ft (50-75 m) surveyed according to unpublished PABFC data. Only 1 collection made in this reach of the river by PABFC in 2005, in a snail survey that turned into a mussel salvage operation (Nevin Welte).
Notes: Less than 100 ever reported from this reach of the Allegheny River; four individuals located in a receding backwater with 30 minutes of effort. Given there is only one collection from this reach of the upper Allegheny River above Allegheny Reservoir, the density and extent of this population is unknown. This population is isolated from other populations further downstream in the Allegheny River by reservoirs, and specifically Kinzua Dam. Species does not appear to occur in the Allegheny River mainstem in New York state.

Management Unit: Upper Allegheny
State: Pennsylvania
(2) Contiguous population: Oswayo Creek
Year of last live or fresh dead observation: 2006, PABFC
Estimated occupied length: Unknown. Likely less than 3.1 mi (5 km). Only 1 fresh dead shell of this species collected from this stream, reported in 2006 (Nevin Welte).
Notes: Less than 100 ever reported; one live collected. Given there is only one collection from this reach of the upper Allegheny River above Allegheny Reservoir, the density and extent of this population is unknown. This population is isolated from other populations further downstream in the Allegheny River by reservoirs, and specifically Kinzua Dam. Species does not appear to occur in the Allegheny River mainstem in New York state.

Management Unit: Conewango
State: New York
(3) Contiguous population: Conewango Creek
Year of last live or fresh dead observation: 2010, NYNHP
Estimated occupied length: Approximately 3.1 mi (5 km) according to the NY Natural Heritage Program (Service 2018a, unpublished data). The only survey documenting species presence in the watershed by NYNHP (2010); collected at three locations by Crabtree (2010, p. 16)
Notes: Longsolid was found at three locations only, clustered in the mid-reaches of Conewango Creek. It ranked 17th in abundance (mean catch hr-1 = 0.014 ±0.019 2 SE), and was 17th in number of sites found (2 of 105 sites). It was only considered viable at one of those sites. Longsolid has not been reported from New York prior to this study (NYNHP 2010), and has not been collected in survey efforts since.

Management Unit: Middle Allegheny - Tionesta
State: Pennsylvania
(4) Contiguous population: Allegheny River
Year of last live or fresh dead observation: D. Smith 2006, USGS Leetown in Lit, also recent Hunter Station Bridge replacement relocations
Estimated occupied length: Approximately 78 mi (125 km) according to USGS data from 2003-2005 (Service 2018a, unpublished data). Villella and Nelson (2003, 2004, 2005), reported qualitative and quantitative sampling data from an extensive reach of the Allegheny River (Warren, PA to Kennerdell, PA). *Fusconaia subrotunda* was collected at 40 of 66 sites (at RM 16-90.4).
Notes: 22,300 (16030-36634) population estimate by Villella and Nelson 2005; Smith *et al.* 2001 (p. 123), report one L in 562 ¼ MSQ; MD = <0.01; QNTOT = 395; POP = 132 (18,600 MS) at a bridge replacement site on the Allegheny River at West Hickory, PA (Service 2018a, unpublished data) 258 L in 144 of 756 TR @ 40 of 63 sites; RM 6.8–119; QLTOT = 287,513; RA = <<0.01 (15th of 23 spp. L). In the Allegheny River, the species prefers the more "middle" reaches and is rare in the lowermost and uppermost reaches surveyed in the past. A big driver for the USGS survey work in the Allegheny is the fact that the Clubshell, *Pleurobema clava*, and the Northern Riffleshell, *Epioblasma rangiana*, occur in the river, and co-occur with *Fusconaia subrotunda* at some sites surveyed. This Longsolid population is linear with a highly-developed riparian zone. Current threats to unionids in the Allegheny River likely include channel maintenance activities, sedimentation, additional bridge replacement projects, and silvicultural activities (Butler 2007). Oil and gas extraction is accelerating in the watershed, and a large refinery in Warren, PA, is a potential source for pollutants. Zebra mussels are dense in Chautauqua Lake, a natural headwater lake in New York state. There is a possibility that Zebra mussels will move down the system, or upstream through the navigation channel into areas supporting the Longsolid population.

Management Unit: Middle Allegheny - Tionesta
State: Pennsylvania
(5) Contiguous population: Tionesta Creek
Year of last live or fresh dead observation: 1994, Bier
Estimated occupied length: Unknown. Likely less than 3.1 mi (5 km). Only one collection of a live specimen in this stream, by Bier (1994).
Notes: One reported as fresh dead from the Ohio State University Museum (OSUM) mollusk collection from one location in Forest Co., PA, 1994 (Catalog No. 57280); Bier *et al.* (1997, p. 42) reports collection of one living specimen at 3.6 mi (5.8 km) southwest of Kellettville, PA; Winters (1973, p. 18) reports collection of dead specimens and that the species was rare in Tionesta Creek at Starr, Forest Co., PA. This small, medium gradient river is located primarily within Allegheny National Forest, but is fragmented by downstream impoundments on Tionesta Creek and the Allegheny River. A recent PABFC survey conducted at Wurtemburg, PA for a bridge replacement did not detect Longsolid (Service 2018a, unpublished data).

Management Unit: French Creek
State: Pennsylvania
(6) Contiguous population: French Creek
Year of last live or fresh dead observation: 2005, Smith and Crabtree
Estimated occupied length: Approximately 50 mi (80 km), based on surveys by Smith and Crabtree 2010. Smith and Crabtree (2010, p. 396) report qualitative findings of 39 L at 7 of 29 sites; HE = 135; QLTOT = 7742; RA = 0.5% (18th of 24 spp. L). Smith and Crabtree (2010, p. 398) report 0.4-5 in (11-126 mm) lengths of the specimens found, mean length of 3.3 in (84.8 mm), and five recruits found at two of the seven sites surveyed. Smith and Crabtree (2010, p. 396) report quantitative findings of 32 Longsolid at nine sites in approx. 4000 ¼ MSQ; MD = 0.03; QNTOT = 12,743. Distribution does not appear to extend into New York portion of French Creek.
Notes: Davis and Bogan (1990a, p. 4, report 1) indicate that French Creek has great species diversity and that collections since 1950 have yielded individuals, but that the species is rare and endangered in the drainage, due to the contrasting number of pre-1950 collections of the species in the Allegheny River system (17) to the number of post-1950 collections (five). Estimated densities in French Creek, PA at six sites (Smith and Crabtree 2010, p. 399) per m^2: river kilometer 98 (0.22, SE 0.06), river kilometer 89 (0.04, SE 0.02), river kilometer 68 (0.01, SE 0.01), river kilometer 52 (0.01, SE 0.01), river kilometer 23 (0.01, SE 0.01), river kilometer 19 (0.01, SE 0.01). Additional summary information in Smith and Crabtree (2005, pp. 72-75). Bier (1994, pp. 82-93) reported 19 L/26 FD at 11 (L at 10) of 21 sites sampled qualitatively; QLTOT = >1747; RA = 0.01. Threats to the Longsolid in French Creek include nutrients from agriculture, aging septic systems, sedimentation, and municipal runoff and effluents. Oil and gas development wastes (e.g., brines, organics) are a concern in parts of the watershed. The Zebra Mussel is known from Edinboro Lake on a tributary in Erie County. Smith (2005) reported Zebra mussels at five sites from Crawford County downstream in 2004, but only 10 Longsolid individuals were located during quantitative sampling. Numbers remain low, but monitoring is warranted.

Management Unit: French Creek
State: Pennsylvania
(7) Contiguous population: Muddy Creek
Year of last live or fresh dead observation: 2003, Mohler *et al.*
Estimated occupied length: Approximately 9.3 mi (15 km), based on surveys by Mohler *et al.* (2006); 5 mi (7.9 km) total surveyed, with meanders 11.4 mi (18.3 km), species was found only at four sites
Notes: Only reported collections of the species in the drainage from Mohler *et al.* (2006); found 7 Longsolid at 4 of 20 sites; HE = 54.6; QLTOT = 2965; RA = 0.24% (15th of 22 spp. L). From Mohler *et al.* (2006): Even though the mussel community in the immediate portion of Muddy Creek we sampled is afforded some level of protection due to its location in the Erie National Wildlife Refuge, there are still threats to the integrity of the aquatic community from regional land development, commerce, and other influences (Mohler *et al.* 2006).

Management Unit: Middle Allegheny - Redbank
State: Pennsylvania
(8) Contiguous population: Allegheny River
Year of last live or fresh dead observation: 2005, Smith and Meyer
Estimated occupied length: Approximately 15 mi (25 km). Estimated based on previous collections of the species in this reach of the Allegheny River. Smith and Meyer (2010, p. 548) report collection of a dead specimen in Pool 6. They sampled five total sites, Pools 4-8.
Notes: Evans and Smith (2006, p. 5) report collection of two live individuals at one of 17 sites surveyed in Pools 4 & 6. Specimens were collected at RM 26.6 (pool 4, Allegheny RMs 26.6-27.3), RA = 0.40. Bogan and Davis (1990, p. 13, report #3) report pre-1920 collections of the species from Allegheny River Pools 5 (Godfrey, ARM 33) & 6 (Kelly, ARM 35.9). Davis and Bogan (1990b, p. 9, report #2) report

collection of one live individual at one station (4), 15 stations were sampled from Allegheny RMs 98.4-120.2. They also note it as very rare and recommend endangered status for the species in the river and state (p. 6). This population is isolated from other populations further upstream and downstream in the Allegheny River by reservoirs; Smith and Meyer (2010, p. 555): The lock-and-dam structures on the Allegheny River have altered the river from free-flowing, well-oxygenated riffles and runs into a series of deep, slower-flowing pools or lakes (Ortmann 1909a). Furthermore, the impoundments provide habitat for invasive species such as Zebra mussels, which are a documented threat to freshwater mussels (Ricciardi *et al.* 1998, Strayer and Malcom 2012) and were present in this study. Furedi (2013, p. 14) ranked the species in PA as extremely vulnerable to climate change (abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050). Also, specifically see pp. 43-44 for species account, which cites flooding and potential hydropower development.

Management Unit: Lower Allegheny
State: Pennsylvania
(9) Contiguous population: Allegheny River
Year of last live or fresh dead observation: 2005, Smith and Meyer
Estimated occupied length: Approximately 15 mi (25 km). Estimated based on previous collections of the species in this reach of the Allegheny River. Smith and Meyer (2010, p. 548) listed two live individuals collected in Pool 4 as unknown sex in the Allegheny River, PA during a quantitative survey. They sampled five total sites, Pools 4-8.
Notes: Evans and Smith (2006, p. 5) report collection of two live individuals at one of 17 sites surveyed in Pools 4 and 6. Specimens were collected at RM 26.6 (pool 4, ARM 26.6-27.3), RA = 0.40. Bogan and Davis (1990, p. 13, report #3) report pre-1920 collections of the species from Allegheny River Pools 5 (Godfrey, ARM 33) & 6 (Kelly, ARM 35.9). Davis and Bogan (1990b, p. 9, report #2) report collection of one live individual at one station (4), 15 stations were sampled from Allegheny RMs 98.4-120.2. They also note it as very rare and recommend endangered status for the species in the river and state (p. 6). This population is isolated from other populations further upstream and downstream in the Allegheny river by reservoirs. Furedi (2013, p. 14) ranked the species in PA as extremely vulnerable to climate change (Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050). Also, specifically see pp. 43-44 for species account, which cites flooding and potential hydropower development. Smith and Meyer (2010) indicate two large older individuals found at RMs 26 and 27. Few individuals encountered with large search effort, little evidence of reproduction, threatened immediately by dredging with high potential for extirpation.

Management Unit: Shenango
State: Pennsylvania
(10) Contiguous population: Shenango River
Year of last live or fresh dead observation: 2010, Nelson et al.
Estimated occupied length: Approximately 12.4 mi (20 km), based on unpublished PA Boat & Fish Commission Data; Nevin Welte
Notes: Nelson and Vilella (2010) report collections of 150 Longsolid @ 10 of 15 reaches, R @ 1 other; QLTOT = 12,241; RA = 1.2% (5th of 23 spp. L), and approx. 1000 R @ 1 of 2 reaches; QLTOT = 1. Bursey (1987, p. 43) reported the species as common in Mercer Co., PA ≥ 4 Longsolid @ 4 of 6 sites; HE = ~15; RA = 10% (4th of 13 spp. L); Nelson et al. (2010): 150 Longsolid @ 10 of 15 reaches, R @ 1 other; QLTOT = 12. Ortmann (1909a, p. 201) reported it as abundant in the Shenango River and as the "prevailing" species.

Management Unit: Connoquenessing
State: Pennsylvania
(11) Contiguous population: Slippery Rock Creek
Year of last live or fresh dead observation: 1991; unpublished PA Boat & Fish Commission Data; Nevin Welte
Estimated occupied length: Unknown. Approximately 12 mi (20 km) based on unpublished PABFC data. Only two collections of the species known from this stream, 1991 collection was one live individual.
Notes: There are only two known collections of the species from Slippery Rock Creek, both from 1991, one of a weathered dead valve, and one of a live specimen at the 488 bridge downstream. No negative data since. A Mill Dam and State Park are present in the vicinity of the live collection.

Management Unit: Little Muskingum-Middle Island
State: Ohio/West Virginia
(12) Contiguous population: Ohio River (Willow Island Pool)
Year of last live or fresh dead observation: 2016, Dr. Mike Hoggarth (WVDNR; Service 2018a, unpublished data)
Estimated occupied length: Unknown. The collection of the species in the Willow Island Pool by Hoggarth collection in 2016 has been called into question by WVDNR, due to lack of photo or voucher. Although the species likely occurred in this reach of the Ohio River pre-impoundment, neither Watters and Flaute (2010, p. 10) nor ESI (2000, p. 25) report the species from the Willow Island Pool.
Notes: Hoggarth reported 29 specimens associated with loading facility surveys on the Ohio River off both the Ohio (river right) and West Virginia (river left) banks. No vouchers or photos available.

Management Unit: Little Muskingum-Middle Island
State: West Virginia
(13) Contiguous population: Middle Island Creek
Year of last live or fresh dead observation: 2010, WVDNR (Service 2018a, unpublished data)
Estimated occupied length: Less than 3.1 mi (5 km). Only four total collections from the drainage, all in the vicinity of the Tyler/Doddridge county line. This area is a considerable distance from the Ohio River.
Notes: Only three individuals have been collected live from Middle Island Creek since 2000, with an additional two weathered dead individuals collected in a pipeline crossing survey. Less than 100 ever reported. Water quality was considered good by Taylor and Spurlock (1981, p. 157), but interestingly, the species was not reported from the drainage at that time. Land use is in forest, with scattered towns and sparse industry. At least one mill dam is present on the stream, which is proposed to be altered to allow more stream flow downstream, allow host fish passage, and allow for better mussel colonization. This stream receives large input of sediment from infrastructure development for the Marcellus gas industry. Gas and water pipeline construction, access road and wellpad construction. Water is used for fracking, dust control on roads, and hydrostatic testing of pipes. In 2010 water withdrawals from the stream during drought conditions lead to stranding and subsequent mortality of mussels (WVDNR; Service 2018a, unpublished data).

Management Unit: Little Muskingum-Middle Island
State: West Virginia
(14) Contiguous population: Meathouse Fork
Year of last live or fresh dead observation: 2000, WVDNR (Service 2018a, unpublished data)
Estimated occupied length: Tributary to Middle Island Creek; 3.7 mi (6 km). Only collections since 2000. Approximately 0.3 mi (0.5 km) upstream of confluence with Middle Island Creek.
Notes: Two collected live by WVDNR in 2000; only 27 ever collected in the drainage. Less than 100 ever reported. Since such small numbers of individuals have ever been collected in this stream it is difficult to make inferences of population size, likely a small population. From Clayton (2018, pers. comm.) 49 surveys have been conducted on Meathouse Fork since 1995. At least 10 of these have been

directly related to gas pipeline crossing. In 1998 16 individuals of F. sub were collected during a 420 min qualitative search effort. This site was later established as a long term monitoring site. Mark/Recapture survey (approximately 600m2) with significant sweeping (no excavations); surveyed in 2011 and 2016. No F. subrotunda were observed. In 2016 significant substrate scouring was oberved at the upstream end. Stream has been significantly impacted by Marcellus gas activities. Increased sediment load due to pipeline, well pad, and access road construction. Numerous pipeline crossings, open trench, of stream. Another compressor station is being built within the streams floodplain. County road along stream has been seriously degraded and has required bank stabilization activities due to heavy water and brine truck traffic. At least one truck has rolled into the stream. Landowners talk about brown surface film being evident over the weekends. Heavy oil sheen observed. This population will be extirpated, if not already, under current conditions.

Management Unit: Little Kanawha
State: West Virginia
(15) Contiguous population: Little Kanawha River
Year of last live or fresh dead observation: 2018, WVDNR (Janet Clayton)
Estimated occupied length: Approximately 101 mi (163 km). Based on surveys primarily by WVDNR since 2001 (WVDNR, 2016)
Notes: 1150 live individuals have been collected at sites qualitatively and quantitatively sampled by WVDNR since 2000 from 29 records, including an ongoing mark/recapture survey. WVDNR has two long term quantitative monitoring sites (Annamoraiah, est. 2014 & Burning Springs, est. 2011), data will produce information that can provide a population estimate of the species at these sites. In 2011, at Burning Springs, a 2500 m^2 area was surveyed using three random start (quadrat excavation) methodology. Estimated population size of *F. subrotunda* was 2083. The survey was repeated in 2016. The area was reduced to 2000 m^2 to concentrate efforts on the more dense mussel population. The estimated population size of *F. subrotunda* was 4750. At Annamoriah using the same methodology in 2014 a 2150 m^2 area produced an estimated population size of 614 individuals. Preferred habitat was much more limited at the Annamoriah site. Juveniles were observed during all three surveys. Burning Springs monitoring site on Little Kanawaha 2012 had 4 of 58 individuals of *F. subrotunda* less than 40 mm. This was a 5 by 10 m mark recapture area with significant sweeping only, no excavations. 11 of 71 < 40mm in 2016. From Schmidt *et al.* (1983, p. 132): The streams and rivers of the basin are turbid the majority of the year. While water quality is considered good, major problems include sedimentation due to soil conditions aggravated by timbering and oil and gas exploration and elevated fecal coliforms due to inadequate domestic wastewater treatment. Although the stream tends to be turbid due to the soils and land use within the area, since 2010 the stream is even more sediment laden, almost appearing as a mud flow at times. This is primarily due to the extensive Marcellus gas activities in the area. While the well pad and drilling in of itself has not been that detrimental, the needed transmission lines (both gas and water) and access roads have significantly impacted the area. While much of this activity has not directly affected the mainstem Little Kanawha (pipeline crossings), it has significantly impacted the watershed. Over 30 open trench pipeline crossings have occurred or close to construction since 2011. Six major FERC regulated gas lines are currently being constructed across WV. It is hoped that once these are completed (one in particular is responsible for many of the stream crossings in the Little Kanawaha Watershed) and all the associated adjoining lines that the sediment load to the State's mussel stream will significantly decline. The oil and gas coalition projects drilling for the next 50 years to be significant. As previously mentioned once the Marcellus is played out WV, OH, PA, and NY all contain another vast natural gas reserve, the Utica shale.

Management Unit: Little Kanawha
State: West Virginia
(16) Contiguous population: North Fork Hughes River
Year of last live or fresh dead observation: 2012, WVDNR (Janet Clayton)

Estimated occupied length: Approximately 12 mi (20 km) based on collections by Miller and Payne (2000). Apparently confined to Ritchie County. Tributary to the Hughes River, collections are considerable distance from Hughes River and largely concentrated below impoundment (North Bend Dam), which has a prescribed minimum flow of 1 cubic foot per second (cfs).
Notes: Miller and Payne (2000, p. 22) report collections of individuals at four sites (% abundance) 0.8 (site 28), 1.3 (site 29), 1.55 (Site 30), 6.67 (Site 32) in qualitative and one collected from eight sites quantitatively sampled. Size ranges 90.10 min – 115.50 max (0.03 in (0.78 mm)) indicates collection of larger, older individuals. Although less than 20 live individuals have been collected since 2000, this river is likely undersampled and the population may be larger in terms of extent. However, the North Fork Hughes River population is probably limited in terms of density, and larger size classes represented in surveys by Miller and Payne (2000) indicate older individuals potentially not reproducing. From Miller and Payne (2000, p. 2): The North Fork Hughes River lies in the Little Kanawha River Basin, within the Appalachian Plateau physiographic province. This province is characterized by steep hills, narrow ravines, and ridges. Valleys consist of broad bottoms and terraces of gravel, sand, silt, and clay. Water quality has been described as good, although sedimentation from eroding soils is often a problem (Schmidt *et al.* 1983). During construction of North Bend Dam, standing timber was left in place for fish habitat. During fall turnover of the lake dissolved oxygen levels have dropped to 0 throughout much of the lake. It is unknown what levels are reached at the discharge. Extensive Marcellus gas activities in the area. While the well pad and drilling in of itself has not been that detrimental, the needed transmission lines (both gas and water) and access roads have significantly impacted the area. Much of this activity has been upstream of the Dam which actually may help retain a small portion of the sediment load. There has been a new frack fluid processing plant placed above the lake. Associated with this is a salt landfill that is supposed to have 0 discharge. It is located on a small tributary of the North Fork so hopefully if there are issues, they can be addressed before reaching the North Fork.

Management Unit: Little Kanawha
State: West Virginia
(17) Contiguous population: Hughes River
Year of last live or fresh dead observation: 2018, WVDNR (Janet Clayton)
Estimated occupied length: Approximately 5 mi (8 km) based on collection by WVDNR (Service 2018a, unpublished data). Only two individuals collected in the Hughes River since 2000 - live specimens collected by WVDNR.
Notes: One collected live by WVDNR in 2014 and in 2018 (WVDNR 2014; Service 2018a, unpublished data); Less than 100 ever reported. Since only one individual has been collected in this stream it is difficult to make inferences of population size, likely a small population but benefits from upstream presence in NF Hughes and downstream presence in the Little Kanawha.

Management Unit: Tuscawaras
State: Ohio
(18) Contiguous population: Tuscawaras River
Year of last live or fresh dead observation: 1979, D. Stansbery (Ohio State Museum Collection)
Estimated occupied length: Less than 3.1 mi (5 km). The only contemporary collections of the species are upstream of Dover Dam, between Zoar and Dover.
Notes: Last reported collection of a live animal was by D. Stansbery at OSUM in August of 1979. From State Wildlife Action Plan (ODNR 2015, p. 96): The Longsolid is now limited to the Muskingum River system where it is rare, including Tuscawaras and Walhonding Rivers. Less than 100 ever reported. The continued presence of this species in the Tuscawaras River is tenuous. Enviroscience (2007, p. 5): The stream and especially its tributaries suffer a number of water quality impacts including habitat alterations, mercury and PCB contamination, municipal and industrial discharge, and others. P. 10: Increased use of agricultural chemicals, CSO releases, toxic spills and other sources may be a cause of the loss of native mussel fauna in the Tuscawaras. Another possible problem is that the immense numbers of Asian clams

found in the prime mussel habitat of the study site (and most probably other parts of the Tuscarawas River) may produce competition with indigenous freshwater mussel species.

Management Unit: Muskingum
State: Ohio
(19) Contiguous population: Muskingum River
Year of last live or fresh dead observation: 2011, (ESI, 2012) (Heidi Dunn)
Estimated occupied length: Approximately 28 mi (45 km). ESI (2012, pp. 125, 127) reported collection of one live at 1 of 10 sites, found below Beverly Dam using brail, estimated age 26-30 years. Prior to this collection, last reported documentation of the species in vicinity of Beverly Dam was 1977 (ESI 2012, p. 128). Enviroscience (2009, p. 38): Dead shell material collected below RM 90 in 2003-2004, considered rare in the drainage (Ohio Department of Natural Resources State Wildlife Action Plan 2015, p. 96).
Notes: From Watters and Dunn (1993-94, p. 252): This Ohio endangered species was found in all beds except Bed 2 (Beverly Dam). However a single specimen was found living some miles below that bed. It comprises 0.18% of the total fauna of the study area (lower 34 miles of the river). This was also a rare species in 1983, but Bates (1970) reported 93 specimens in 1970 from Bed 1 where it was the second most abundant species. By contrast, it was 16th in 1983 and 14th in the present study. This species has some commercial value, and if Bates' (1970) figures are correct, this species may have been over-harvested in that bed. Most specimens found in 1992 were old individuals, the youngest being a seven-year-old specimen in Bed 6. This is a rare species in the Ohio River, and the Muskingum River population may the only remaining within the state boundary. 20 L/FD at six beds in 240 ¼ MSQ; TOT = 11,145 (1875 L); RA = 0.18% (17th of 40 spp.). Of importance is that Bates in 1970 found 93 Live at Bed 1 later sampled by Watters and Dunn (1993-94), indicating significant decline of this population. The occupied reach of the Muskingum river is highly fragmented by impoundments, and Watters and Dunn (1993-94, p. 258) state: It is foreseeable that a single major environmental accident upstream, such as an oil or pesticide spill, could irreparably damage or even eliminate this fauna. One such spill, although apparently minor and well contained occurred in 1992. They also cite potential dam removal and associated silt and sediment loads, dredging activities and harvesting pressure as long-term impacts on the mussel fauna in the Muskingum River. Additionally, ESI (2012) did extensive surveys related to proposed hydropower development at existing dams, and cite changes in shear velocity as potentially affecting substrate and unionid communities.

Management Unit: Walhonding
State: Ohio
(20) Contiguous population: Walhonding River
Year of last live or fresh dead observation: 1993, Dr. Mike Hoggarth; Relic reported by Ahlstedt (2009)
Estimated occupied length: Approximately 9 mi (15 km). The most recent collection of this species live in the Walhonding River is below Six Mile Dam, which is slated for removal (Boyer, 2018, pers. comm.). The currently occupied reach is considered to be between Six Mile Dam and the mouth of Killbuck Creek.
Notes: From Hoggarth *et al.* (1995-96): during the present study, the Longsolid was taken alive at two sites and as old dead shells at seven other sites. Although rare within the river, it was frequently found in the fast riffle and run habitats at RM 22.2. This species comprised 0.27% of the unionid fauna of the river but only 0.09% of the living mussels collected. From Hoggarth *et al.* (1995-96): 7 Longsolid at two of 19 sites, 16 R at seven others; QLTOT = 7997; RA = 0.1% (tied for 23rd of 31 spp. L). Less than 100 ever reported. From Enviroscience (2010, p. 9): Several state of Ohio endangered species were found and include the Longsolid (*F. subrotunda*), sharp ridged pocketbook (*L. ovata*), and Ohio pigtoe (*P. cordatum*). Although only one Longsolid was collected live, there is a good mussel community in this reach of the river and potential for population expansion. Six Mile Dam is a low-head dam at approximately RM 9 that impounds a 0.5-mi (0.8-km) reach of the Walhonding. Gravel mining also

occurs in the lower portion of river below Six Mile Dam. An upstream impoundment on the Walhonding River, Mohawk Dam (~RM 17.5), was built on the main stem in 1936 and operates as a “dry dam” to temporarily control flood waters. Some developmental and agricultural pressure occurs, particularly upstream of Mohawk Dam.

Management Unit: Upper Kanawha
State: West Virginia
(21) Contiguous population: Kanawha River
Year of last live or fresh dead observation: 2018, WVDNR (Janet Clayton)
Estimated occupied length: Approximately 22 mi (35 km). Although the species has been collected sporadically in the Marmet and London pools of the Kanawha River since 2000, the best remaining mussel habitat is the 5 mi unimpounded reach between London Pool and Kanawha Falls upstream.
Notes: Douglas (2000, pp. 7-12) reported 147 live at three sites on the Kanawha River QLTOT = 829, “dominant, most abundant species”. Taylor (1983a, p. 9) reports that the species made up 26% of the total mussel population historically from shells recovered from the archeological deposits at the Buffalo Site in Putnam Co. From Clayton (2018, pers. comm.): In The Kanawha River, bulk of population is within the 5 mi reach of non-impounded riverine habitat from Kanawha Falls downstream to Deepwater near the head of the London Pool. Smaller densities occur within the London and Marmet Pools. No dredging occurs except for fleeting areas and the upstream and downstream approaches of the lock chambers. Most navigation traffic is related to the coal industry and as that declines so will the traffic. There was at least some commercial sand and gravel dredging in the London Pool, which has had very little survey work but not any in at least 20 years if not longer. WVDEP discussed the mining impact from the three main tributaries were Cabin Creek, Paint Creek, and Loop Creek. The coal mine associated with discharging into Cabin Creek was required to install a diffuser and release directly into the Kanawha River. Through Section 7 consultation, the discharge was required to meet reduced chloride levels to ensure the protection of the federally listed Fanshell. In the impounded sections in the lower ends of the navigational pools, specifically the Marmet Pool, there is a large amount of coal fines evident in the predominantly sandy/gravel substrate. Much of this from the commercial barge traffic and fleeting areas where coal is loaded and off-loaded. This is based on WVDNR survey (mussels and habitat) from 2005 to 2009 of the entire Marmet Pool of the Kanawha River. Long-term monitoring site at Kanawha Falls consists of a 50 by 100 m three random start (RS) quantitative survey area and a 25 by 25 m mark recapture area. The 3RS area has been surveyed 3 times from 2005 to 2016. Longsolid estimated densities have ranged from 1481 in 2017 to 2533 in 2005. The difference in estimated densities is most likely related to the number of quadrat excavations conducted (108 and 300 respectively). A total of 705 Longsolid have been tagged within the mark/recapture area from 2005 to 2015. Mortality over the 15 year period was only estimated at 2.7%. Even if you include the untagged dead shell collected in 2015 the mortality estimate was 10.2% which is equivalent to 1% annual mortality. Threats within the occupied reach include coal mining as mentioned above and below, threat of commercial fleeting attempting to expand to the head of navigation, and spills from vehicle transport along State Route 60 and CSX railroad. A train derailment occurred in 2014 releasing Bakken crude oil and subsequent fire. No mussel mortality was apparent as a result of the event. There is the possibility of future events that could result in toxic spills as railroad traverses both sides of the river.

Management Unit: Elk River (WV)
State: West Virginia
(22) Contiguous population: Elk River
Year of last live or fresh dead observation: 2015, WVDNR (Janet Clayton)
Estimated occupied length: Approximately 78 mi (125 km). Probably the largest remaining population in the Ohio Drainage in terms of density and extent.
Notes: ESI (2009) report 360 Longsolid; QLTOT = 4175; RA = 8.6% (3rd of 21 spp. L). Clayton (1994, p. 7) reported ≥18 Longsolid @ 18 of 21 sites from surveys in 1991-1992. Taylor and Hughart (1981, p.

23) report 8 Live/Fresh Dead at 8 of 15 sites on the Elk River, WV. The best location unionids is below Kanawha Falls (Butler 2002). Taylor (1983a, p. 60) in an extensive survey of the entire river, reported 264 Longsolid @ 12 of 14 sites; QLTOT = 3024; RA = 8.8% (3rd of 27 spp. L). Morris and Taylor (1978, p. 153) state that timbering and surface mining in the upper Kanawaha River contributes sizable sediment loads, and that the river for decades has had low water quality resulting from industrial, urban organic sewage, and acid mine runoff pollution. P. 155: Limiting factors for absence of unionids at lower sites may include industrial wastes, urban organic enrichment, and habitat destruction resulting from navigational impoundment, as well as the presence of the introduced Asian Clam, Corbicula. Threats to the Longsolid include sedimentation, mine runoff, and developmental activities in the narrow band of bottomlands along the deeply entrenched Kanawha River. Chemical spills are an ongoing threat with the concentrations of railroad and highway rights-of-ways that lie immediately parallel to the river. On June 12, 2014, a closed fly ash landfill discharged ash into the Kanawha River at Deepwater, London Pool, Fayette County, West Virginia (WVDNR 2015). The potential for chronic impacts associated with the ash spill to mussel resources continues, and fly ash still covers the Kanawha River substrate (WVDNR 2015). The Kanawha River valley contains significant deposits of coal and natural gas, and is dredged for navigation. Dunn *et al.* (2000, p. 179) report recovery and survival of 10 relocated individuals at 1 grid site on Elk River, WV in 1994. 0.02 in (0.5 mm) growth in 1 year, no movement. From Butler (2007): Land use is primarily in forest, agriculture, and occasional towns. Primary threats include silvicultural activities, coal mining, and natural gas exploration and production. Riparian and floodplain roads and development raise concerns with contaminant runoff. Straight piping, sedimentation (especially from Big Sandy Creek in northeastern Kanawha County), and localized channel alterations are also threats. Sutton Dam impounds ~15 RMs and impacts tailwater habitat. ESI (2009, p. 19) cite abandoned mine lands, inadequate sewage treatment and erosion as being the primary factors currently affecting the Elk River unionid fauna, but also Cold water releases from Sutton Dam between 1960-1980 contributed to lack of mussel recruitment and population densities.

Management Unit: Lower Levisa
State: Kentucky
(23) Contiguous population: Levisa Fork
Year of last live or fresh dead observation: R. Cicerello, KSNPC 1999
Estimated occupied length: Approximately 15 mi (25 km) based on data collected by Kentucky State Nature Preserves Commission (Service 2018a, unpublished data)
Notes: From Haag and Cicerello (2016, p. 139): The population in the lower Big Sandy River drainage is small. Less than 100 ever reported. Haag and Cicerello (2016, p. 138) indicate collections in the drainage since 1990. Cicerello *et al.* (1991, p. 118) considered it to be sporadic and rare in the Big Sandy River drainage (including Levisa Fork). Haag and Cicerello (2016, p. 20): Water quality in nearly the entire watershed is seriously and profoundly de-graded by coal mining. Water quality also is degraded by oil drilling, and domestic and municipal pollution.

Management Unit: Raccoon-Symmes
State: Ohio/West Virginia
(24) Contiguous population: Ohio River (lower Gallapolis Pool, upper Greenup Pool)
Year of last live or fresh dead observation: 1999, ESI (Heidi Dunn)
Estimated occupied length: The Greenup Pool, Ohio RMs 282.5-292.8 is one of the few upper Ohio River impoundments that has had collections of live specimens in the past 30 years, and these were only larger individuals estimated to be older than 25 years (ESI 2000, pp. 60, 66). Twenty-one individuals were collected in 1998-99 (three brail, 17 qualitative sampling, one quantitative sampling; 2.9-3.5 in (73-88 mm), one aged at 29 years) (ESI 2000, p. 64). Fleece (2012, p. 26) reports collection of one weathered shell from Meigs Co., OH, from three sites between RMs 255.25-253.75 in the Gallapolis = Byrd Pool. Miller and Payne (1995, p. 12) report collection of *F. subrotunda* through qualitative sampling at two sites, rivermile 287.2 and 284.0. Miller and Payne (1995, pp. 20, 21) also reported collecting the species

at ORM 284.0 (4 % Abundance, 2.5 % occurrence) during 1993 quantitative sampling, as well as during qualitative sampling at ORM 287.2 (0.16 % Abundance, 1.75 % occurrence), 284.0 (0.08 % Abundance, 1.39 % occurrence) (pp. 12, 13). Total numbers of the species collected were not reported, but WVDNR, has six live specimens recorded from these collections, although they are reported as from Gallapolis (Byrd) Pool (WVDNR Database ID 174; Service 2018a, unpublished data).
Notes: Spurlock 1981, p. 43 reported the Longsolid to be the dominant species, comprising 20% of the mussel fauna at 2 midden sites in Mason County, WV. Haag and Cicerello (2017, p. 139) state that it is now 'extremely rare in the Ohio River,' and report collections in the lower Ohio since 1990. Contemporary surveys indicate that the species is extant in possibly three of the 11 formerly occupied Ohio River pools (Watters and Flaute 2000). Only one recent WVDNR Subfossil record of *F. subrotunda*, in 2016, at RM 284, in the Greenup Pool. Considered rare in the Ohio River from Greenup to Pittsburgh by Taylor (1980, p. 27) collected as subfossil shells only at RM 97 (Hannibal Pool), 284 (Greenup Pool). WVDNR mussel database has collections of live specimens made by Miller & Payne (1998). In qualitative sampling, two were collected at Ohio RM 284.0 LDB, three were collected at Ohio RM 287.2 LDB in 1998 (WVDNR Database IDs 1713 & 1715), and 1 was collected at RM 292.0 RB, and 1 was collected at 287.2 RDB in 2003 (WVDNR Database IDs 1289 & 418). The 1998 collections were noted in ESI (2000, p. 64). Due to the lack of survey efforts targeting the species in the Ohio River, it is difficult to make inferences about the current status of the population, but all indications point to a significant decline, and the loss of the species from over 200 RMs in the upper Ohio River mainstem. Large river habitats are under-surveyed, and it is likely the species survives in low numbers in various pools upstream of Cincinnati, OH, but it has not been detected in a recent survey of the Greenup Pool. Threats include the non-native zebra mussels, Corbicula, industrial pollution, excessive sedimentation, municipal wastewater overflows, channelization, dredging for navigation channel, barge traffic (scour and wave disturbance from tows). From Butler (2002, p. 14): Navigational improvements on the Ohio River began in 1830 (Cicerello *et al.* 1991), leading to the construction of 53 locks and dams by the 1960s. Since that time, several high level locks and dams were constructed and replaced all but the two lowermost older and smaller structures (Williams and Schuster 1989). Today, 18 (16 high and 2 low) locks and dams impound nearly the entire 981 mile length of river (all but the lowermost portion near the Mississippi River confluence). Threats, such as chemical spills that cause major mussel kills, Chemical Contaminants, maintenance dredging, and the zebra mussel invasion are primary threats in the Ohio River. Although the zebra mussel population growth appears to have slowed, damage to existing mussel beds was realized and continue to impact native mussels over time.

Management Unit: Middle Ohio-Laughery
State: Indiana/ Kentucky
(25) Contiguous population: Ohio River (Markland Pool)
Year of last live or fresh dead observation: 2016, Lewis Environmental Consulting (Chad Lewis)
Estimated occupied length: Unknown. Collected live near Ohio RM 528 by Chad Lewis (unpublished Kentucky Department of Fish and Wildlife data). Last reported by Goodrich and van der Schalie (1944, p. 307). Approximately 25 mi (40 km) from Markland Dam to Gallatin/Boone county line.
Notes: Spaeth *et al.* (2015, p. 32) report collection of a subfossil shell from the Markland pool. Lewis Environmental Consulting (2016) report collection of one live individual in recent surveys (2016) on Kentucky side (River Left - Left descending bank). Due to the lack of survey efforts targeting the species in the Ohio River, it is difficult to make inferences about the current status of the population, but all indications point to a significant decline, and the loss of the species from over 200 RMs in the upper Ohio River mainstem. Large river habitats are under-surveyed, and it is likely the species survives in low numbers in various pools downstream of Cincinnati, OH, but it has not been detected in numerous mussel surveys near the site of the proposed Olmsted L&D, and is currently considered extirpated from the states of Illinois and Indiana. Threats include the non-native zebra mussels, Corbicula, industrial pollution, excessive sedimentation, municipal wastewater overflows, channelization, dredging for navigation channel, barge traffic (scour and wave disturbance from tows). On Monday August 18, 2014, an

inadvertent discharge of diesel fuel was released on land and drained into Markland Pool of the Ohio River at Duke Energy's W.C. Beckjord Station (Beckjord) in Clermont County, Ohio (ESI 2015). It is estimated that 9,000 gallons were released during a transfer of fluids near Ohio River RM 452.6 (ESI 2015, p. 6)

Management Unit: Licking
State: Kentucky
(26) Contiguous population: Licking River
Year of last live or fresh dead observation: 2015, Kentucky Department of Fish & Wildlife (Monte McGregor)
Estimated occupied length: Approximately 93 mi (150 km) according to multiple data sources in Kentucky. Laudermilk (1993, p. 46) reported collecting the species at 17 of 69 sites on the mainstem Licking River, and described the species as occasional, but locally abundant with regards to distribution in the Licking River.
Notes: Haag and Cicerello (2016, p. 138) indicate collections in the drainage since 1990, and consider it to be generally distributed to occasional in the Licking River drainage. The upper Licking River contains one of the largest remaining populations in Kentucky, and it can be locally common and shows evidence of recruitment (Haag and Cicerello 2016, p. 139). KDFW data (2017, pers. comm.) from the Licking River indicate collections at multiple sites since 2002, and collection of juveniles. A linear population distributed below Cave Run Lake Dam. Water quality problems in the Licking River drainage are nutrients, bacteria, and sediments. Also, lack of stream buffers, channelization, wastewater discharge are cited as contributing to water quality problems (KYDOW 1998).

Management Unit: Licking
State: Kentucky
(27) Contiguous population: Slate Creek
Year of last live or fresh dead observation: 1993, E. Laudermilk
Estimated occupied length: Unknown, likely less than 3.1 mi (5 km). Laudermilk (1993, p. 46) surveyed 10 sites and detected the species at two sites but considered it sporadic and rare with regards to distribution in the drainage.
Notes: Considered rare. Water quality problems in the Licking River drainage are nutrients, bacteria, and sediments. Also, lack of stream buffers, channelization, wastewater discharge are cited as contributing to water quality problems (Kentucky Division of Water, 1998).

Management Unit: Rolling Fork
State: Kentucky
(28) Contiguous population: Rolling Fork River
Year of last live or fresh dead observation: 2018, Monte McGregor
Estimated occupied length: Only 1 individual recorded (McGregor 2018).
Notes: Although species considered extirpated from Salt River drainage, M. McGregor found 1 live individual in the Rolling Fork in 2018. The Rolling Fork is a major southern tributary of the Salt River in central Kentucky, flowing in a northwesterly direction to join the Salt near its mouth.

Management Unit: North Fork Kentucky
State: Kentucky
(29) Contiguous population: North Fork Kentucky River
Year of last live or fresh dead observation: R. Cicerello 1997, KSNPC.
Estimated occupied length: Approx. 15.5 mi (25 km) based on unpublished Kentucky State Nature Preserves Commission data.
Notes: Haag and Cicerello (2016, p. 138) indicate collections in the drainage since 1990. However, they also note that populations in the Kentucky River drainage are small and that the species is generally

distributed to occasional in the Kentucky River drainage (Haag and Cicerello 2016, p. 139). Kentucky State Nature Preserves Commission collections from Lee and Breathitt Counties.

Management Unit: South Fork Kentucky
State: Kentucky
(30) Contiguous population: South Fork Kentucky River
Year of last live or fresh dead observation: 2015, KSNPC (Mike Compton)
Estimated occupied length: Approximately 6.2 mi (10 km) according to Evans (2010). Evans (2010, p. 39) collected 21 live *F. subrotunda* at eight of 35 sites sampled in the lower reaches of the stream from near the mouth of Buffalo Creek to near Booneville, sizes ranged from 3.5-5 in (90–129 mm) length (p. 60). Evans (2010, p. 13): Mucket-Medium River assemblage: This group is dominated by Actinonaias ligamentina, as well as most of the rare species in the basin (*Epioblasma triquetra, Fusconaia subrotunda, Obovaria subrotunda, Villosa lienosa*). With the exception of one location in the lower Redbird River, where very high quality habitat occurred, this was the dominant assemblage from stations in the reach above Buffalo Creek to the lower sections of the South Fork Kentucky River. It generally was found in areas greater than 463 mi^2 (1,200 km^2).
Notes: Evans (2010) is the only recent substantial survey, based on his results less than 100 live specimens have ever been collected from this river. Haag and Cicerello (2016, p. 138) indicate collections in the drainage since 1990. However, they also note that populations in the Kentucky River drainage are small and that the species is generally distributed to occasional in the Kentucky River drainage (Haag and Cicerello 2016, p. 139). From Evans (2010): Threats observed to the mollusk fauna in the South Fork Kentucky basin are numerous. Overall, perturbations to the mollusk fauna of the basin likely stem from water quality and habitat conditions as opposed to a net hydrological alteration in the basin. In the Goose Creek watershed, coal mining and floodplain agriculture has taken a visible toll on the mussel fauna. Coal deposits, in the form of coal fines and coal pieces, were visible at many sites in mainstem Goose Creek. Further, several areas examined in Goose Creek were scoured down to bedrock, possibly as a result of long-term hydrological alterations in the watershed and a complete lack of riparian area along several stretches of the mainstem. Lower sections of Collins Fork (RK 4.0 to 10.5), is listed on the KY DOW 303(d) list as being impaired due to sedimentation (KY DOW 2008). Acid drainage was noted on the South Fork Kentucky coming out of several tributaries; namely the confluences of Indian Creek, Fish Creek, Matton Creek, and in Booneville above KY 28 bridge. Coal and coal fines was present in the river in the Chestnut Gap area upstream of Booneville and acid seeps were seen coming into the river in the area west of Eversole in this river reach. At one of the lowermost sites on the Redbird River a new surface mining operation upstream of Laurel Branch was beginning operation during this study.

Management Unit: South Fork Kentucky
State: Kentucky
(31) Contiguous population: Redbird River
Year of last live or fresh dead observation: Although not reported by Evans (2010), likely occurs in the Redbird River, which is the largest tributary to the SF KY River (Koch 2018, pers. comm.)
Estimated occupied length: Unknown; population extent is likely small
Notes: Haag and Cicerello (2016, p. 138) state that populations in the Kentucky River drainage are small and that the species is generally distributed to occasional in the Kentucky River drainage (p. 139).

Management Unit: Lower Kentucky
State: Kentucky
(32) Contiguous population: Kentucky River
Year of last live or fresh dead observation: 1996, KSNPC (R. Cicerello)
Estimated occupied length: unknown; Approximately 31 mi (50 km) according to unpublished Kentucky State Nature Preserves Commission Data.

Notes: Only contemporary collections known from unpublished KSNPC data. Populations in Lower Kentucky river are small (Haag and Cicerello 2016, p. 139). Haag and Cicerello (2016, p. 138) indicate collections in the drainage since 1990. However, they also note that populations in the Kentucky River drainage are small and that the species is generally distributed to occasional in the Kentucky River drainage (p. 139). Listed as common throughout the Kentucky River Basin in Danglade (1922, p. 5).

Management Unit: Upper Green
State: Kentucky
(33) Contiguous population: Green River
Year of last live or fresh dead observation: 2016, KYDFW (Monte McGregor)
Estimated occupied length: Approximately 311 mi (500 km). Likely extends the length of the Green River within this HUC below Green River Dam. Cicerello (1999, p. 21) reported on collections made at 25 quantitative and 15 supplemental sites from 1996-1998. He collected 38 live *F. subrotundaat* 14 of 25 quantitative sites surveyed from Green River Lake Dam (Green River RM 303.9) to Mammoth Cave National Park (Green River RM 209) and live specimens were collected from two supplemental sites. Layzer *et al.* (2001, p. 12) report collecting seven total live specimens from three sites in the Green River between river kilometer 489.1 and 343.6. The species accounted for 0.47% of the live mussels collected and was ranked 14th in terms of abundance (Layzer *et al.* 2001, p. 21). Cicerello (1999, p. 21) also states live specimens were found at nine sites extending from MCNP upstream to the Little Barren River confluence. Rahm (2008, p. 21) reports collection of 28 adults and three juveniles at a site on the Green River near Munfordville, 76 mi (122 km) downstream of the Green River Dam. Size of juveniles was < = 1.2 in (31 mm).
Notes: Layzer *et al.* (2001, p. 16) report collecting 10 individuals from eight sites in 2.7 ft^2 (0.25 m^2) quadrats. At site 5 (Munfordville, KY), Layzer *et al.* (2001, p. 17) compare numbers of *F. subrotunda* collected over a 6-year period from 1994-2000, and *F. subrotunda* was only collected in 2000 (5 total). Also, they report collection of individuals less than 1.6 in (40 mm) total length (less than 5 years old) at three of eight sites surveyed, indicating recruitment of the species at these sites. The species accounted for 0.47% of the live mussels collected and was ranked 14th in terms of abundance (Layzer *et al.* 2001, p. 21). Cicerello (1999, p. 21) collected 38 *F. subrotunda* live at 14 of 25 quantitative sites surveyed from Green River Lake Dam (Green River RM 303.9) to Mammoth Cave National Park (Green River RM 209) and live specimens were collected from two supplemental sites. McGregor *et al.* (2009) report relative abundances of *F. subrotunda* increased during quantitative sampling at Thomas Bend (RM 234) between 2004 (2.29) to 2009 (2.79). Although there are multiple dams on the Green River mainstem, there is a large amount of riverine habitat available in numerous reaches. The KY CWCS (2015) lists the following as threats to the species: aquatic habitat degradation, loss of fish hosts, point and non-point source pollution, siltation and increased turbidity. Cochran and Layzer (1993, p. 64) determined that mussels in the middle Green and Lower Barren Rivers selected habitats that were less impacted by commercial harvest activities although harvest was lighter in the Barren than the Green.

Management Unit: Barren
State: Kentucky
(34) Contiguous population: Barren River
Year of last live or fresh dead observation: 2016, KYDFW (Monte McGregor)
Estimated occupied length: Unknown. Potentially less than 15.5 mi (25 km) based on recent collections, but Haag and Cicerello (2016) have records since 1990 extending all the way up to Barren River Lake Dam. LEC (2008, p. 57) reported collection of live *F. subrotunda* at two sites in qualitative and quantitative surveys; one at RM 9.7, two at RM 12 (p. 61) downstream of Lock & Dam 1 in quantitative surveys associated with pipeline crossings. Gordon and Sherman (1995) report 3 L/1 FD at 4 of 38 sites, R at other site; HE = 5.3 @ 3 L sites.
Notes: Haag and Cicerello (2016, pp. 138, 139) indicate collections in the drainage since 1990, but that the population in the Barren River drainage (lower Green) is small. Weiss (1993, p. 65) reported six live

at four of five sites surveyed using timed diving and quantitative quadrat searches. Cochran and Layzer (1993, p. 63) report collection of one individual in 1990 and 4 individuals in 1991 from the Barren River using quantitative sampling, from two sites below Lock and Dam No. 1 near Richardsville, KY. Although fragmented by dams, potentially some dispersal of host fishes between the lower Barren and Green Rivers. There are multiple dams on the Barren River mainstem. The KY CWCS (2015) lists the following as threats to the species: aquatic habitat degradation, loss of fish hosts, point and non-point source pollution, siltation and increased turbidity. Cochran and Layzer (1993, p. 64) determined that mussels in the middle Green and Lower Barren Rivers selected habitats that were less impacted by commercial harvest activities although harvest was lighter in the Barren than the Green.

Management Unit: Middle Green
State: Kentucky
(35) Contiguous population: Green River
Year of last live or fresh dead observation: 2011, LEC (Chad Lewis)
Estimated occupied length: Unknown. Potentially as much as 40.4 mi (65 km) based on recent collections and Haag and Cicerello (2016). Recent live collections of the species have been between Rockport and Woodbury, Butler and Muhlenburg counties, Kentucky (Monte McGregor, KDFW) (Service 2018a, unpublished data). LEC (2011, p. 140) reports collections of *F. subrotunda* from the middle and lower Green River; they collected six individuals in pool 4.
Notes: Morey and Crothers (1998, p. 913) report the species was once a dominant component of the pre-impoundment mussel fauna at the Hayes Site, a Archeological Site on the Green River in Butler County. It was the third-most abundant species represented in material excavated from the site which is located between Green River RMs 102 and 155. Although there are multiple dams on the Green River mainstem, there is a large amount of riverine habitat available in numerous reaches. The KY CWCS (2015) lists the following as threats to the species: aquatic habitat degradation, loss of fish hosts, point and non-point source pollution, siltation and increased turbidity.

Management Unit: Lower Green
State: Kentucky
(36) Contiguous population: Green River
Year of last live or fresh dead observation: 2011, LEC (Chad Lewis)
Estimated occupied length: Unknown. LEC (2011, p. 140) reports collections of *F. subrotunda* from the lower and middle Green River. They collected four individuals in pool 2, one individual in pool 3.
Notes: Haag and Cicerello (2016, p. 139) indicate populations in the lower Green River drainage are small. There are multiple dams on the Green River mainstem, and there is the least amount of riverine habitat available in the lowermost reaches. The KY CWCS (2015) lists the following as threats to the species: aquatic habitat degradation, loss of fish hosts, point and non-point source pollution, siltation and increased turbidity. This reach of the river was more heavily impacted by towboats before reduced commercial traffic (Miller *et al.* 1994, p. 53) also cite hypolimnetic discharges as an impact to the lower Green River mussel fauna.

Management Unit: Highland-Pigeon
State: Kentucky
(37) Contiguous population: Ohio River (Cannelton Pool)
Year of last live or fresh dead observation: Unknown; Only extant occurrence is based on Haag and Cicerello (2016, p. 138); Henderson Co., Kentucky
Estimated occupied length: unknown; "Formerly generally distributed to occasional in the Ohio River…" (Haag and Cicerello 2016, p. 138).
Management Unit: Lower Ohio-Little Pigeon
State: Kentucky

(38) Contiguous population: Ohio River (Newburgh Pool) Lower Ohio - Little Pigeon HUC 8
Year of last live or fresh dead observation: Unknown, Likely Chad Lewis 2000s. Only extant occurrence is based on Haag and Cicerello (2016, p. 138).
Estimated occupied length: Only extant occurrence is based on a KDFW record of a collection of a weathered dead shell by Chad Lewis in 2008, and Haag and Cicerello (2016, p. 138).

Management Unit: Lower Ohio
State: Kentucky
(39) Contiguous population: Ohio River (L&D 52, 53)
Year of last live or fresh dead observation: Unknown; Only extant occurrence is based on Haag and Cicerello (2016, p. 138), McCracken Co., Kentucky
Estimated occupied length: "Formerly generally distributed to occasional in the Ohio River…" Haag and Cicerello (2016, p. 138).

CUMBERLAND RIVER BASIN

Management Unit: Lower Cumberland-Old Hickory Lake
State: Tennessee
(40) Contiguous population: Cumberland River (Old Hickory Reservoir)
Year of last live or fresh dead observation: 2011, TWRA (Don Hubbs)
Estimated occupied length: Approximately 19 mi (30 km). Cumberland River RM 281-300 (Rome Landing to Lock 7; and Hartsell to Rome Island)
Notes: Collected live during TWRA dive survey work within the TWRA Rome Landing Mussel Sanctuary in 2011 (TWRA 2011): three at Cumberland River RMs 292-300 (Rome Landing to Lock 7) - 0.05 CPUE/hour (60 hrs), 0.10% abundance (Hubbs 2012, p. 27); one collected live at Cumberland River RMs 281-291 (Hartsell to Rome Island) - 0.10 CPUE/hour (10 hrs), 2.50% abundance (Hubbs 2012, p. 28). This represents the last remaining population in the Cumberland River drainage (Haag and Cicerello 2016, p. 139). Parmalee *et al.* (1980, p. 95) report eight individuals collected live from a commercial mussel bed on the Cumberland River, Smith Co., TN (Bartletts Bar, CRM 296.8) at depth 15 ft (4.5 m) (2.09 % of composition at site). The species was also reported from two prehistoric rock shelter deposits on the Cumberland River (Parmalee *et al.* 1980, p. 101). A crow-foot brail was used for these surveys. Dennis (1984, p. 434) reported recent collection of the species from the Cumberland River RMs 270-305, and classified the species as primarily occurring in small to medium sized streams and large rivers, p. 69. A crow-foot brail was used for these surveys. From Hubbs (2012, p. 3): Historically the Cumberland River contained a diverse mussel fauna with approximately 80 species reported from the drainage (Wilson and Clark 1914); however, habitat alteration from impoundment and maintenance dredging of the navigation channel has substantially reduced the species richness and abundance. Mussel habitat is highly fragmented in the main channel throughout the 310 mi (499 km) reach in the Tennessee portion of the Cumberland River from the Kentucky/Tennessee state line (mile 385) near Celina, TN downstream to the Kentucky/Tennessee state line near Tobaccoport (mile 75). The upper reach of Old Hickory Reservoir located between Carthage and Lebanon, runs 49 RMs and contains much of the physical habitat favorable to mussel colonization and still holds approximately 33 species including 13 state GCN and five federally endangered. Mussel recruitment in this reach of the Cumberland River has long been suppressed by cold water resulting from the hypolimnetic releases from upstream reservoirs (Wolf Creek, Dale Hollow, and Center Hill).

TENNESSEE RIVER BASIN

Management Unit: Holston
State: Tennessee
(41) Contiguous population: Holston River
Year of last live or fresh dead observation: 2002, TVA (Steve Fraley)
Estimated occupied length: Reach below Cherokee Dam to Tennessee River (Ft. Loudon Reservoir) is approximately 25 mi (40 km). Fraley (2002, p. 10) report 44 L total in qualitative surveys in reach downstream of Cherokee Dam to Tennessee River. The species was found live at 7 of 20 sites, and mussels from all sites reported in good condition.
Notes: Was once a dominant component of the mussel fauna of the Holston River. Parmalee and Faust (2006, p. 74) reported it to be the three most abundant species from two archaeological sites and four muskrat deposits along the lower Holston River. Probably decreasing population trend; Parmalee and Faust (2006, p. 75) found that *F. subrotunda* shells indicate it was the third most abundant species of 50 species collected from six prehistoric sites on the Holston River, and it was represented at all sites. Parmalee and Faust (2006, p. 77) state: Since construction of Cherokee Dam in 1941 until 2006, approximately 75% of the naiad taxa have been extirpated in the lower Holston River downstream from the Dam. Primary impacts from the dam include large fluctuations in discharges, water temperatures, and water depth.

Management Unit: Upper French Broad
State: North Carolina
(42) Contiguous population: Little River
Year of last live or fresh dead observation: 2018, NCWRA (Luke Etchison)
Estimated occupied length: Approximately 5 mi (8 km). This small population occurs downstream of a water supply dam which impounds Cascade Lake, and is the only known extant population in the French Broad River drainage in North Carolina.
Notes: Very small, but recruiting population. This is the last remaining population in the upper French Broad River system. The man-made water supply dam - Cascade Lake - holds back considerable Little River sediments that provide for good habitat conditions downstream. From Schwartzman (2008, p. 406): Flooding in September 2004, associated with the remnants of Hurricanes Ivan, Frances, and Jeanne, was particularly severe in the French Broad and the Catawba River Basins. NCWRC biologists conducted mussel surveys in these basins before and after the 2004 floods to characterize the effects on mussel populations. Stream habitat heterogeneity, presence of flow refuges, and natural channel design with a functioning floodplain all appear to contribute to habitat preservation, and therefore, mussel survival during severe flooding. The floodplain along the Little River Aquatic Habitat is quite broad and mostly used for sod farming and pasture.

Management Unit: Nolichucky
State: Tennessee
(43) Contiguous population: Nolichucky River
Year of last live or fresh dead observation: 2015, VDGIF (Dan Schilling)
Estimated occupied length: Approximately 21.7 mi (35 km) based on unpublished TVA data Ahlstedt (1991b, p. 136) reported three Longsolid at three of 41 sites, TVA (2006) reported two Longsolid at two of 10 sites, (NRM 39.5, 60.6; TVA 2006, Appendix B, p. 22). Sites where *F. subrotunda* were collected differed in these two surveys. One specimen was collected by Schilling (2015, p. 40).
Notes: Less than 100 live ever reported. Extant only in reach of river below Nolichucky Dam at RM 46, which is full of sediment from land use legacy effects associated with mining and logging. It no longer generates hydropower. From the TVA (2006): In 1980, TVA personnel surveyed mussel communities at

41 sites on the Nolichucky River downstream from Nolichucky Dam. Mussel communities then were more similar to conditions found in 2000 than they apparently had been in 1960. Twenty one species were collected in 1980 while 20 species were collected in the same reach in 2000. Four species collected in 1980 were not found in 2000 and three species were encountered in 2000 that were not found in 1980. At least three of the four species last collected during the 1980 survey are still likely to exist in the Nolichucky River. TVA (2006 p. 11) states that threats to the aquatic fauna in the Nolichucky River include residual sediment in the river bed and continuing local sedimentation and other non-point source problems, primarily of agricultural origin, entering the main river from certain tributaries. As the reservoir pool has filled, its ability to trap sediment has declined dramatically, and it has become easier for high flows to carry sand over the top of the dam. Intensive row-crop agriculture has led to increased pesticides and herbicide application and removal of stream buffers.

Management Unit: Upper Clinch
State: Tennessee
(44) Contiguous population: Clinch River
Year of last live or fresh dead observation: 2018 (personal observation)
Estimated occupied length: Approximately 108.7 mi (175 km). From Norris Reservoir upstream to Russel Co. VA; Ahlstedt (1991a) reported the species from RMs 168.0–321.7.
Notes: The population in the Clinch River is likely be best remaining in the Tennessee River system. It also has the best, most consistent level of survey effort and some trend data is available due to the river's importance for global mussel diversity. In 1994, Barr *et al.* (1993-94, p. 203) gave a population estimate for one site, Kyles Ford, for the species at 3978.36 (-75.21, 8031.93) CI. In the Clinch River, TN, densities of *F. subrotunda* at the following sites decreased from 1979-2004 (density/m2): Swan Island, TN 0.30 to 0.20, Buchanan Ford, TN, 1.0 to 0.00, McDowell Shoal, TN, 0.10 to 0.00, Bales Ford, TN, no change. Densities at Brooks Island increased 0.46 to 1.40 and Kyles Ford, TN increased: 0.78 to 1.70, total abundance of *F. subrotunda* in quantitative samples from 2005 to 2009 at Swan Island (8), Frost Ford (19), Wallen Bend (5) (Ahlstedt *et al.* 2016a, p. 17). Contaminant spills have been particularly detrimental and are an ongoing threat to this population. Ahlstedt *et al.* (2017a, p. 224), state that the mussel fauna of the Clinch River downstream of the Appalachia Power Company's Steam Plant at Carbo, Virginia, was severely affected by a fly ash spill in 1967 and a sulfuric acid spill in 1970. Jones *et al.* (2001, p. 20) reference a 1,400 gallon spill of rubber accelerator into the upper Clinch River just above Cedar Bluff, Virginia (Clinch River RM 323) in August 1998, which killed at least 7,000 mussels of 16 species, the species has been documented to occur within the affected reach (Jones *et al.* 2001, p. 22). High concentration levels of the toxic metals zinc and copper in sediments present below a coal processing plant resulted in reduced survival of juvenile mussels in the Clinch River, Virginia (Ahlstedt and Tuberville 1997, p. 75). Ahlstedt *et al.* (2016a, p. 8) give a chronology of significant perturbations that have occurred in the Clinch and Powell rivers. These include: logging of the landscape, resulting in increased sedimentation, deep and surface coal mining; including discharges of industrial and mine wastes, mine blowouts, black water release events and fly-ash spills from mining activities, soil erosion from agricultural activities, construction of impoundments, overharvest, sulfuric acid spills, 100-year floods. Mussel die-offs of unknown origin have been and continue to be a significant threat, mussel die-offs and were documented in the Clinch (1986-1988) and recently (2016) in the Clinch River, VA. Longsolid were observed dead with meat inside their shells in the Clinch River from 2001-2004 with no direct cause for mortality, however, black-water release events associated with mining activity were documented in the same drainage in 2002-2003 (Ahlstedt *et al.* 2016a, p. 9). 96 specimens of *F. subrotunda* were collected from muskrat middens in the Clinch River at Slant, VA, 1984-1985, indicating that this species is vulnerable to mammal predation (Bruenderman 1989, p. 11). The Clinch River in Virginia and Tennessee has significant chronic threats including concentrated agricultural and mining activities and transportation corridors, as well as acute threats such as wastewater treatment effluents and chemical spills (Zipper *et al.* 2014, p. 810).

Management Unit: Upper Clinch
State: Virginia
(45) Contiguous population: Indian Creek
Year of last live or fresh dead observation: 2009, Dinkins Biological Consulting (Gerry Dinkins)
Estimated occupied length: Approximately 0.6 mi (1 km). Watson (1999, p. 15) indicated lower 0.75 mi (1,200 m) of Indian Creek have the best mussel habitat, diversity, and abundance.
Notes: Less than 100 ever reported, connectivity between Indian Creek and Clinch River. Jones and Neves (2004, p. 25) reported relative abundance as Rare; Jones *et al.* (2001, p. 22) summarize collections of the species in the upper Clinch drainage, Tazewell Co., VA, reference Watson live collection in 1999). Dinkins (2011, p. 17) reported collection of two specimens, one in 2007, and one in 2009, with an uncertain population trend. Jones and Neves (2004, p. 1) state that water quality degradation as a result of residential development as a primary threat. Also muskrat predation, logging, contaminant spills and coal mining were cited as ongoing threats, specifically coal mining and recent discharged wastes associated with coal mines are a primary threat (Jones and Neves 2004, p. 2).

Management Unit: Powell
State: Tennessee/Virginia
(46) Contiguous population: Powell River
Year of last live or fresh dead observation: 2018, Steve Ahlstedt
Estimated occupied length: Approximately 31 mi (50 km). A recent comprehensive survey of the Powell River mainstem by Johnson *et al.* (2012) found the species from Powell River kilometer 236-189.
Notes: Johnson found 32 Longsolid at 9 of 20 sites; QLTOT = 15,084; RA = 0.2% (16th of 29 spp. L). Barr *et al.* (1993-94) reported a population estimate at Buchanan Ford (Powell River kilometer 99) of 1861.89 (-1121.05, 4444.85) CI, and at Fletcher Ford (Powell River kilometer) 117.4 of 2032.75 (-382.66, 4448.15) CI. Recent survey work has indicated all mussel species in the Powell River are in decline. Estimated densities in the Powell River, Tennessee and Virginia at four sites (Johnson *et al.* 2012, p. 98): Powell River kilometer 197.9 (0.08), PRkm 193.4 (0.02), 180.7 (0.03), 153.4 (0.03). From Johnson *et al.* (2012, p. 84): Mussel declines in the Powell River have largely been attributed to habitat degradation caused by agricultural practices, urban development, and coal mining (Dennis 1981; Ahlstedt & Tuberville 1997; Diamond *et al.* 2002; Ahlstedt *et al.* 2005b). Additional studies have shown that runoff of sediments contaminated with by-products from coal mining activities is a potential factor leading to mussel declines (McCann & Neves 1992). Black-water events have occurred frequently over the last 100 years in this watershed (Ahlstedt *et al.* 2005b).

Management Unit: Middle Tennessee-Chickamauga
State: Tennessee
(47) Contiguous population: Tennessee River
Year of last live or fresh dead observation: 2010, Third Rock Consultants (Chelsey Olson)
Estimated occupied length: ? ; best location is in mussel beds below Watts Bar Dam; have been found from Tennessee River RMs 470-529. One live individual reported by Olson (2010, p. 6), during mussel surveys of the Tennessee River near Watts Bar Nuclear Plant – "downstream" site. Total RA 0.11, site RA 0.28 (354 total mussels at site, 907 total mussels in survey). It was 2.7 in (68 mm) (Olson 2010, p. 24), and likely an older individual based on shell condition. Pardue (1981, p. 48) gives a percent of abundance total for *F. subrotunda* in within Chickamauga Reservoir (Tennessee River RMs 520.0-521.0) of 0.2, and reports collections of the species at Tennessee River RMs 520.3, 520.4, and 525.0 (p. 50).
Notes: In an assessment of freshwater mussels from 14 prehistoric aboriginal settlement locations along the Chickamauga Reservoir, *F. subrotunda* was found at five sites reported – sites lumped – and 1,386 valves of *F. subrotunda* were collected, 4.97 percent of total valves, making it the 6th most abundant species represented (Parmalee *et al.* 1982, p. 82). Ahlstedt (1989, p. 25) reported collecting two live individuals in quantitative surveys in 1983-1985. Surveys were conducted in the vicinity of the Tennessee Valley Authority's Watts Bar Nuclear Plant (TRM 470-529). Mean length of these two

individuals was 2.4 in (61.39 mm), and the species is mentioned as rare or uncommon in this reach of the Tennessee River. These collections are also reported in Ahlstedt and McDonough (1995-96, p. 112). Relative abundance was estimated to have decreased from 4.97 to 0.01 over the past 2000 years. This population was considered to be reproducing in 1996, but subsequent surveys have either not detected the species or only found small numbers. This population is likely terminal (Ahlstedt 2018, pers. comm.).

Management Unit: Wheeler Lake
State: Alabama
(48) Contiguous population: Paint Rock River
Year of last live or fresh dead observation: 2018, ADCNR (Todd Fobian)
Estimated occupied length: Approximately 43.5 mi (70 km). Based on Alabama Aquatic Biodiversity Center (Service 2018a, unpublished data).
Notes: Estimated densities from Paint Rock, AL at 3 sites (#/m^2) were: (19) pop. est. of 1900 – Jones property site; (2) pop. est of 200 – Tractor Ford; (2) pop. est of 200 – TNC restoration site 23 L @ 4 sites in 320 ¼ MSQ; MD = 0.29; POP = 2300; QNTOT = 372; RA = 4.6% (6th of 32 spp. L) Fobian et al 2014: 47 L/FD @ 18 of 42 sites, R @ 8 others; QLTOT = 1798+; RA = 2.6% (10th of 40 spp. L). 23 L @ 4 sites in 320 ¼ MSQ; MD = 0.29; POP = 2300; QNTOT = 372; RA = 4.6% (6th of 32 spp. L). The Paint Rock River drainage was severely affected in past decades by small impoundments, stream channelization, erosion, and agricultural runoff. These habitat influences have led to the possible extirpation of 10 mussel and eight fish species from the river within the past 75 years. A major detrimental impact on habitat occurred with the channelization and removal of snags and riverbank timber in the upper drainage and the lower reaches of Larkin and Estill forks and Hurricane Creek by the USACE during the 1960s (Ahlstedt 1995-1996). This direct headwater habitat manipulation was probably a large contributor to freshwater mussel loss in the drainage. Wheeler Dam was completed by the Tennessee Valley Authority in 1936, resulting in loss of most of the mussel fauna and riverine habitat in the lower 13 mi (21 km) of the Paint Rock River (Ahlstedt 1995-1996).

Management Unit: Wheeler Lake
State: Alabama
(49) Contiguous population: Estill Fork
Year of last live or fresh dead observation: 2018, ADCNR (Todd Fobian)
Estimated occupied length: Less than 3.1 mi (5 km). Small stream, peripheral population.
Notes: Likely a small population, peripheral occurrence to the Paint Rock, this probably serves as a metapopulation with Hurricane Creek and Paint Rock River. Last reported live by Godwin (2002, p. 16) from five sites on Estill Fork. 8 Longsolid @ 5 of 19 sites; QLTOT = 705; RA 11.9% (tied 3rd of 9 spp. L). Continuing threats to the watershed include siltation and erosion from poor farming practices along with commercial and residential development (Godwin 2002).

Management Unit: Wheeler Lake
State: Alabama
(50) Contiguous population: Hurricane Creek
Year of last live or fresh dead observation: 2012, Jim Godwin
Estimated occupied length: Less than 3.1 mi (5 km). Small stream, peripheral population.
Notes: Likely a small population, peripheral occurrence to the Paint Rock, this probably serves as a metapopulation with Estill Fork and Paint Rock River. Last reported live by Godwin (2002, p. 16) from one site on Hurricane Creek. 1 Longsolid @ 1 of 15 sites; QLTOT = ?; RA 0.5% of 10 spp. L). Continuing threats to the watershed include siltation and erosion from poor farming practices along with commercial and residential development (Godwin 2002).

Management Unit: Wheeler Lake

State: Alabama

(51) Contiguous population: Tennessee River (Wheeler Reservoir)

Year of last live or fresh dead observation: 2004, Paul Yokley; also Williams *et al.* (2008).

Estimated occupied length: Approximately 15.5 mi (25 km). Guntersville Dam tailwater downstream to US 231 bridge. (Yokley 2004)

Notes: Yokley (2004) collected 9 Longsolid at US 231 bridge site; QLTOT = 65,840; RA = T 23rd of 33 spp. L, during a relocation survey. Williams *et al.* (2008, p. 324) state that it is extant only in the tailwaters of Wilson and possibly Guntersville dams on the Tennessee river, and that it is rare in all extant populations. From Ahlstedt and McDonough (1995): Beginning in the early 1950's, the Japanese discovered that freshwater mussel shells from the United States were ideal material for implantation in oysters to form the nucleus for cultured pearls. The mussel shells were cut into small blocks, which were then tumbled and polished into smooth, round beads for surgical implanting in the oysters. This development resulted in a sudden, rapid demand for shells and was a tremendous economic boost for the declining American musseling industry. The mainstream reservoirs of the Tennessee River became the nation's most important source of shell for shipment to Japan. The annual shell harvest from the Tennessee River exceeded 10,000 tons for a number of years (lsom 1969). Although a past threat, this is a considerable contributor to the decline of freshwater mussels in Wheeler Reservoir. Additional threats are the continued operation of Guntersville Dam, Wheeler Dam, and Browns Ferry Nuclear Plant.

Management Unit: Upper Elk (TN)

State: Tennessee

(52) Contiguous population: Elk River

Year of last live or fresh dead observation: 2015, TVA (Chuck Howard)

Estimated occupied length: This population is limited to the reach below Harms Mill Dam near Fayetteville, TN (RM 77)

Notes: Small numbers always reported in the Elk River, this continues to be a small but recruiting population. A small population may have once occurred in Sugar Creek, a tributary to the Elk River, based on the recovery of 1 shell at one site by S. Ahlstedt, B. Butler, and J. Garner in 2014. The TVA does routine quantitative monitoring every 3 years on the Elk River at six sites, C. Howard (2017, pers. comm.) reported collection of two live at ERM 75.7 and two live at ERM 97 in 2005, one live at ERM 75.7 in 2008, and one weathered dead at ERM 97 in 2008. Additionally, the TVA collected two live at ERM 75.7 in 2012, one live at ERM 75.7 in 2015, and 4 live at ERM 105 in 2015 (TVA) (Service 2018a, unpublished data). Ahlstedt *et al.* (2005a p. 6) report two live individuals 3 and 3.3 in (76 and 85 mm), respectively from ERM 97 (Chennault Ford), and two live individuals 1.7 and 3 in (44 mm & 76 mm), respectively from ERM 75.7 (Harms Mill), and noted a 1.7 in (44 mm) individual at ERM 75.7. The Elk River in Tennessee, which has significant agricultural activity throughout the watershed, supports a recruiting population (Hoos *et al.* 2000). Additionally, construction and operation of Tims Ford Dam has impacted the fauna considerably above Harms Mill dam (Ahlstedt 1983, p. 44).

Management Unit: Hiwassee

State: North Carolina

(53) Contiguous population: Hiwassee River

Year of last live or fresh dead observation: 2002, TVA (Steve Ahlstedt)

Estimated occupied length: Approximately 9.3 mi (15 km). just above Mission Dam to Murphy is considered occupied (North Carolina Natural Heritage Program, TVA Heritage Program, Unpublished Data).

Notes: Very small population that does not appear to be recruiting, the most collected live at any qualitative sampling effort is seven individuals North Carolina Natural Resources Commission, (Service 2018a, unpublished data). This small population is likely terminal, non-recruiting, comprised of larger older individuals. This is a small population that is subject to hypolimnetic releases from Mission Dam upstream.

Management Unit: Hiwassee
State: North Carolina
(54) Contiguous population: Valley River
Year of last live or fresh dead observation: 2002, North Carolina Natural Heritage Program
Estimated occupied length: Approximately 3.1 mi (5 km); lower Valley River
Notes: Only 1 known record for this stream NCNHP (2002) collection in NC Museum of Natural Sciences. This is likely a small peripheral population to the Hiwassee River.

Management Unit: Hiwassee
State: Tennessee
(55) Contiguous population: Hiwassee River
Year of last live or fresh dead observation: 2003, USFS (Steve Ahlstedt)
Estimated occupied length: Approximately 3.1 mi (5 km). This population occurs in the cutoff channel below Apalachia Dam.
Notes: The species in the Hiwassee River in Tennessee has been considered a small population for decades (Parmalee and Bogan 1998, p. 120). Ahlstedt *et al.* (2016b, p. 16) reported two larger individuals collected upstream of the powerhouse discharge, 2.40 and 2.48 in (61 & 63 mm) in 2003, but subsequent sampling at this site has not yielded additional specimens. If the Longsolid persists in the Hiwassee River in Tennessee, it is probably in very low numbers and may not represent a viable, recruiting population (S. Ahlstedt, 2017, pers. comm.). The reach of Hiwassee River between Apalachia Dam and the powerhouse is referred to as the "Apalachia Cutoff", where water is mostly derived from inflows from tributary streams, leakage from the dam, minimum flow releases of 25 cfs, and dam spillage during storm events and reservoir level management. Although buffered by National Forest, the minimum flows that do not vary seasonally restrict the capability to move and flush fine sediment and aquatic vegetation from the river channel (Ahlstedt 2016b). Cold water and low dissolved oxygen likely inhibit the species ability to expand further downstream (Ahlstedt 2016b).

Management Unit: Pickwick Lake
State: Alabama
(56) Contiguous population: Tennessee River (Pickwick Reservoir)
Year of last live or fresh dead observation: 2018, Alabama Department of Conservation and Natural Resources (ADCNR) (Jeff Garner)
Estimated occupied length: Approximately 15.5 mi (25 km); Gooch *et al.* (1979 p. 95) report ≥ 3 at three of 16 sites from RMs 234.2–258.9 (Pickwick Reservoir, including Wilson Dam tailwater). Gooch *et al.* (1979, p. 96) report the species represented 0.4 % of the fauna at Tennessee River RM 258.4, and 0.3% of the fauna at Tennessee River RM 252.9. Williams *et al.* (2008, p. 324) state that it is extant only in the tailwaters of Wilson and possibly Guntersville dams on the Tennessee river, and that it is rare in all extant populations.
Notes: J. Garner (2018, pers. comm.) and ADCNR Heritage database records total eight collected below Wilson Dam since 2000. Garner and McGregor (2001, p. 162) report it as rare in the Wilson Dam tailwaters. Isom (1969, p. 410) reported the species from the Sevenmile Island Area Muscle Shoals, Wilson Dam tailwater (TRM 247-253). Also, Isom (1969, p. 402) reported the species to be of some commercial importance.

Management Unit: Lower Tennessee-Beech
State: Tennessee
(57) Contiguous population: Tennessee River (Kentucky Reservoir)
Year of last live or fresh dead observation: 2015, TWRA (Don Hubbs)
Estimated occupied length: Less than 0.6 mi (1 km). Tennessee River RMs 170.1 to 170.2. Gooch *et al.* (1979) report 46 Longsolid at 17 of 177 sites, RA = 0.4% (11th of 29 spp. L), from RMs 125.9–206.7
Notes: Repeated sampling of freshwater mussels at sites in Kentucky Reservoir, TN have yielded only one live individual in over 20 years of annual survey efforts (Hubbs 2015, p. 29). One Longsolid @ 22 sites in 3 reaches in 166 hours total dive time. From Hubbs (2015): Commercial sand and gravel dredging, conducted on the Lower Tennessee River since at least the 1920's, and currently permitted on approximately 48 of the 95 RMs in this reach has degraded a significant portion of the available aquatic habitat. Significantly lower mussel abundance and diversity values have been observed at dredge sites indicating bottom substrates altered by dredging and resource extraction operations do not provide suitable habitat to support mussel populations similar to those found inhabiting non-dredged reaches (Hubbs *et al.* 2006).

Management Unit: Buffalo
State: Tennessee
(58) Contiguous population: Buffalo River
Year of last live or fresh dead observation: 2014, University of Tennessee (Matt Reed)
Estimated occupied length: Approximately 3.1 mi (5 km). Reed (2014, p. 44) reports collection of one relict individual of *F. subrotunda* at RM 4.6, but no live specimens were found.
Notes: Known from only dead specimens, no live records. It was not previously reported in published studies from the Duck or Buffalo River drainages, but a museum record exists for the species from the Buffalo River drainage in the McClung Museum Collection at the University of Tennessee (Reed 2014, p. 15). Reed (2014, p. 13) cites increases in human population and associated municipal effluent as the primary source of degradation in Buffalo River tributaries. Additional increased herbicide and pesticide use and changes to hydrology were also cited as contributors to mussel decline in the river.

Management Unit: Kentucky Lake
State: Tennessee
(59) Contiguous population: Tennessee River (Kentucky Reservoir & 5 km of tailwater)
Year of last live or fresh dead observation: 1999, TVA (KY Dam Tailwater Database); see Sickel and Burnett 2005
Estimated occupied length: Approximately 3.1 mi (5 km). A small population persists below Kentucky Dam (Haag and Cicerello 2016, p. 138).
Notes: Reported percent abundances from Tennessee River miles 0-61 (0.52), TRM 5-22 (0.21), TRM 7-22 (0.82) (Sickel *et al.* 2007 p. 72). A total of 114 individuals collected from 1907-2002, and it may still occur in the Kentucky Dam tailwater, despite difficulties differentiating specimens of *F. subrotunda* from *F. ebena* (Sickel & Burnett 2005, p. 16). This HUC does not end at Kentucky Dam, rather downstream in the tailwater. Habitat in lower Kentucky Reservoir is lacking for the species and any representatives in this HUC are from the Kentucky Dam tailwater. Dredging for navigation, tows. From Sickel and Burnett (2005): Downstream from the sanctuary, the river provides a valuable source of mussel shell for the cultured pearl industry. During the pearl button days from the late 1800's until the mid 1950's, the river was a source of valuable shells for the button industry. With the construction of Kentucky Lock and Dam completed in 1944, major changes occurred in the aquatic habitat upstream from the dam in Kentucky Lake, with sediment accumulation in deeper areas, while the tailwater area remained riverine and retains its original gravel bottom. In July 1998, the USACE, Nashville District, began construction of a new 1,200-ft (366 m) long navigation lock at Kentucky Lock and Dam to help alleviate the bottleneck in river

traffic caused by the existing single 600-ft (183-m) lock. This addition accommodates increased commercial river traffic. Also, new industries are being added and established industries are expanding in the tailwater area.

Management Unit: Lower Tennessee
State: Tennessee/Kentucky
(60) Contiguous population: Tennessee River
Year of last live or fresh dead observation: 1999, TVA (KY Dam Tailwater Database); see Sickel and Burnett 2005
Estimated occupied length: reach from Kentucky Lake HUC to Mainstem Ohio R. is approximately 18.6 mi (30 km). A small population persists below Kentucky Dam (Haag and Cicerello 2016, p. 138).
Notes: Reported percent abundances from TN Rivermile 0-61 (0.52), TRM 5-22 (0.21), TRM 7-22 (0.82) (Sickel *et al.* 2007 p. 72). A total of 114 individuals collected from 1907-2002, and it may still occur in the Kentucky Dam tailwater, despite difficulties differentiating specimens of *F. subrotunda* from *F. ebena* (Sickel & Burnett 2005; p. 16; KY Dam Tailwater Database). Dennis (1984, p. 44) summarized collections from beds in the Tennessee River. Kentucky Lake and tailwater collections of the species were done by Yokley 1972, Ortmann 1925, van der Schalie 1939. Dredging for navigation, tows. From Sickel and Burnett (2005): Downstream from the sanctuary, the river provides a valuable source of mussel shell for the cultured pearl industry. During the pearl button days from the late 1800's until the mid 1950's, the river was a source of valuable shells for the button industry. With the construction of Kentucky Lock and Dam completed in 1944, major changes occurred in the aquatic habitat upstream from the dam in Kentucky Lake, with sediment accumulation in deeper areas, while the tailwater area remained riverine and retains its original gravel bottom. In July 1998, the USACE, Nashville District, began construction of a new 1,200-ft (366-m) long navigation lock at Kentucky Lock and Dam to help alleviate the bottleneck in river traffic caused by the existing single 600-ft (183-m) lock. This addition accommodates increased commercial river traffic. Also, new industries are being added and established industries are expanding in the tailwater area.

APPENDIX B - FORMER CONTIGUOUS POPULATIONS AND MANAGEMENT UNITS, NOW CONSIDERED EXTIRPATED, ACROSS THE LONGSOLID RANGE.

GREAT LAKES BASIN= 6; OHIO BASIN = 65; CUMBERLAND = 9; TENNESSEE = 26; TOTAL EXTIRPATED = 106

Management Unit	Record State	Former Contiguous Population	Last Collected/Reported
GREAT LAKES BASIN			
St. Joseph	IN	(1) St. Joseph's River	Watters 1998, p. 33 reported collection of 1 weathered dead individual from 1 site on the mainstem St. Joseph's River, (Johnny Appleseed Park, Ft. Wayne, Allen Co. IN), and also referenced a relic/subfossil specimen found in 1988 further downstream in the St. Joseph's river below Ft. Wayne (p. 2).
	OH	(2) St. Joseph's River	EnviroScience, Inc. (2012) report collection of dead shell from 1 quantitative sampling site (p. 9, Site 64, 1 shell).
	IN	(3) Cedar Creek	Watters 1988, reported 1 relic shell from 1 of 13 sites surveyed, p. 11.
Upper Maumee	OH	(4) Maumee River	Watters et al. 2009, p. 131, fig. 80 has collections from Defiance County represented.
Lower Maumee	OH	(5) Maumee River	Watters et al. 2009, p. 131, fig. 80 has collections from Henry County represented.
Lake Erie	PA, OH?	(6) Lake Erie (Sand Point, Huron Co, MI; Presque Isle Bay, PA	Last collected from Lake Erie pre-1919 (Ortmann 1919).
OHIO RIVER BASIN			
Upper Monongahela	WV	(7) Monongahela River	Considered extirpated, not reported live since Ortmann 1919, p. 9.
Lower Monongahela	PA	(8) Monongahela River	Considered extirpated, not reported live since Ortmann 1919, p. 9.
	PA	(9) South Fork Tenmile Creek	Considered extirpated, not reported since Bates 1970, p. 26, 32.
French Creek	PA	(10) Conneaut Outlet[9]	Pre-1919; Ortmann collection, Crawford Co. (Ortmann 1919). No confirmed records from this stream since 1919 (Welte, PABFC, Pers. Comm.)

[9] The Longsolid is considered extirpated from this river; however, it is still extant in the Management Unit in another stream.

Management Unit	Record State	Former Contiguous Population	Last Collected/Reported
	PA	(11) North Deer Creek[1]	OSUM Records, Mercer County (Database Query).
Upper Ohio	PA	(12) Ohio River (Dashields Pool, Elmsworth Pool, Montgomery Pool)	Considered extirpated from Beaver and Allegheny Counties (Tolin 1987, p. 11).
	WV/OH	(13) Ohio River (New Cumberland Pool, Pike Island Pool, Hannibal Pool)	Considered extirpated from Hancock, Brooke Counties (WVDNR) (Service 2018a, unpublished data).
	WV/OH	(14) Ohio River (New Cumberland Pool, Pike Island Pool, Hannibal Pool)	Considered extirpated from Jefferson and Columbiana Counties (Watters *et al.* 2009, p. 131).
Upper Ohio - Wheeling	WV/OH	(15) Ohio River (Hannibal Pool)	1984 - W. Tolin USFWS (Tolin 1987).
	WV	(16) Fish Creek	1993 - WVDEP Weathered Dead (WVDNR) (Service 2018a, unpublished data).
Upper Ohio - Shade	OH/WV	(17) Ohio River (upper Gallapolis = Byrd Pool, Racine Pool, Belleville Pool)	Fleece (2012, p. 26) reports collection of one weathered shell from Meigs Co., OH, from three sites between RM 255.25-253.75 in the Gallapolis = Byrd Pool.
Little Scioto - Tygarts	OH/KY	(18) Ohio River (upper Meldahl Pool, lower Greenup Pool)	Reported only as relic/subfossil in Meldahl Pool since 1969 (ESI 2000, p. 10).
Silver-Little Kentucky	KY/IN	(19) Ohio River	Considered extirpated based on KSNPC database (KSNPC Unpublished Data).
Cheat	PA	(20) Cheat River	Considered extirpated, not reported live since Ortmann 1919, p. 9.
Beaver	PA	(21) Beaver River	considered extirpated, not reported live since Ortmann 1920, p. 276.
Middle Allegheny - Redbank	PA	(22) Little Mahoning Creek (Tributary to Allegheny river)[1]	considered extirpated, not reported live since Ortmann 1920, p. 276.
Lower Allegheny	PA	(23) Little Buffalo Creek[1]	Winters 1973.
Shenango	PA	(24) Pymatuning Creek (Trib. to Shenango River)[1]	Considered extirpated, not reported live since Ortmann 1920, p. 276.
Mahoning	PA	(25) Mahoning River	Considered extirpated, not reported live since Ortmann 1920, p. 276; he reported 61 specimens from 3 sites.
	OH	(26) Mahoning River	Considered extirpated, not collected live or fresh

Management Unit	Record State	Former Contiguous Population	Last Collected/Reported
			dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
Mohican	OH	(27) Mohican River	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
Walhounding	OH	(28) Killibuck Creek[1]	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
Licking	OH	(29) Otter Fork Licking River	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
Little Muskingham - Middle Island	OH/WV	(30) Ohio River[1]	M. Hoggarth 2016
	OH	(31) Moss Run[1]	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
	OH	(32) Little Muskingum River[1]	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
Muskingum	OH	(33) Lucas Run[1]	OSUM Record Morgan County, OH (Watters *et al.*, 2009, p. 131, fig. 80)
	OH	(34) Wakatomika Creek[1]	OSUM Record Muskingum Co., OH (Watters *et al.*, 2009, p. 131, fig. 80)
	OH	(35) Little Wolf Creek[1]	OSUM Record Morgan Co., OH (Watters *et al.*, 2009, p. 131, fig. 80)
Upper Scioto	OH	(36) Scioto River	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
	OH	(37) Walnut Creek	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
	OH	(38) Big Darby Creek	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
Lower Scioto	OH	(39) Frederick Creek	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).

Management Unit	Record State	Former Contiguous Population	Last Collected/Reported
	OH	(40) Deer Creek	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
	OH	(41) Yellowbud Creek	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
	OH	(42) Scioto River	Subfossil shell collected by Stantec in 2014 at ODNR Kinnikinnick Boat Ramp in Ross County, OH (Stantec 2014, p. 11).
Tippecanoe	IN	(43) Tippecanoe River	Reported only as weathered relic shells at three sites on the mainstem by ESI (1993, p. 48).
Ohio Brush - Whiteoak	OH/KY	(44) Ohio River	OSUM 1929 (Database Query)
	OH	(45) White Oak Creek	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
Lower Great Miami	OH	(46) Great Miami River	Considered extirpated, not collected live or fresh dead since pre-1980 (Watters *et al.*, 2009, p. 131, fig. 80).
Middle Wabash-Deer	IN	(47) Wabash River	One valve reported from Carroll Co., 1989, INHS 8240; five specimens reported from Tippecanoe Co., D. Stansbery, INHS 6217 (1988)
Sugar	IN	(48) Sugar Creek	Lewis 1991, as reported in Fisher 2006.
Eel (05120203)	IN	(49) Eel River	Only a single record exists, pre 1944, not reported live since Goodrich and van der Schalie (1944, p. 307).
Middle Wabash-Little Vermillion	IN	(50) Wabash River	INHS (Database Query) & OSUM Museum Records (Database Query)(Fountain & Tippecanoe Counties).
Middle Wabash-Busseron	IN, IL	(51) Wabash River	INHS Records (Database Query).
Lower Wabash	IL, IN	(52) Wabash River	Considered extirpated (Stodola *et al.* 2014, p. 25).
Embarras	IL	(53) Embarras River	Last reported by Fetchner (1963, p. 100).
Upper White	IN	(54) West Fork White River	Last reported as weathered dead by Cummings *et al.* 1992 (1987-1991 surveys).
Lower White	IN	(55) White River	Last reported as weathered dead by Cummings *et al.* 1992 (1987-1991 surveys).

Management Unit	Record State	Former Contiguous Population	Last Collected/Reported
Lower East Fork White	IN	(56) East Fork White River	Considered extirpated (Fisher 2006, p. 105).
Blue-Sinking	KY	(57) Ohio River (Cannelton Pool)	Prior to 1990 (Haag and Cicerello 2016, p. 138).
	IN	(58) South Fork Blue River	Last reported by Weilbaker *et al.* (1985, p. 689); abundance and condition unknown.
Tug	WV/KY	(59) Tug Fork	Haag and Cicerello (2016, p. 138) indicate no collections of live since 1990.
West Fork	WV	(60)West Fork River	1919 - not reported since Ortmann 1919 (Carnegie Museum Records).
	WV	(61) Hackers Creek	1995 - Relic only (WVDNR Unpublished Data).
Little Kanawha	WV	(62) South Fork Hughes River[1]	1981 - R. Taylor, Marshall University erga Collection Record (Ritchie Co.) (Database query).
	WV	(63) Leading Creek[1]	1994 - Relic only (WVDNR Unpublished Data).
Lower Kanawha	WV	(64) Kanawha River	Taylor 1983a.
Coal	WV	(65) Coal River	1969 (Kanawha County) (WVDNR Unpublished Data).
Upper Kentucky	KY	(66) Kentucky River	Danglade 1922 (p. 5).
Salt	KY	(67) Floyd's Fork	Floyd's Fork, Bullett County. INHS record 1980 catalog # 7993.
Upper Green	KY	(68) Nolin River[1]	R. Taylor 1981, live (Taylor 1983b, p. 111); Gordon & Sherman 1995 Relic.
Rolling Fork	KY	(69) Beech Fork (Salt River)[1]	OSUM Record, Nelson County (Haag and Cicerello 2016, p. 139).
Rough	KY	(70) Rough River	Extirpated from Rough and Nolin rivers, Green River drainage (Haag and Cicerello 2016, p. 139).
South Fork Licking	KY	(71) South Fork Licking River	Only known collection of the species is by Fallo 1982 - relic only (KSNPC data); Laudermilk 1993.
CUMBERLAND RIVER BASIN			
Rockcastle	KY	(72) Rockcastle River	Last reported live by Neel and Allen (1964, p. 434).
South Fork Cumberland	TN	(73) Big South Fork Cumberland River	Last reported "Rare" at Station Camp Creek by Shute *et al.* (1999).

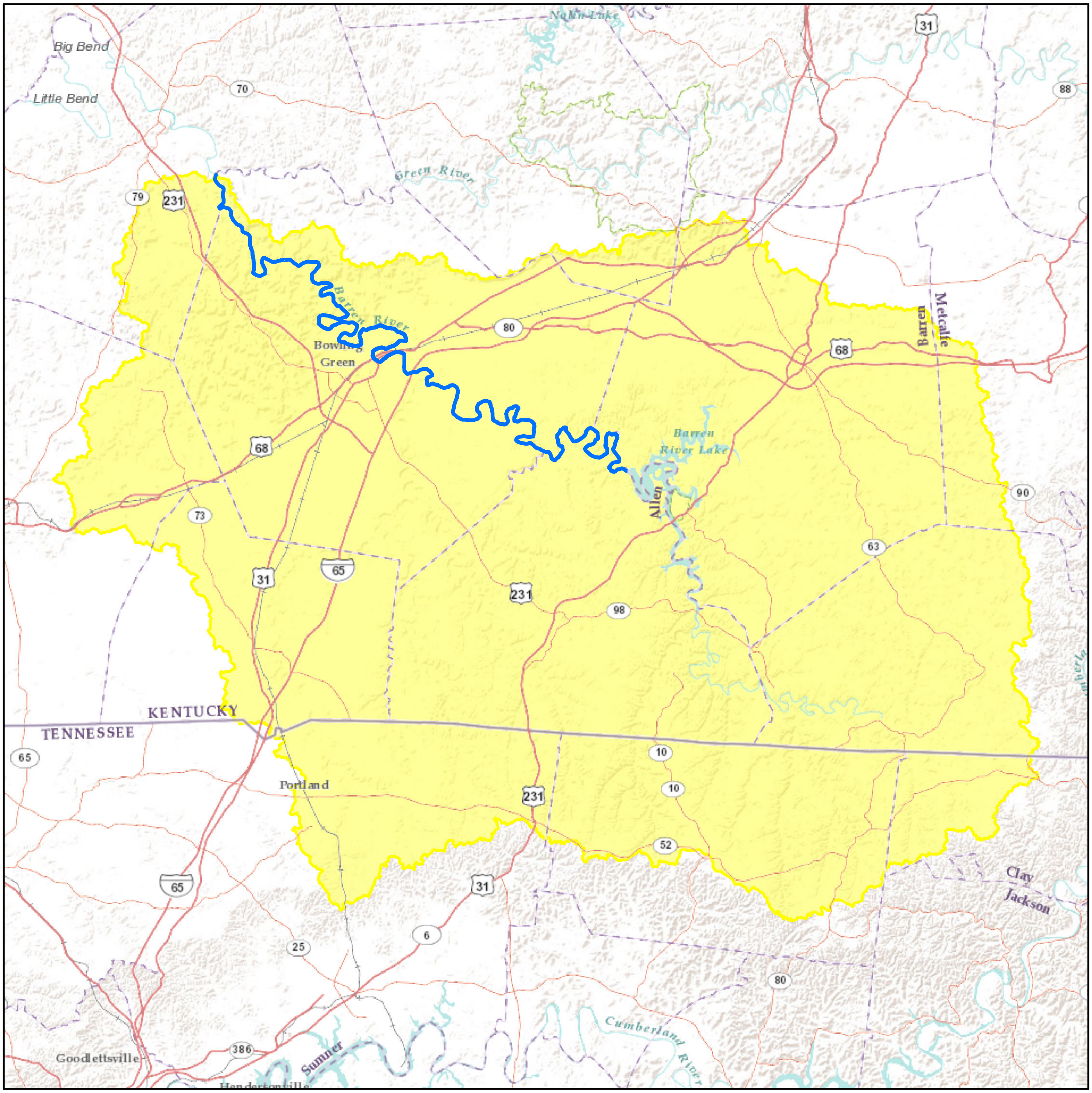
Management Unit	Record State	Former Contiguous Population	Last Collected/Reported
	KY	(74) Big South Fork Cumberland River	Considered extirpated (Haag and Cicerello 2016, p. 139); Mcreary/Wayne Counties (Schuster 1988, p. 395).
Upper Cumberland - Lake Cumberland	KY	(75) Cumberland River	Last reported by Wilson and Clarke 1914; Pulaski County & Russell County (Schuster 1988, p. 395).
Upper Cumberland - Cordell Hull Reservoir	TN	(76) Cumberland River	Parmalee and Bogan (1998, p. 121, map 43).
Lower Cumberland - Sycamore	TN	(77) Cumberland River	OSUM Record (Database Query), Schuster 1988 p. 395.
Lower Cumberland	KY	(78) Cumberland River	Last reported by Wilson and Clarke 1914.
Obey	TN	(79) Obey River	Shoup *et al.* 1941, p. 68.
Caney	TN	(80) Caney Fork	Last reported as relic only in Layzer *et al.* (1993, p. 67).
TENNESSEE RIVER BASIN			
North Fork Holston	VA	(81) North Fork Holston River	Last reported live by D. Neves, VA Tech in 1985 at RM 13.5, during a mussel translocation project.
	TN	(82) North Fork Holston River	Not reported live since Ortmann 1918 (p. 610).
South Fork Holston	VA	(83) South Fork Holston River	Pinder (1995); Virginia Department of Game and Inland Fisheries
	TN	(84) South Fork Holston River	Not reported live since Ortmann 1918 (p. 612).
	VA	(85) Middle Fork Holston River	Braven Beaty (1997), TNC; relic/subfossil.
Watauga	TN	(86) Watauga River	Not reported live since Ortmann 1918 (p. 612).
Lower French Broad	TN	(87) French Broad River	Last reported collection prior to 1960 (Parmalee and Bogan 1998, p. 120).
	TN	(88) West Prong Little Pigeon River	Last reported as relic/subfossil by Parmalee (1988, p. 168), RA 10.6% (2nd of 45 spp.).
Lower Little	TN	(89) Little Tennessee River	Extirpated (Parmalee and Bogan 1998, p. 120).

Management Unit	Record State	Former Contiguous Population	Last Collected/Reported
Tennessee	TN	(90) Tellico River	Last collected live by Parmalee and Klippel (1984, pp. 43-45).
Watts Bar Lake	TN	(91) Tennessee River (Ft. Loudon & Watts Bar Reservoirs)	1978 (Pardue 1981)
Emory	TN	(92) Daddys Creek	Apparently extirpated from upper Emory River basin (Ahlstedt *et al.* 2017b, p. 206).
Upper Clinch	VA	(93) Copper Creek[1]	Fraley and Ahlstedt 2000 (p. 190) Scott County; relic. VA DGIF has 2007 unverified record (no voucher) of individuals from 1 site collected by S. Hanlon (Service 2018a, unpublished data). Potentially extant, recent records by VA Tech, but no voucher.
Powell	VA	(94) South Fork Powell River	Not reported live since Ortmann 1918 (p. 595).
	VA	(95) Cane Creek	Not reported live since Ortmann 1918 (p. 596).
Upper French Broad	NC	(96) French Broad River[1]	Last reported live by Ortmann 1918 (p. 528).
Hiwassee	NC	(97) Nottely River	One eroded relic valve collected, which represents the only known evidence of mussel occurrence in the Nottely River (Ahlstedt and Fraley 2002, p. 5).
Ocoee	GA	(98) Toccoa River	The six specimens from the Toccoa River, Georgia, collected by Athearn (1957).
	GA	(99) Tiger Creek	Near Cohutta, GA; NCMNS, no date (H. Athearn Record).
Guntersville Lake	AL	(100) Tennessee River	Reported by Ortmann in 1924.
Lower Elk	TN	(101) Sugar Creek	Only collected as relic shell in stream surveys in 2015 (UT McClung Catalog Number 6421).
	AL	(102) Elk River	Considered extirpated in the Alabama portion of the Elk River (Williams *et al.* 2008, p. 324).
Wheeler Lake	AL	(103) Flint River[1]	Considered extirpated (Williams *et al.* 2008, p. 324).
	AL	(104) Limestone Creek[1]	Considered extirpated (Williams *et al.* 2008, p. 324).

Management Unit	Record State	Former Contiguous Population	Last Collected/Reported
	AL	(105) Larkin Fork[1]	Considered extirpated (Williams *et al.* 2008, p. 324).
	AL	(106) Indian Creek[1]	One weathered dead specimen from shell midden on Redstone Arsenal (McGregor 2009).

APPENDIX C—MAPS DEPICTING THE 60 LONGSOLID MUSSEL POPULATIONS WITHIN MANAGEMENT UNITS ACROSS THEIR CURRENT RANGE.

Barren Management Unit



Miles
0 5 10 20

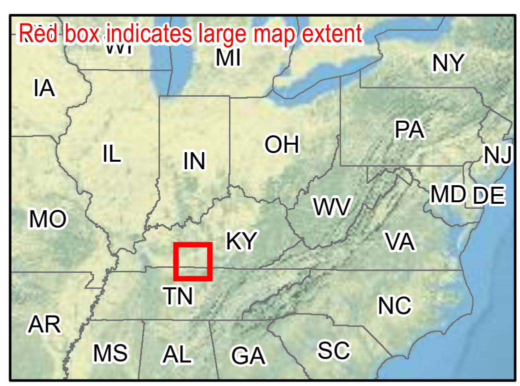
Selected Stream

Management Unit Condition

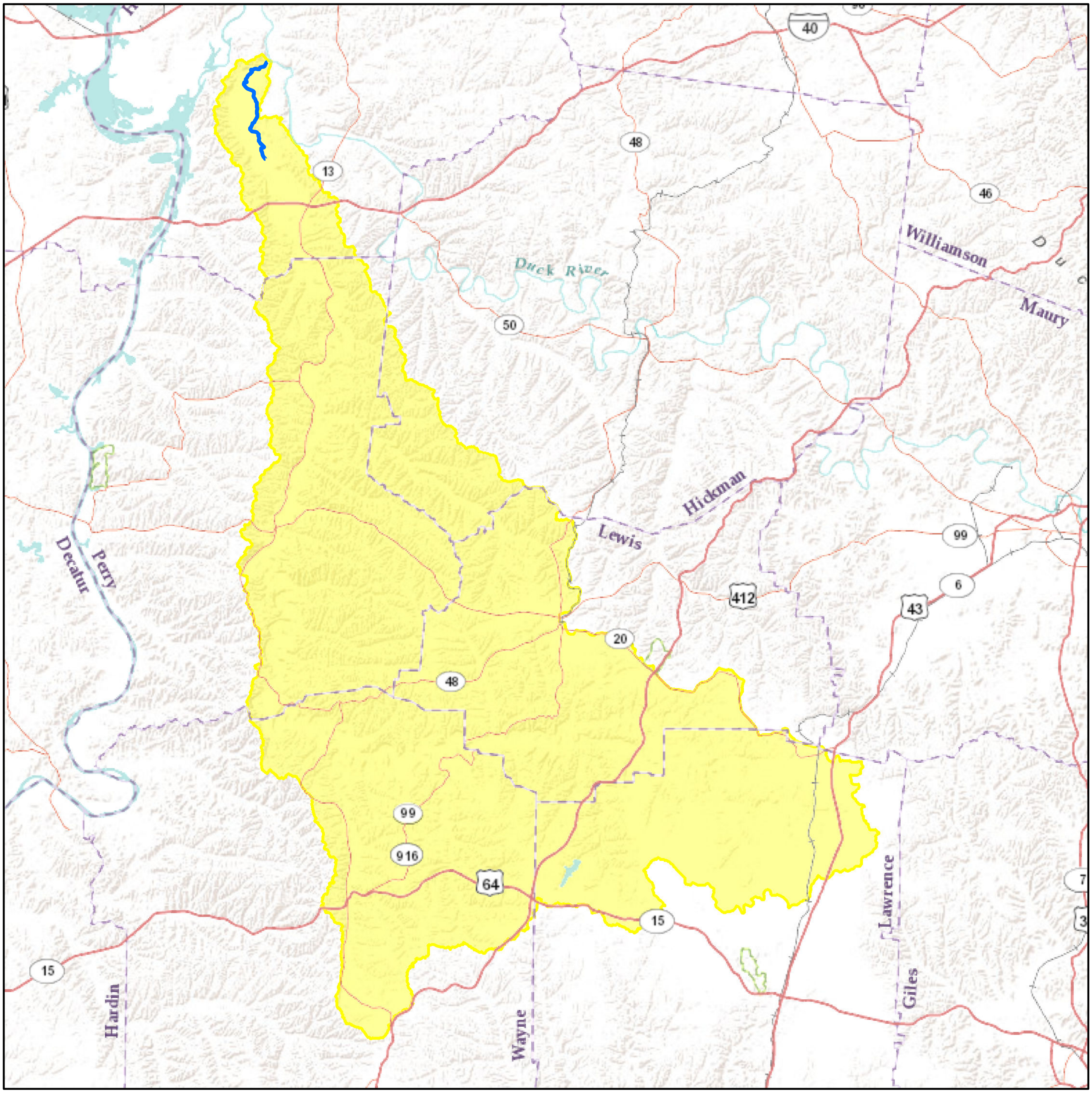
High

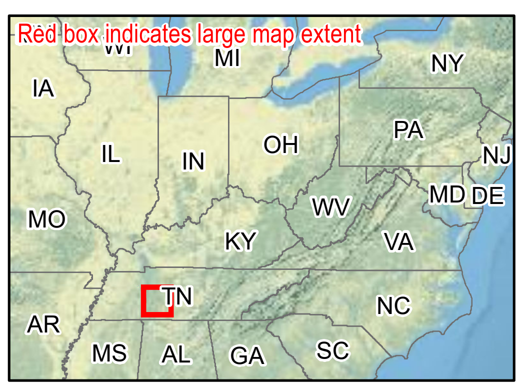
Medium

Low

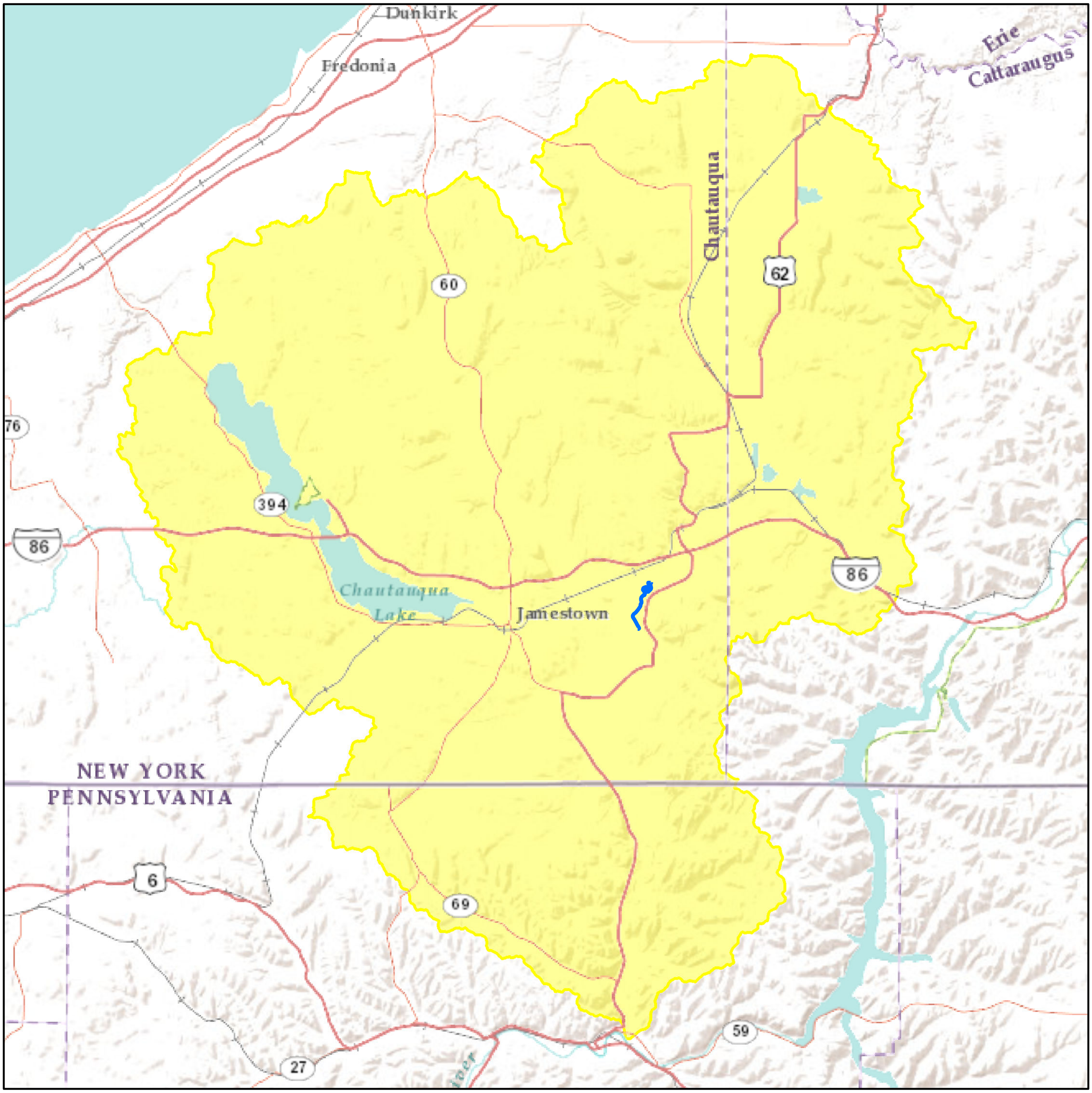


Buffalo Management Unit





Conewango Management Unit



Miles
0 5 10 20

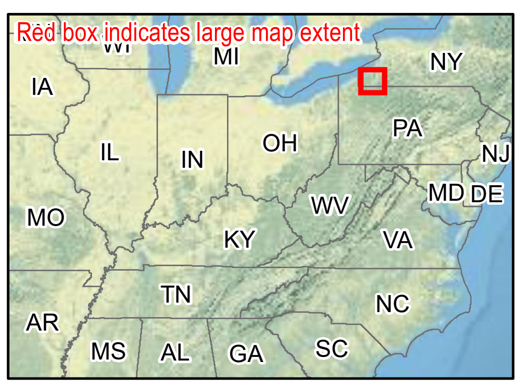
Selected Stream

Management Unit Condition

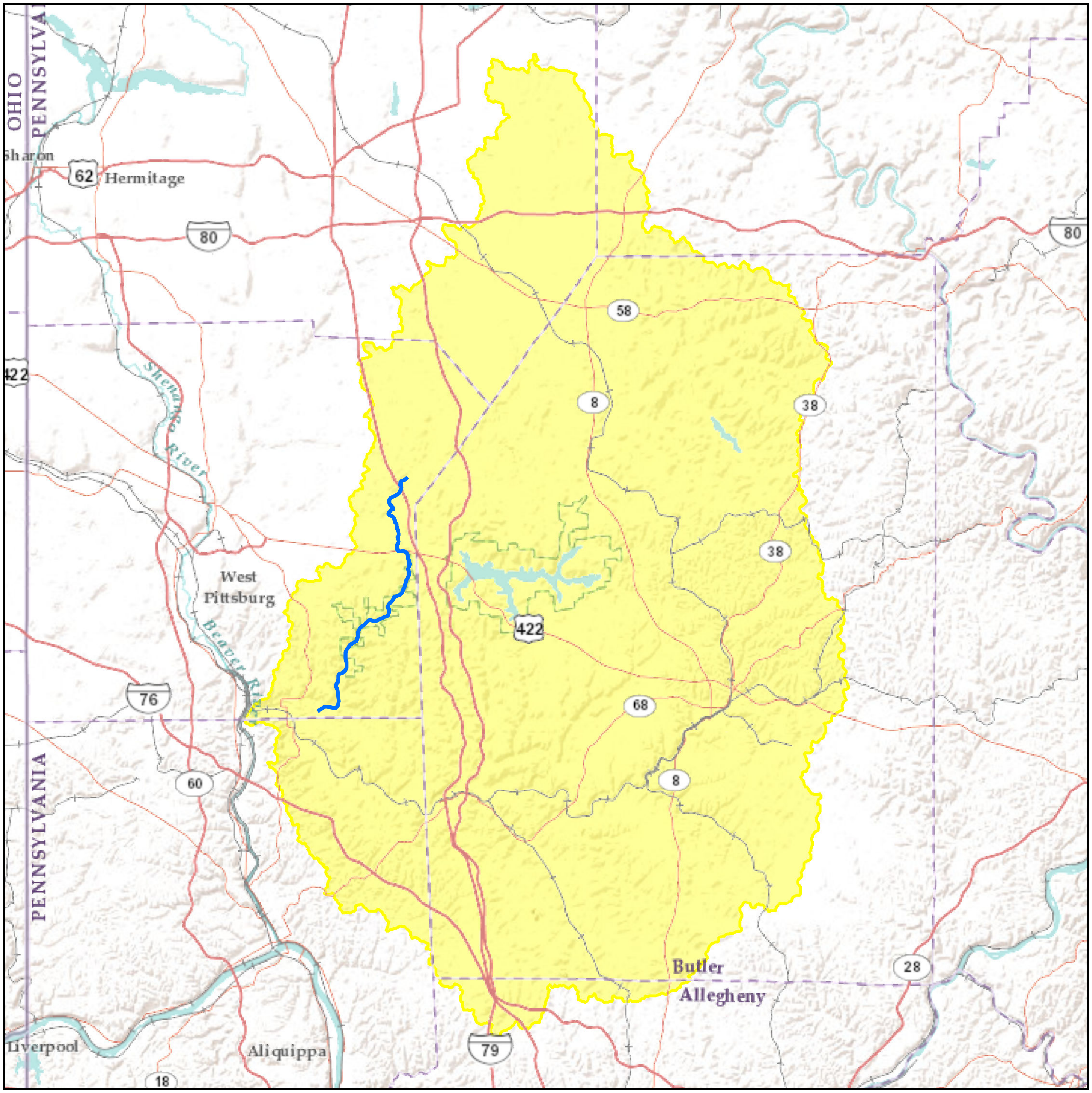
High

Medium

Low



Connoquenessing Management Unit



0 5 10 20 Miles

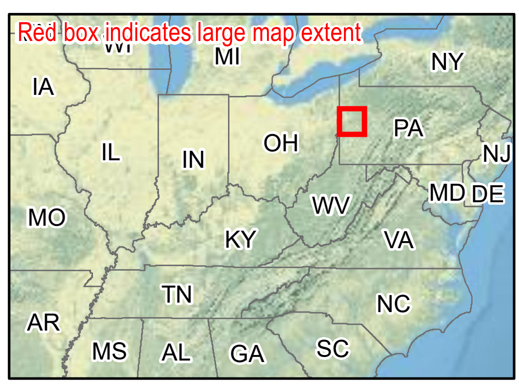
Selected Stream

Management Unit Condition

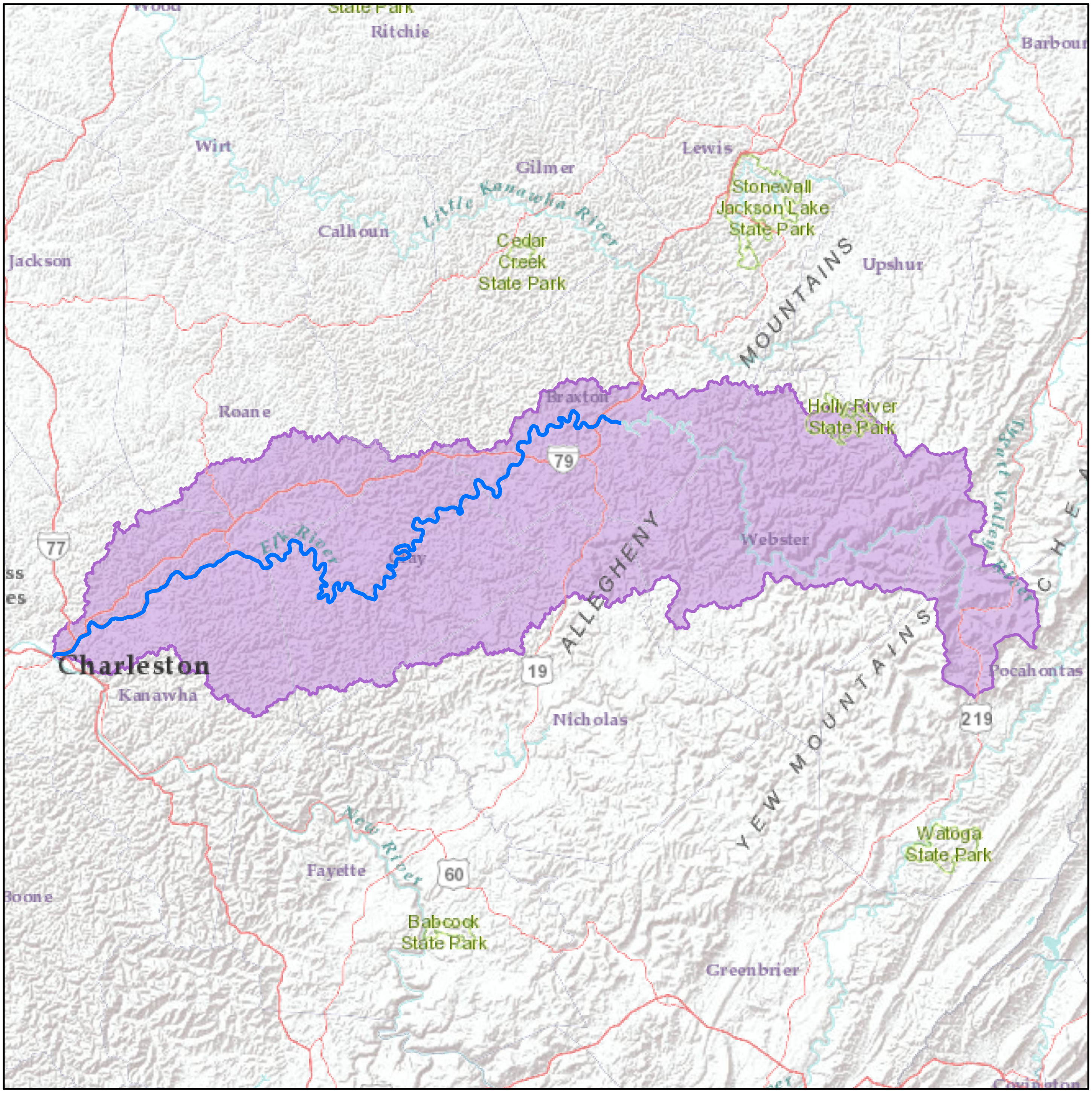
High

Medium

Low



Elk Management Unit



0 10 20 40 Miles

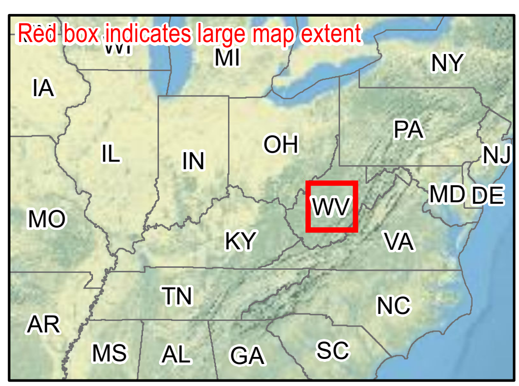
Selected Stream

Management Unit Condition

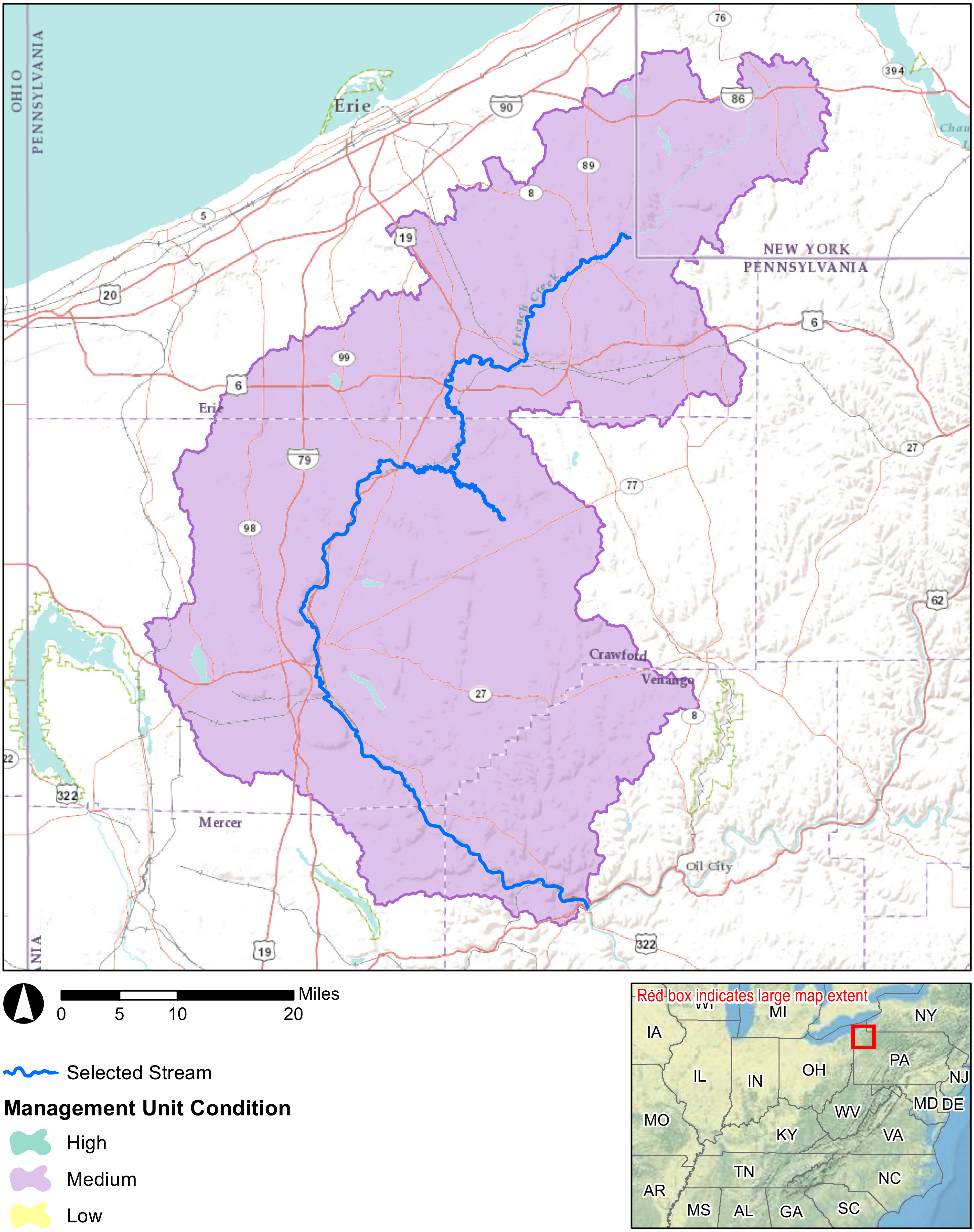
High

Medium

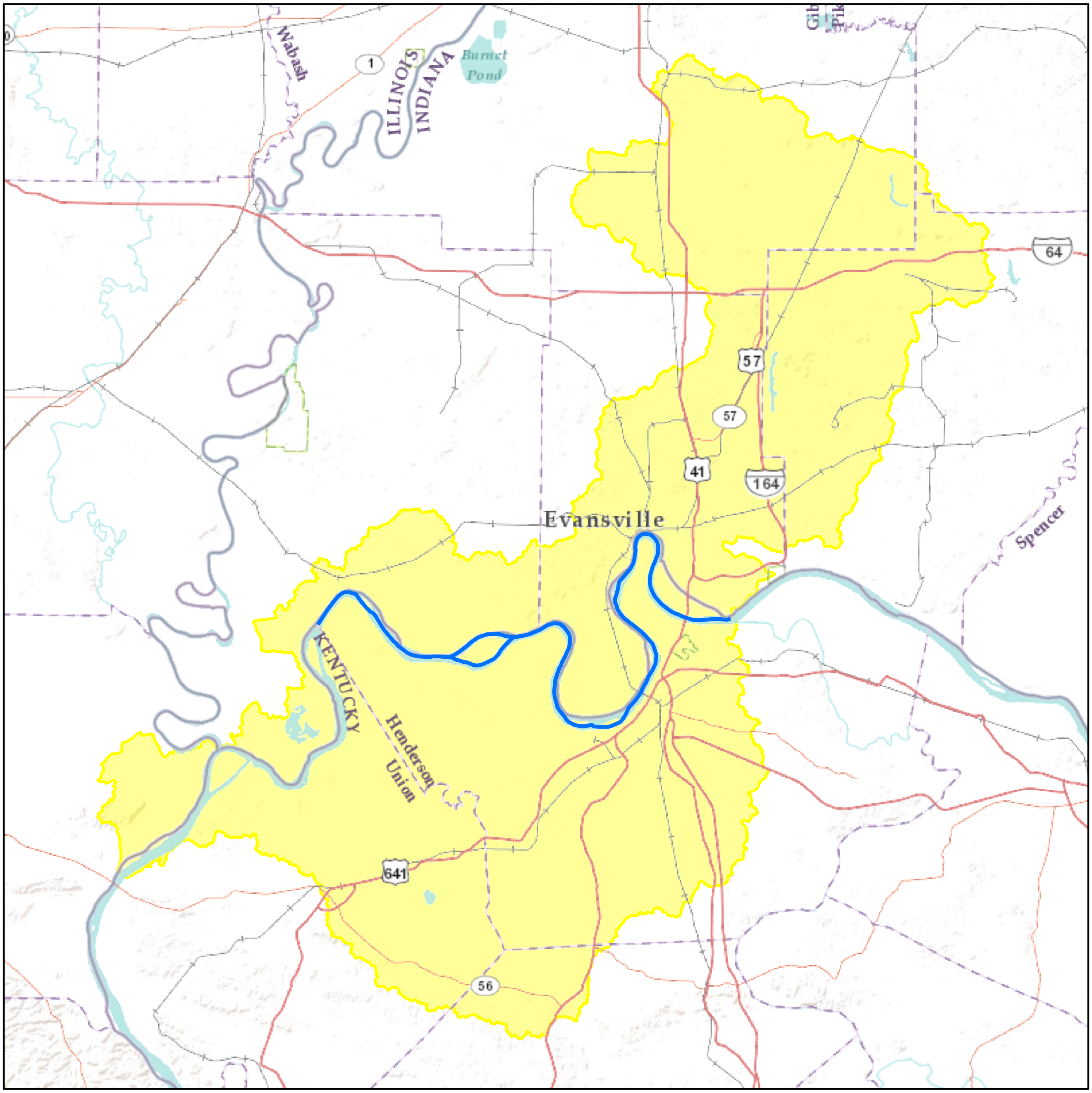
Low



French Management Unit



Highland-Pigeon Management Unit



Miles
0 5 10 20

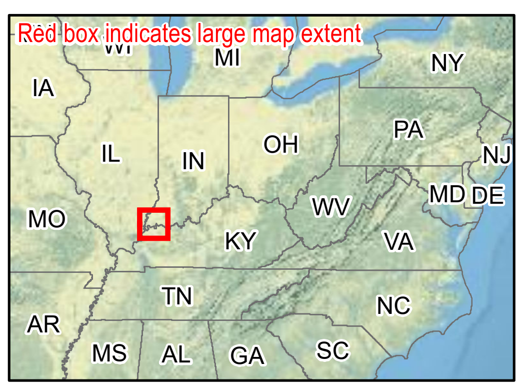
Selected Stream

Management Unit Condition

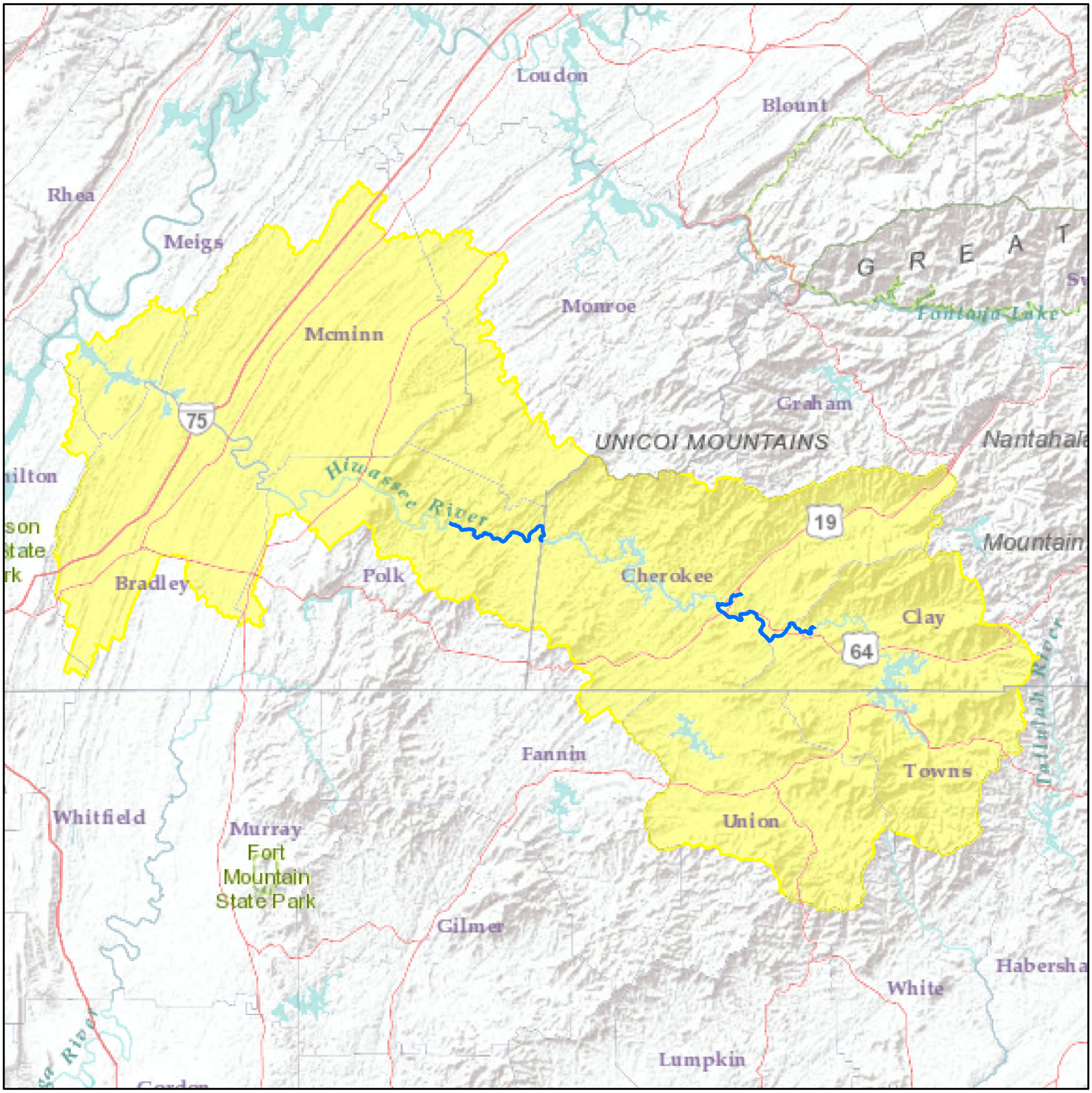
High

Medium

Low



Hiwassee Management Unit



Miles
0 5 10 20

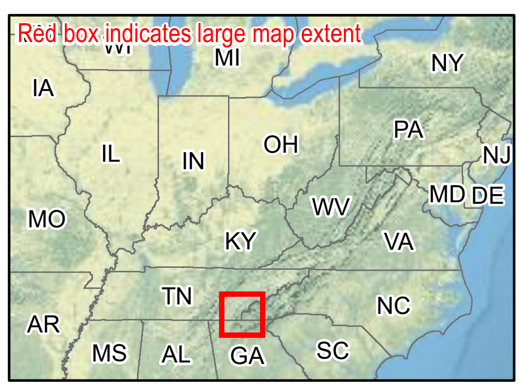
Selected Stream

Management Unit Condition

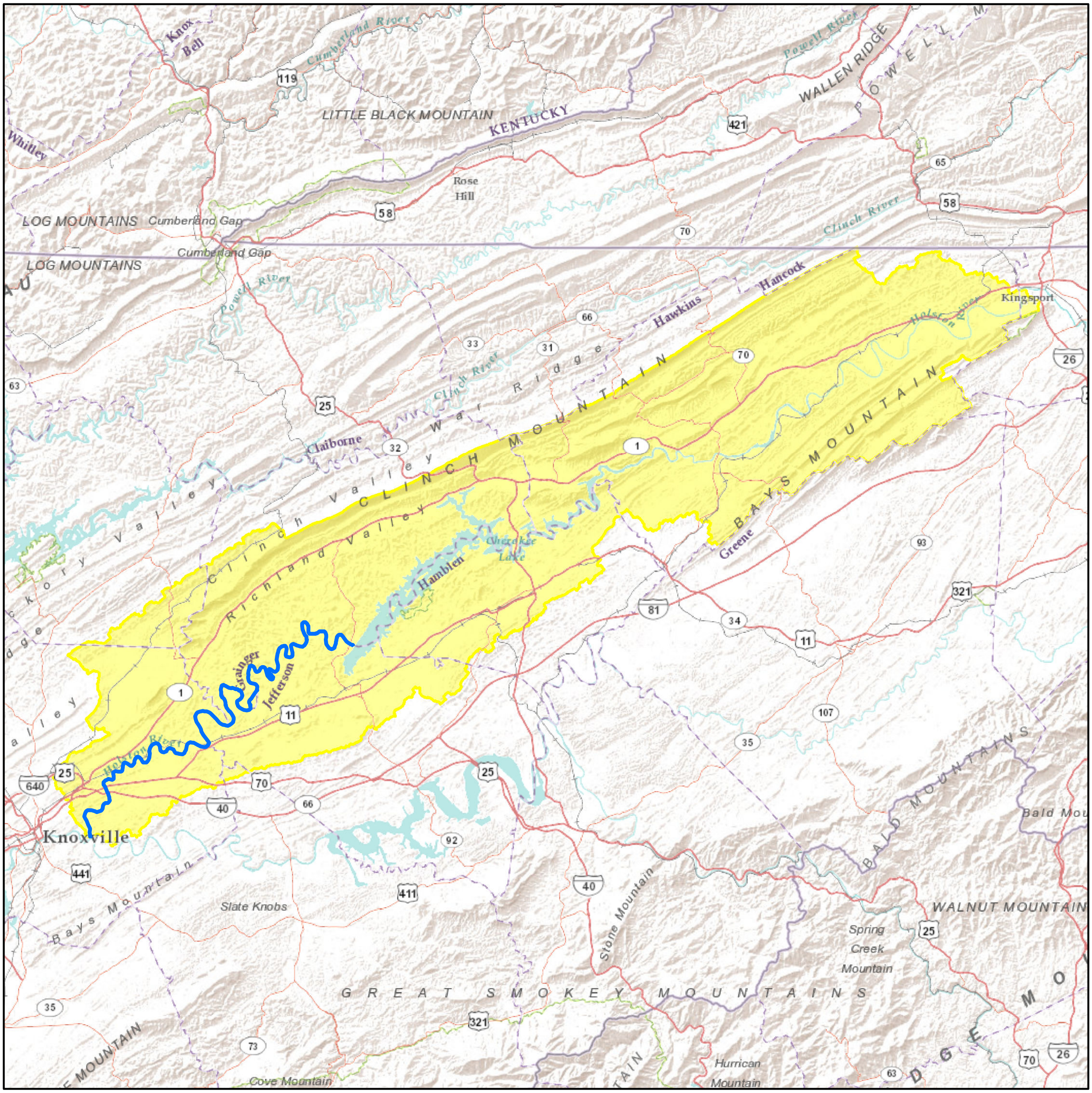
High

Medium

Low



Holston Management Unit



Miles
0 5 10 20

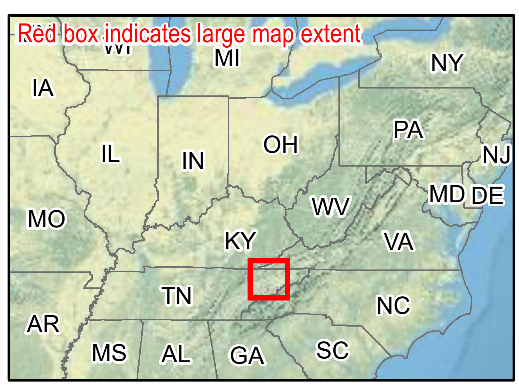
Selected Stream

Management Unit Condition

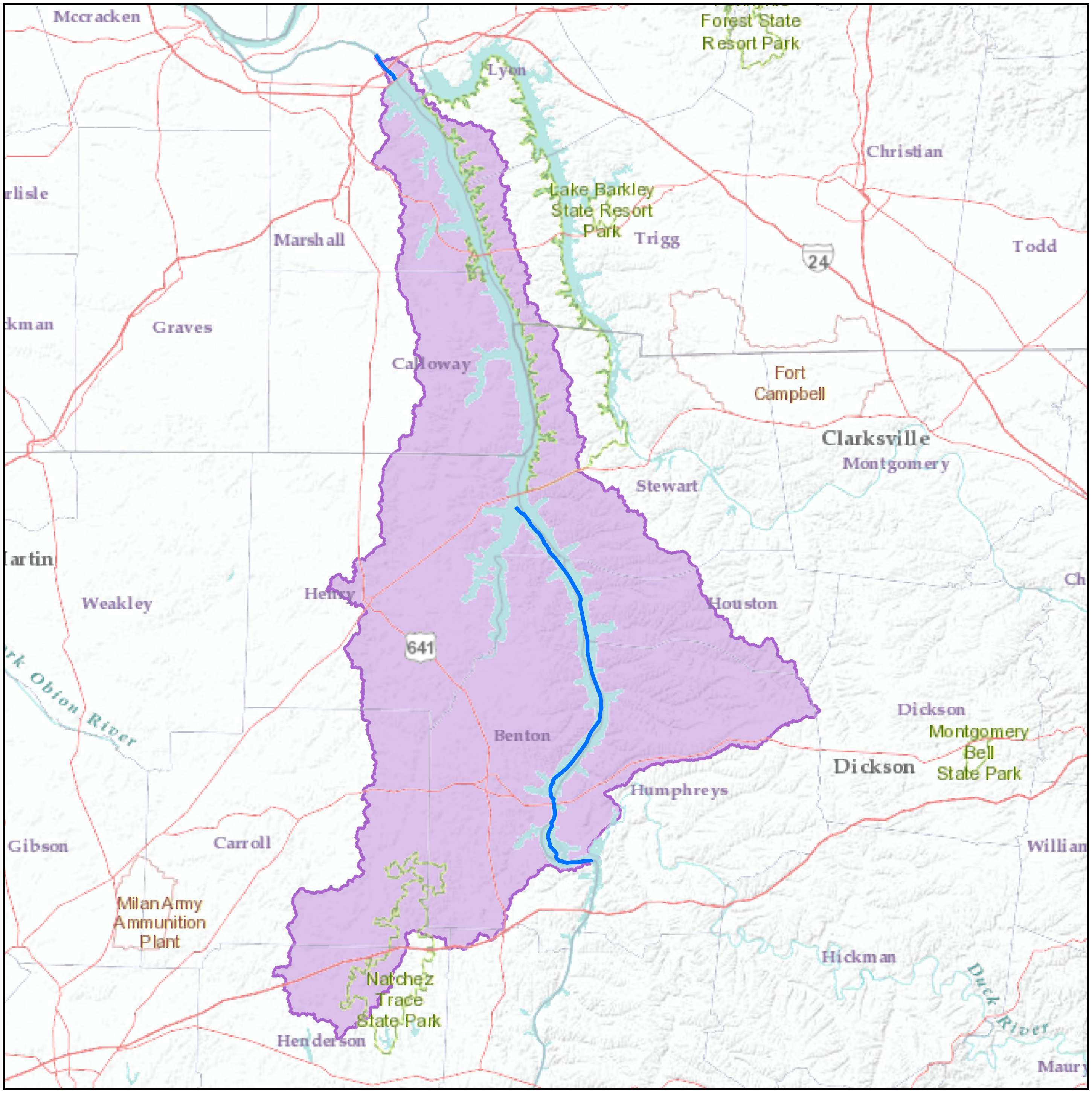
High

Medium

Low



Kentucky Lake Management Unit



0 10 20 40 Miles

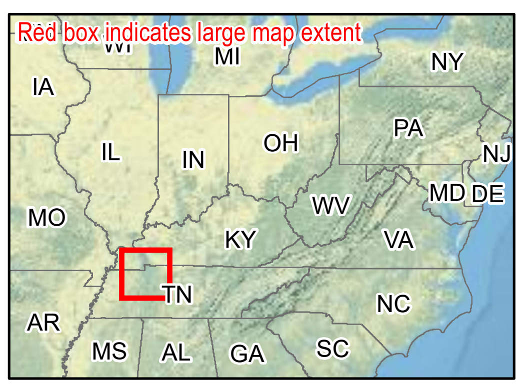
Selected Stream

Management Unit Condition

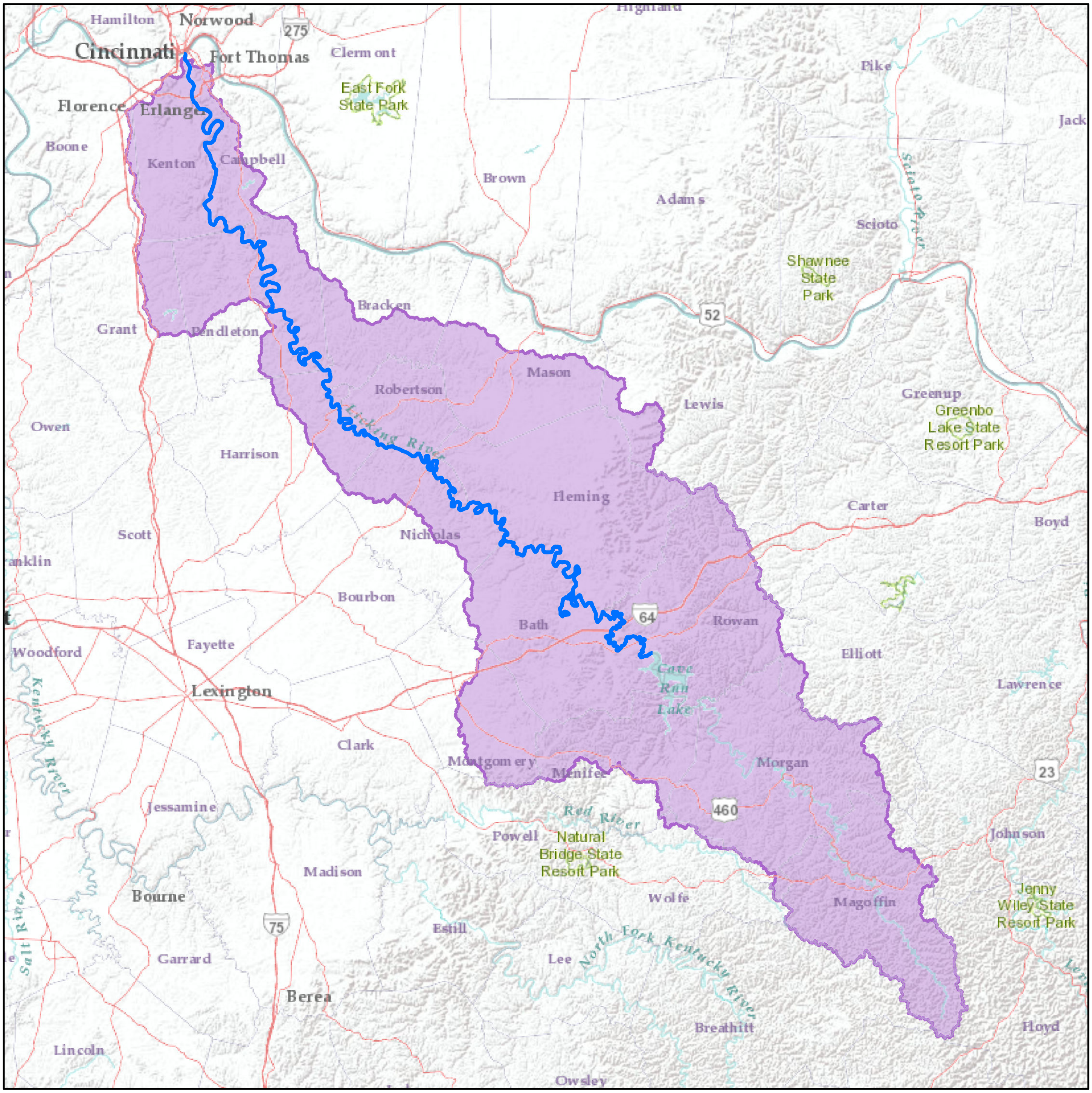
High

Medium

Low



Licking Management Unit



0 12.5 25 50 Miles

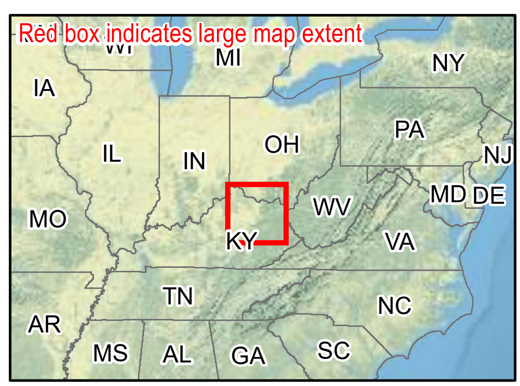
Selected Stream

Management Unit Condition

High

Medium

Low



Little Kanawha Management Unit

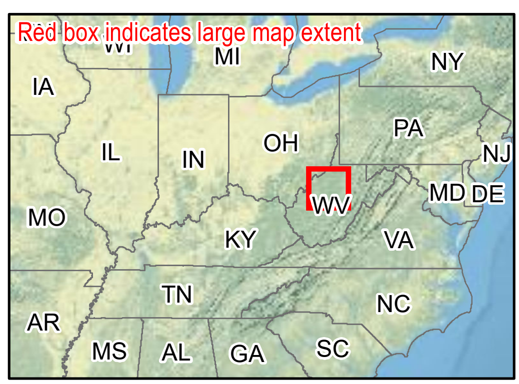
Selected Stream

Management Unit Condition

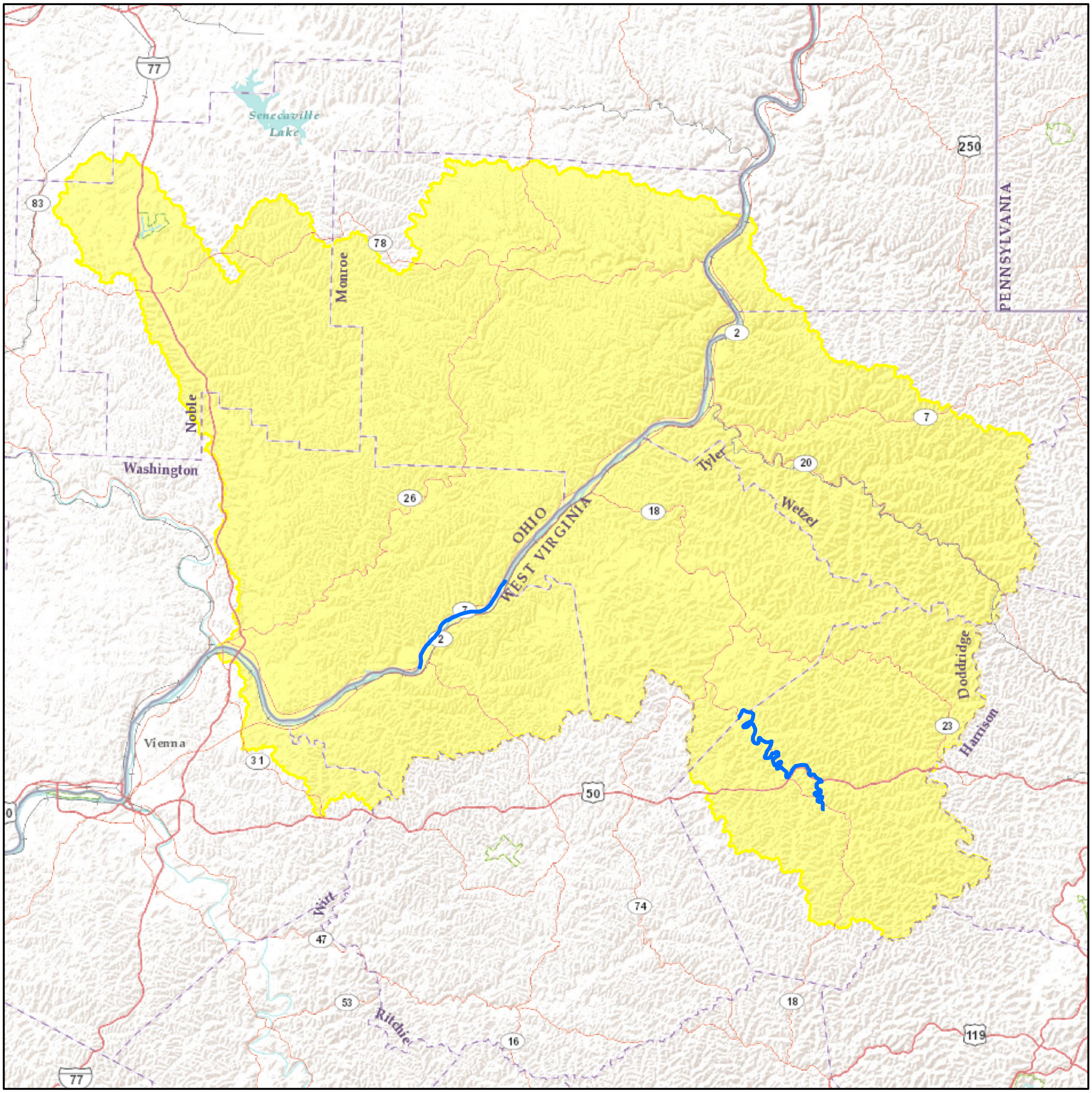
High

Medium

Low



Little Muskingum-Middle Island Management Unit



Miles
0 5 10 20

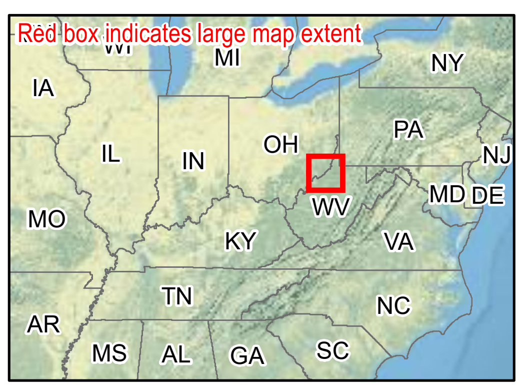
Selected Stream

Management Unit Condition

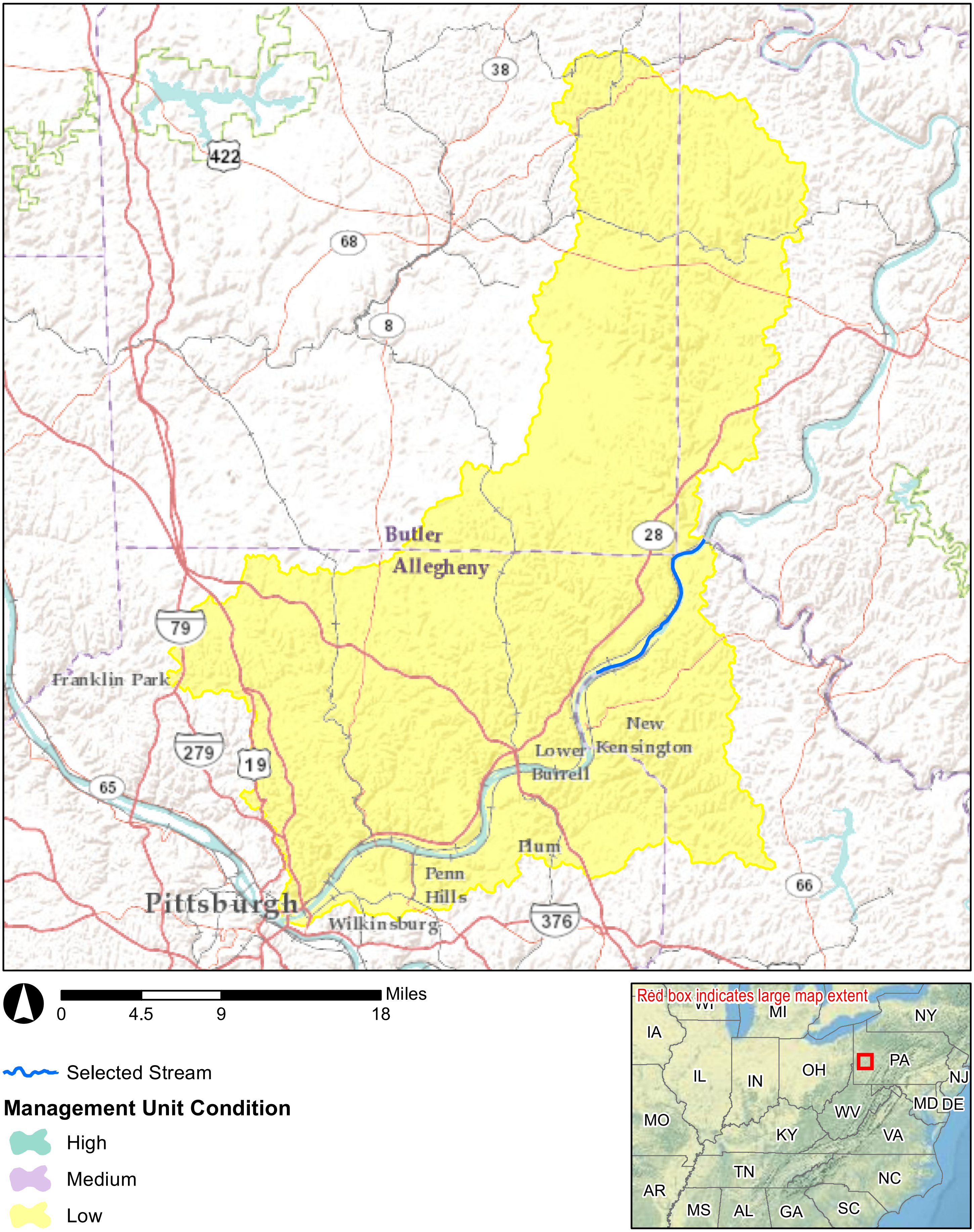
High

Medium

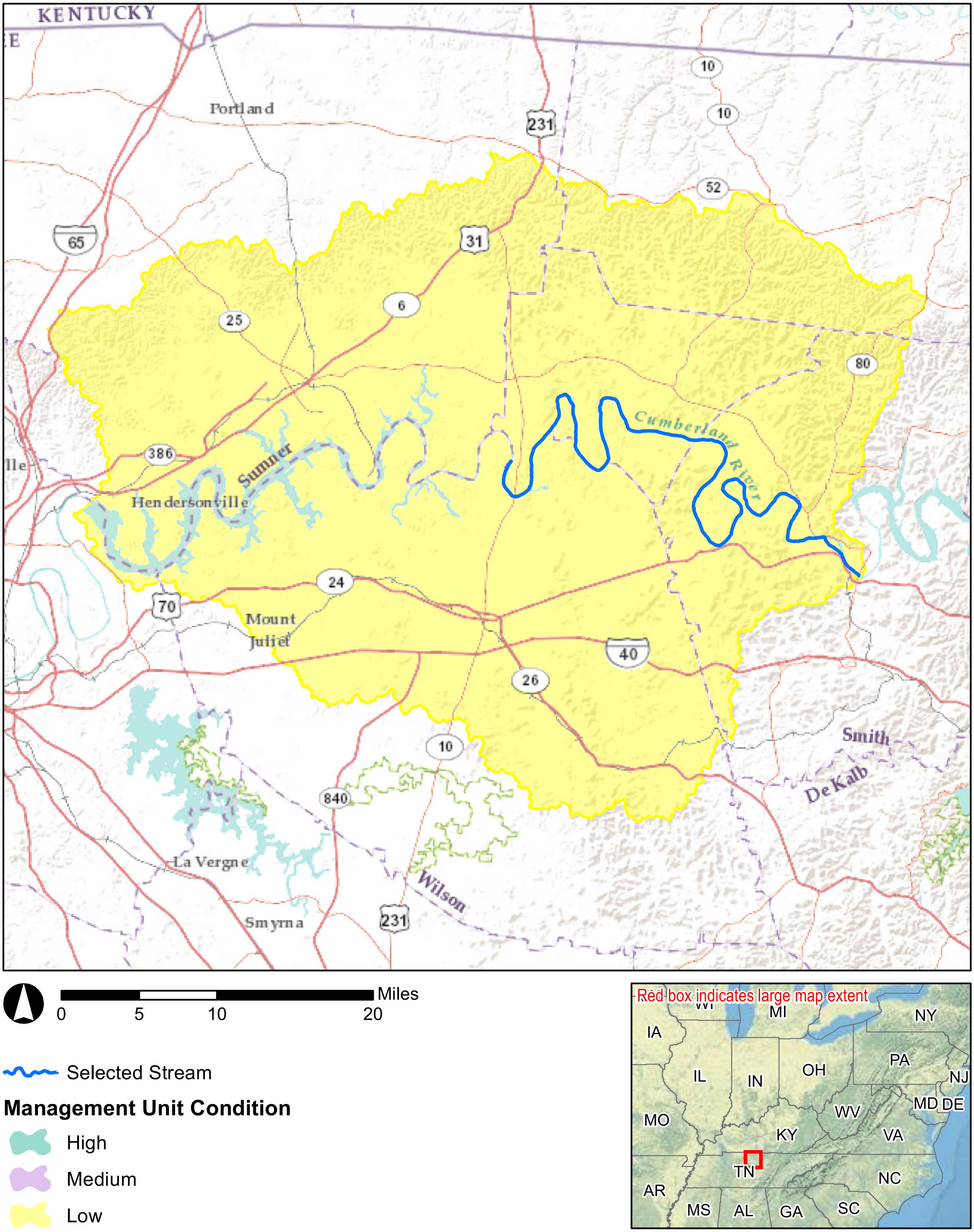
Low



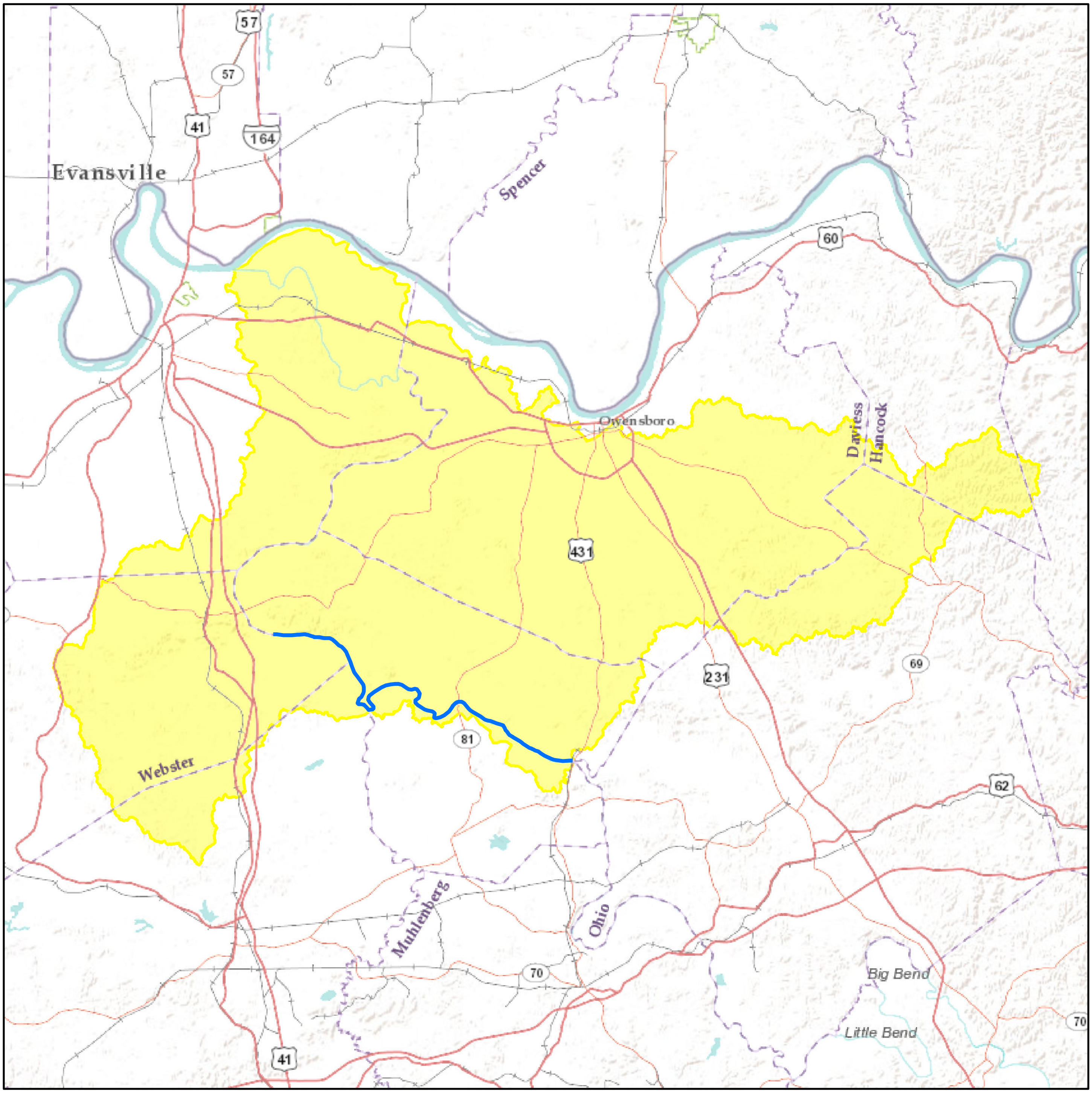
Lower Allegheny Management Unit



Lower Cumberland-Old Hickory Lake Management Unit



Lower Green Management Unit



Miles
0 5 10 20

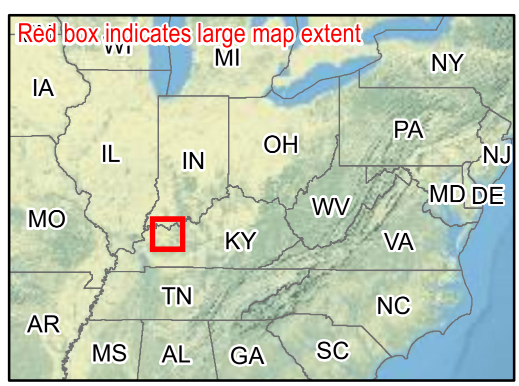
Selected Stream

Management Unit Condition

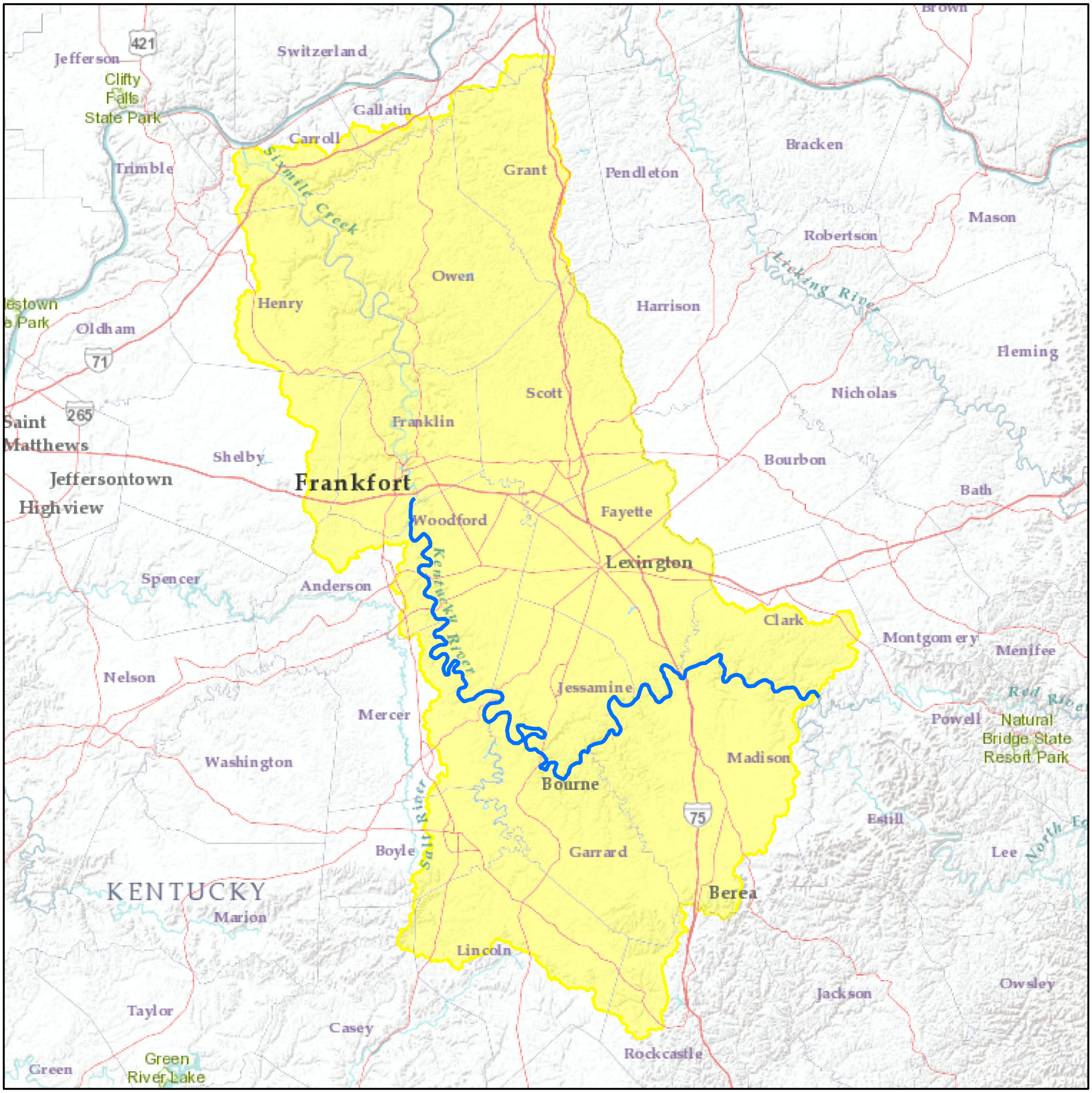
High

Medium

Low



Lower Kentucky Management Unit



Miles
0 10 20 40

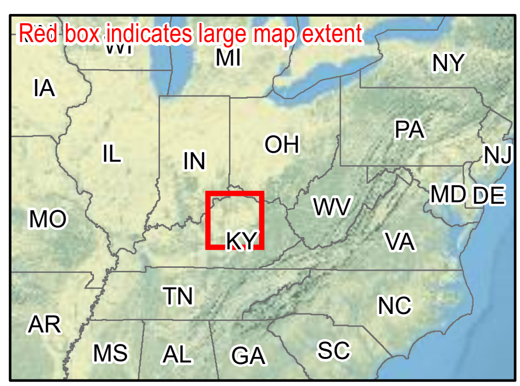
Selected Stream

Management Unit Condition

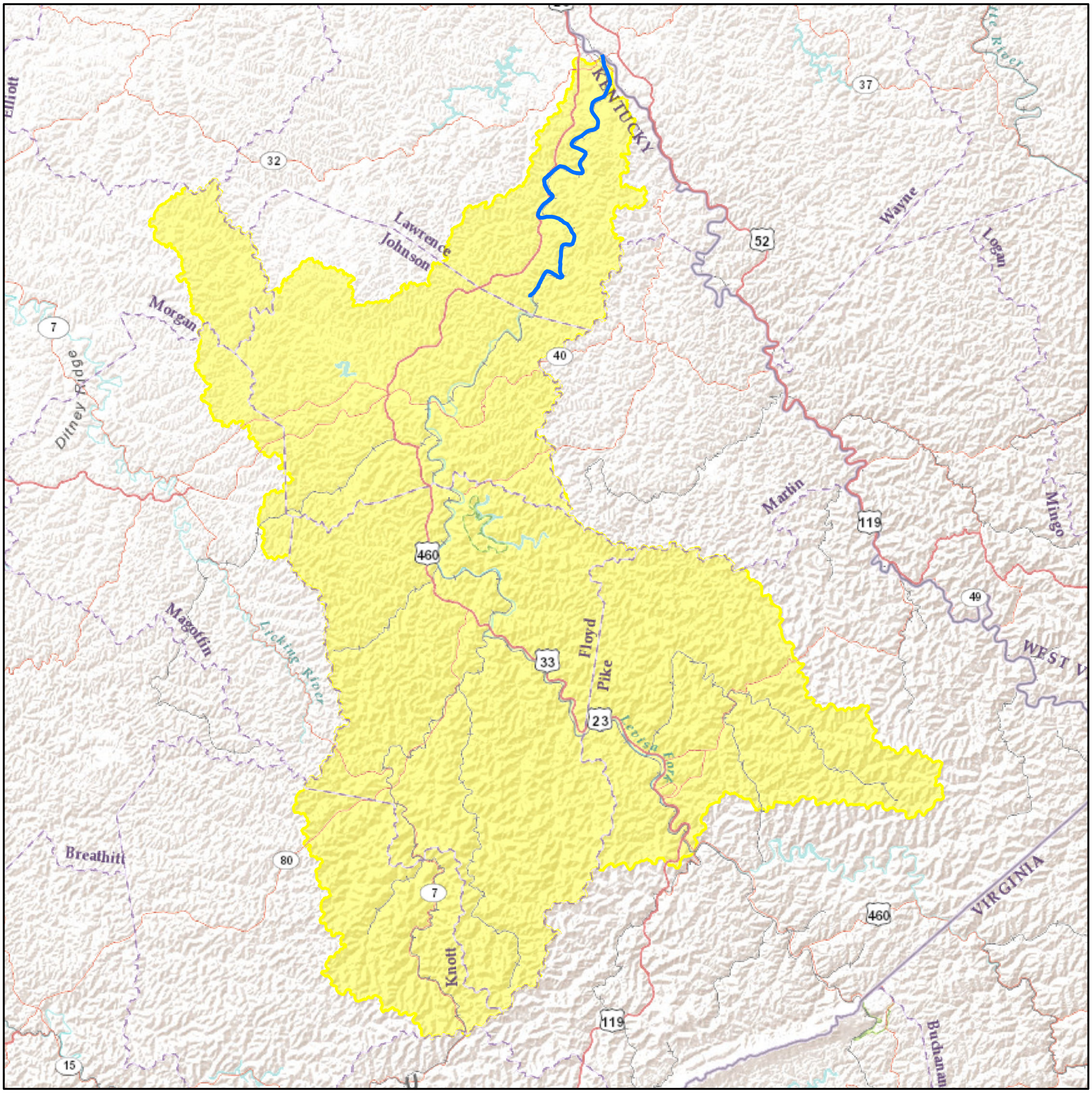
High

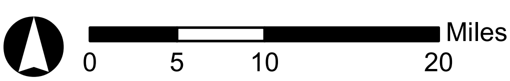
Medium

Low



Lower Levisa Management Unit





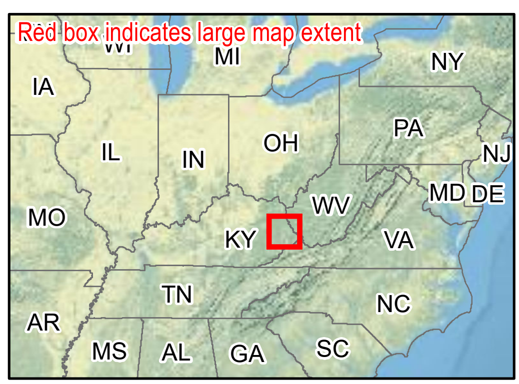
Selected Stream

Management Unit Condition

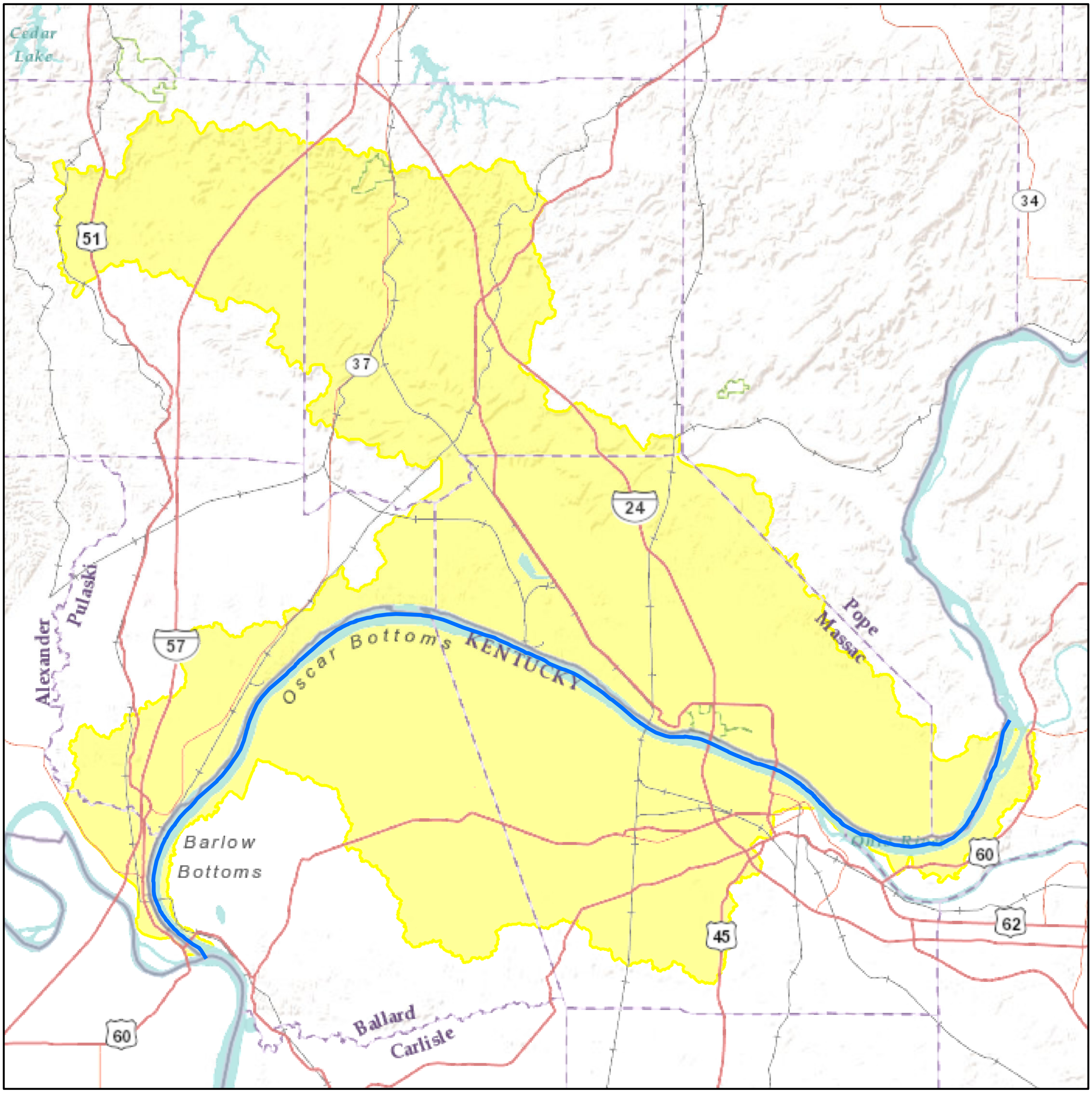
High

Medium

Low



Lower Ohio Management Unit



0 5 10 20 Miles

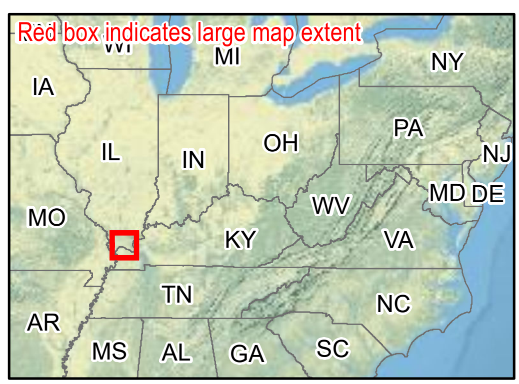
Selected Stream

Management Unit Condition

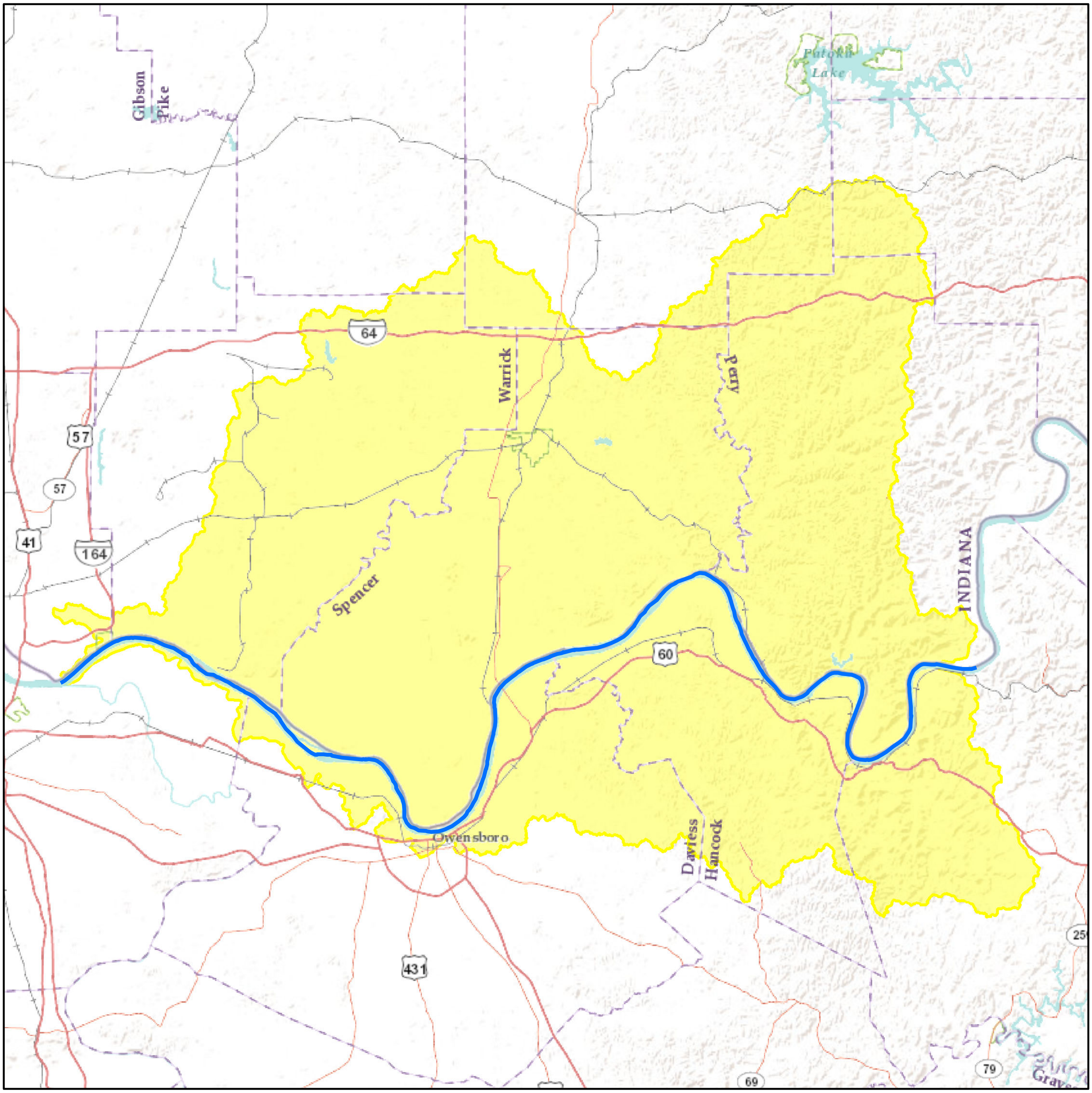
High

Medium

Low



Lower Ohio-Little Pigeon Management Unit



Miles
0 5 10 20

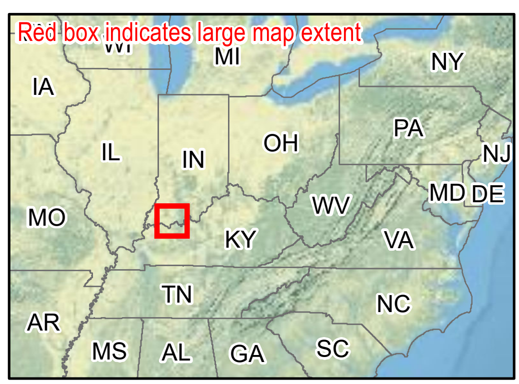
Selected Stream

Management Unit Condition

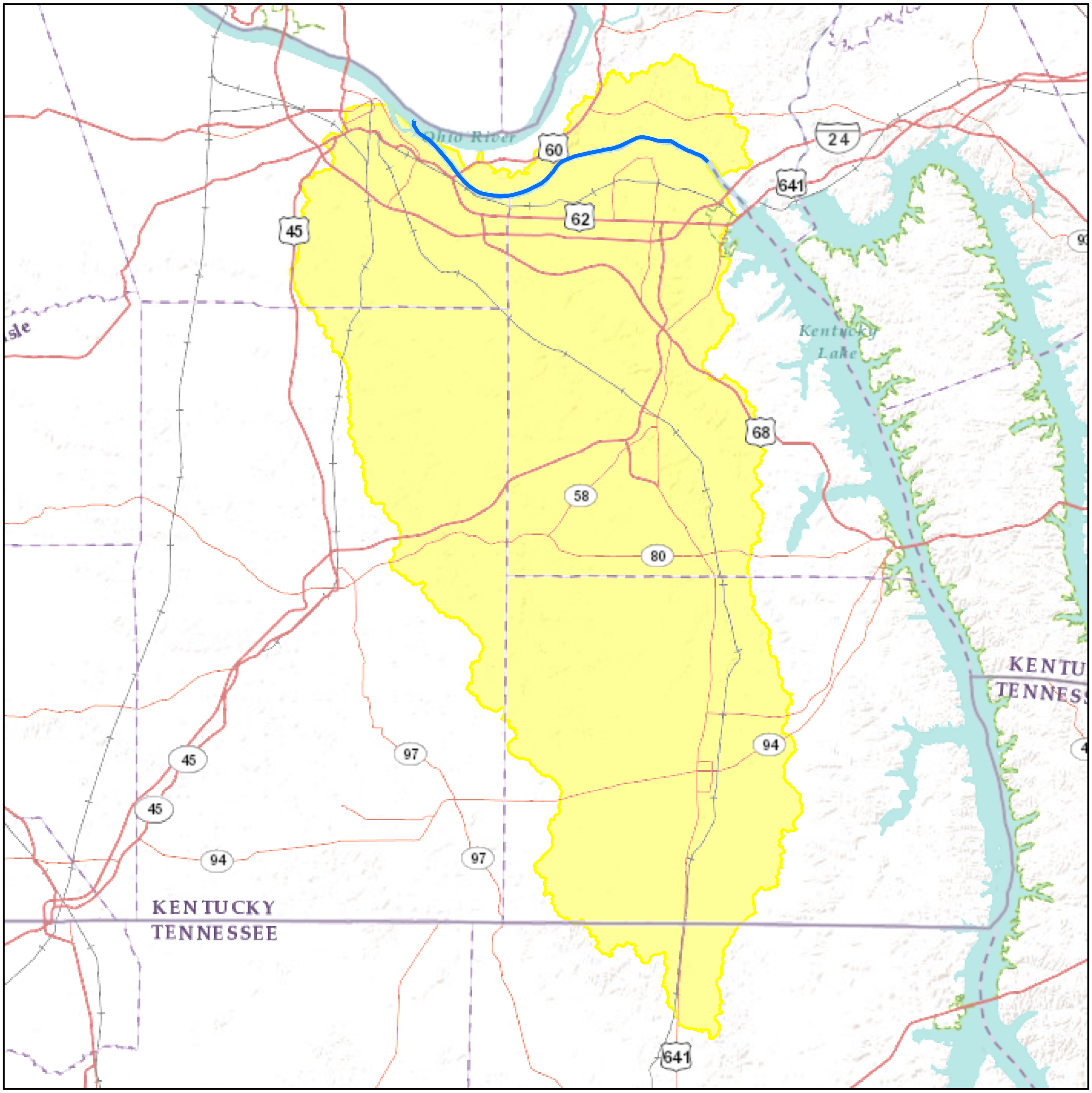
High

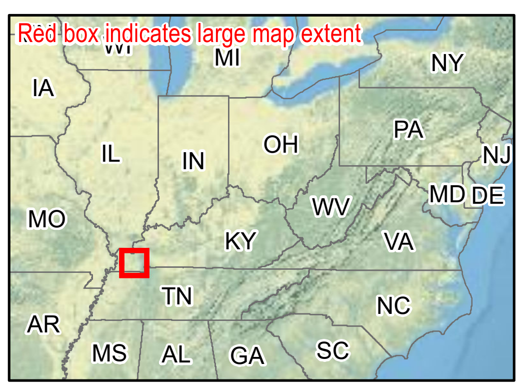
Medium

Low



Lower Tennessee Management Unit





0 5 10 20 Miles

Selected Stream

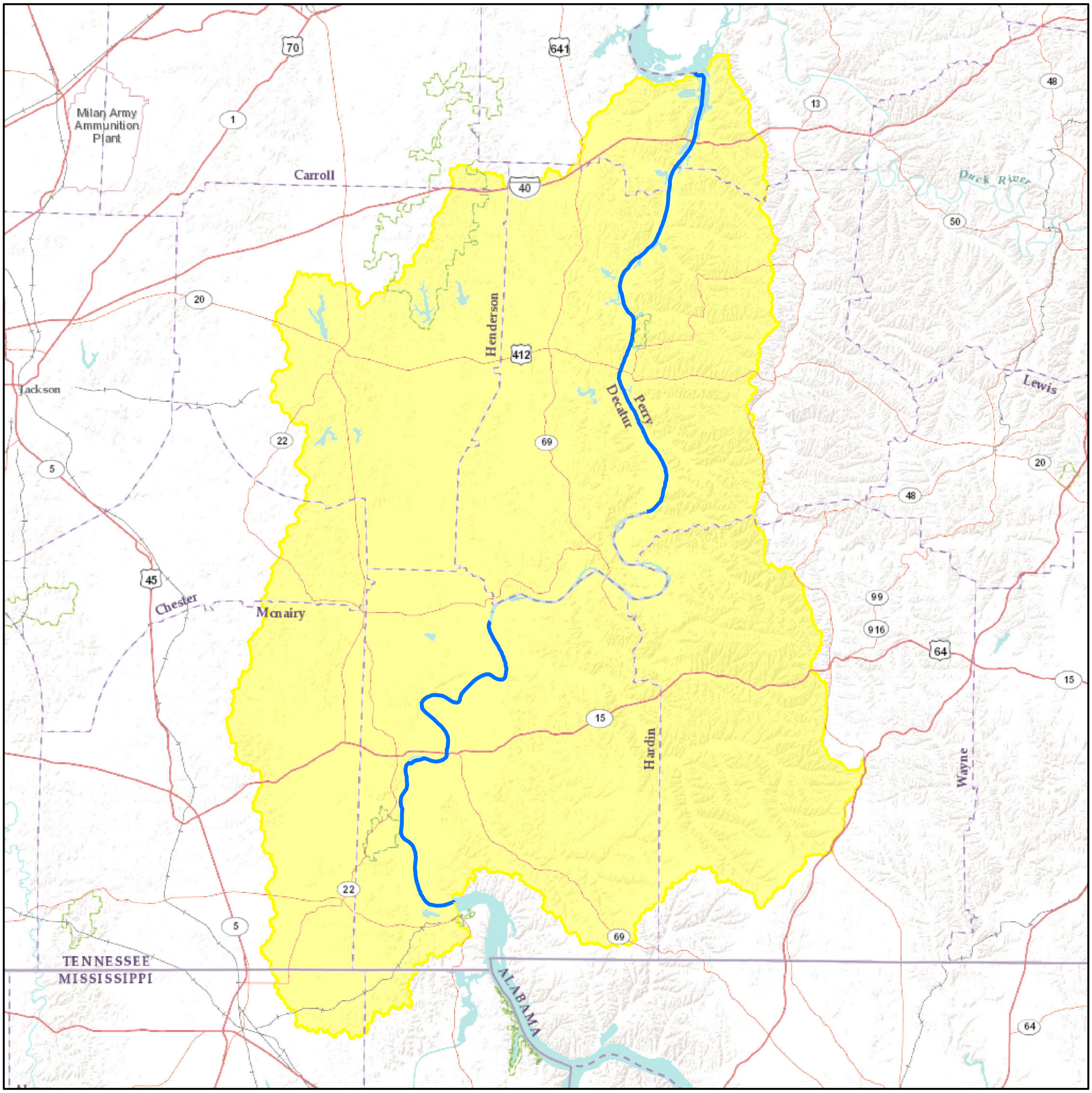
Management Unit Condition

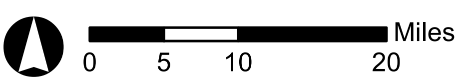
High

Medium

Low

Lower Tennessee-Beech Management Unit





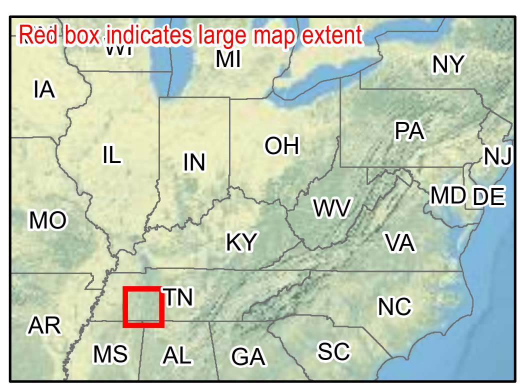
Selected Stream

Management Unit Condition

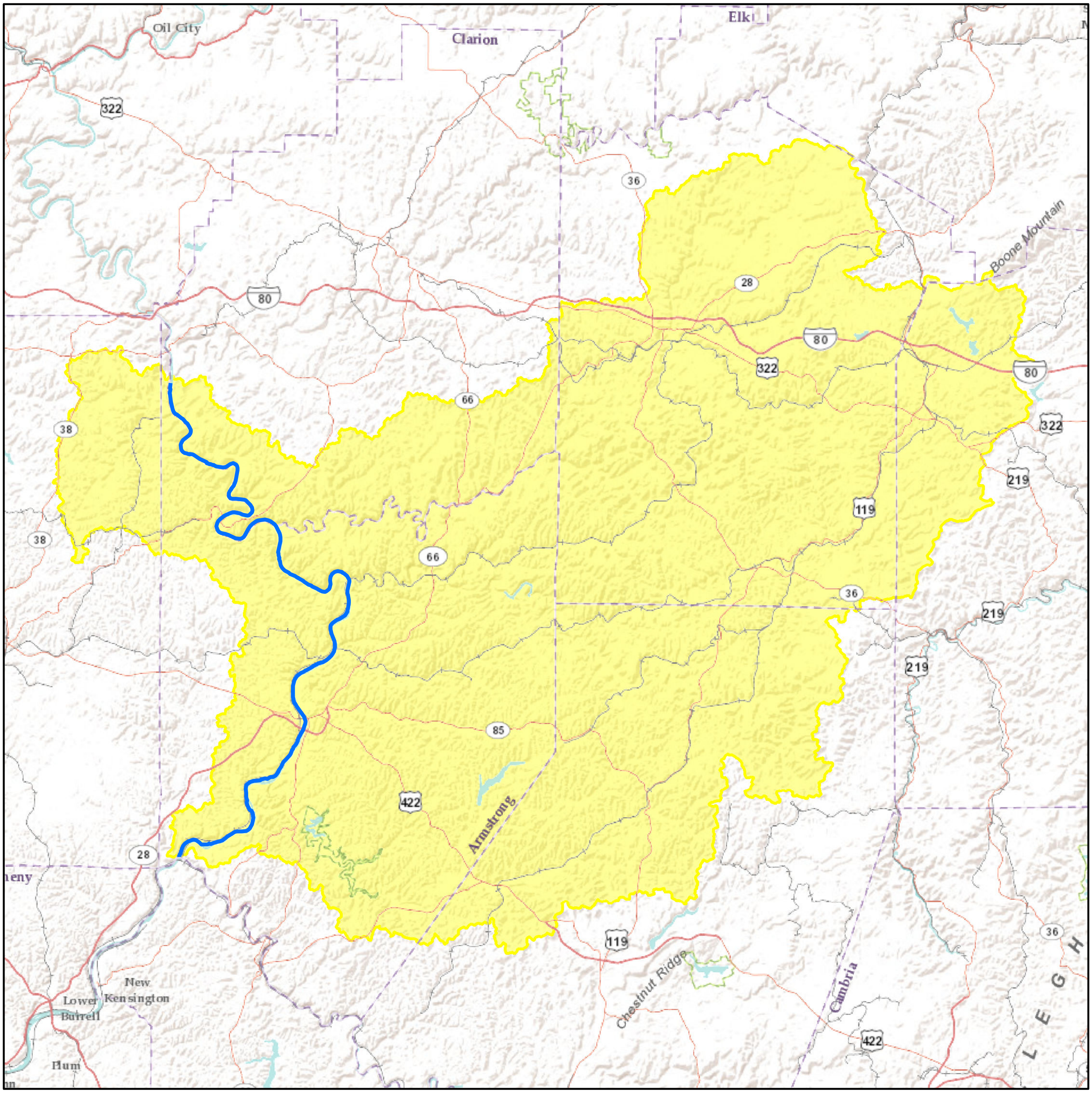
High

Medium

Low



Middle Allegheny-Redbank Management Unit



Miles
0 5 10 20

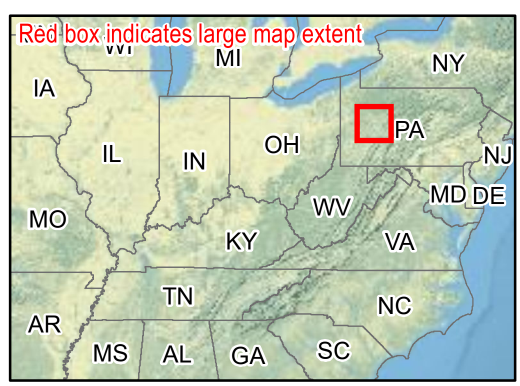
Selected Stream

Management Unit Condition

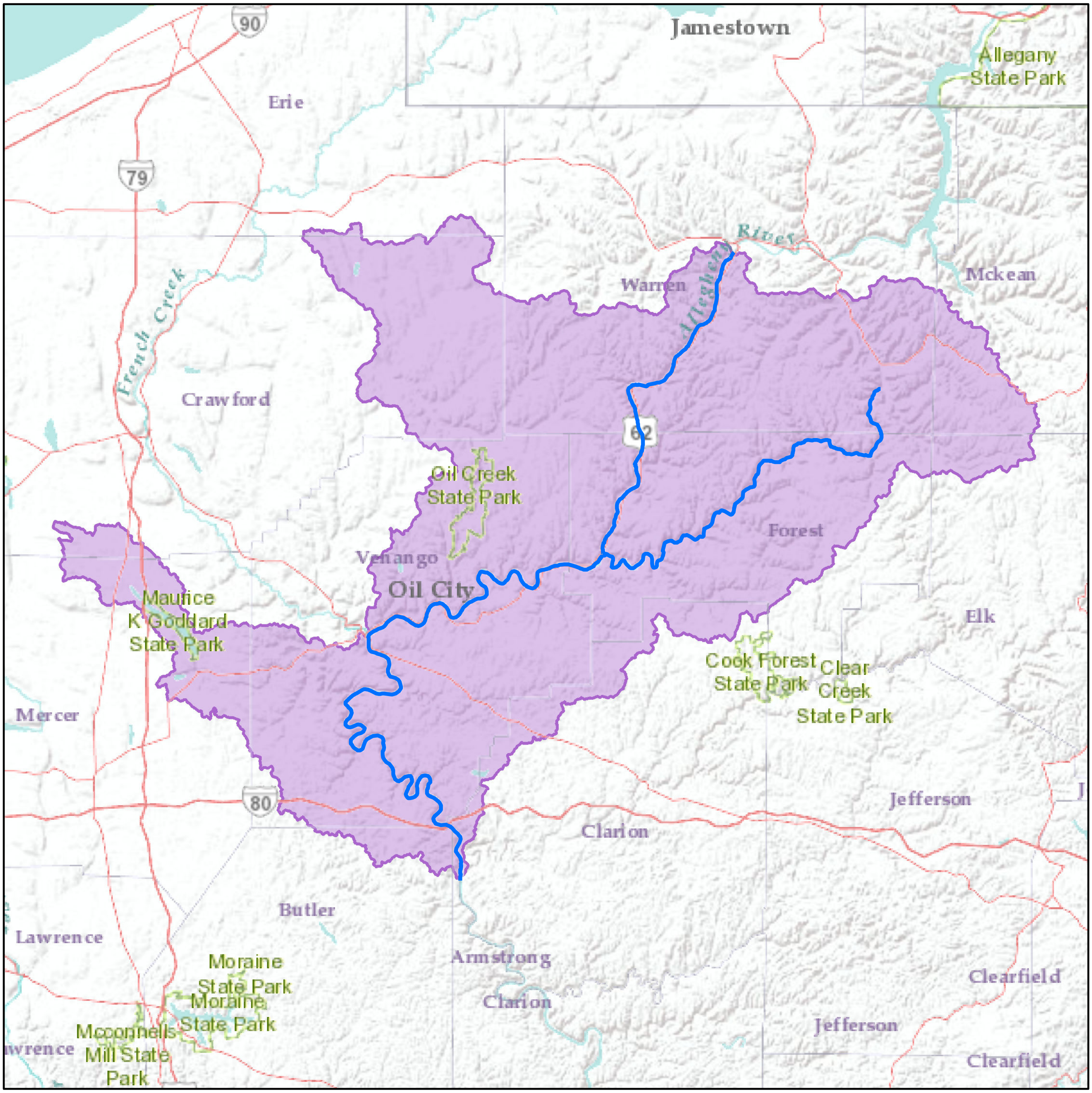
High

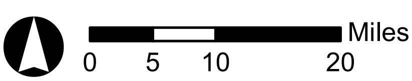
Medium

Low



Middle Allegheny-Tionesta Management Unit





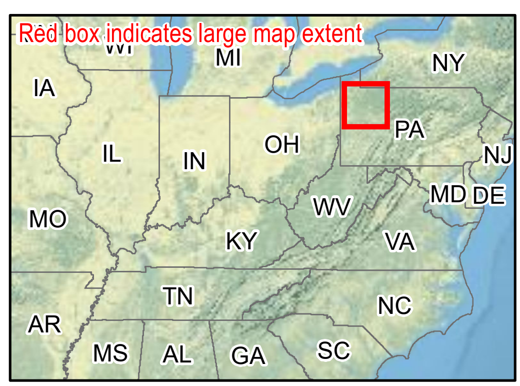
Selected Stream

Management Unit Condition

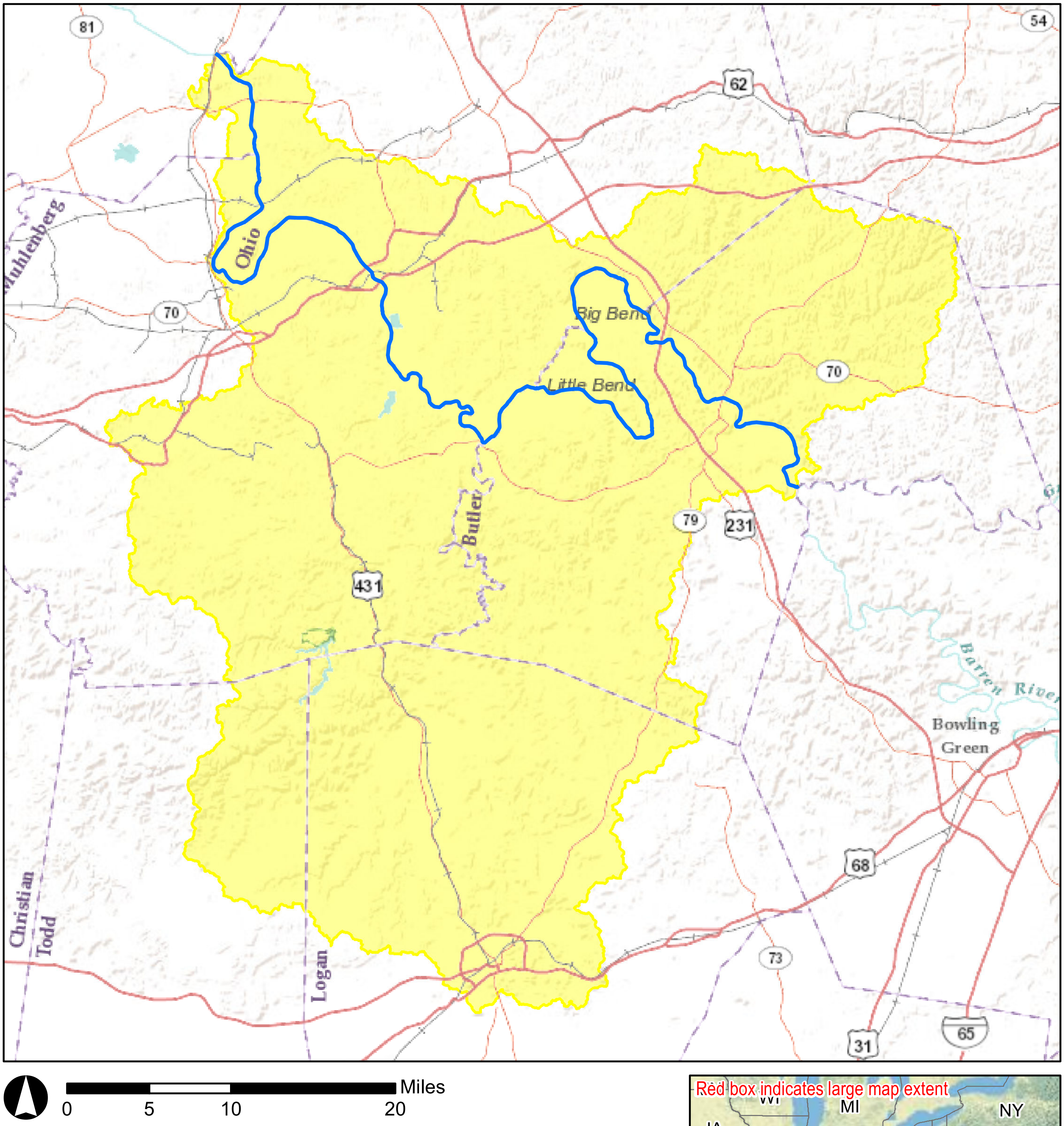
High

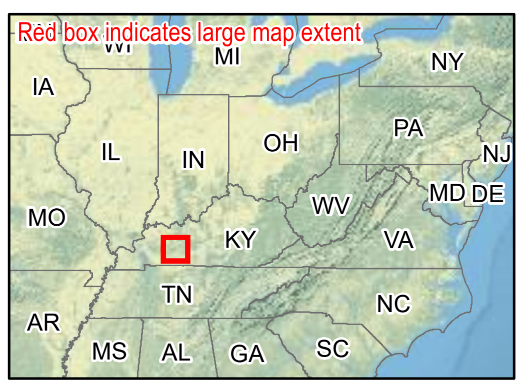
Medium

Low



Middle Green Management Unit





Selected Stream

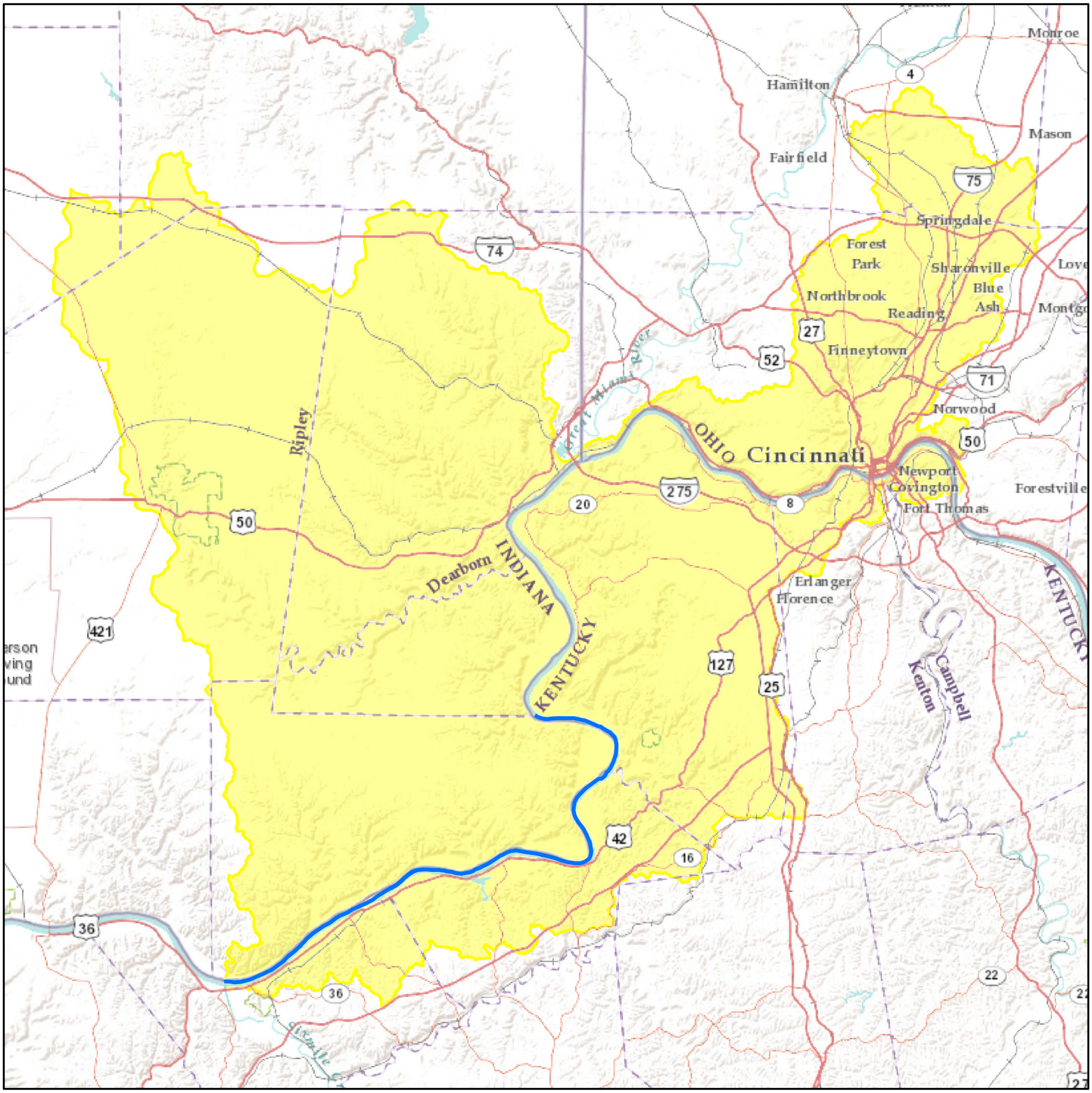
Management Unit Condition

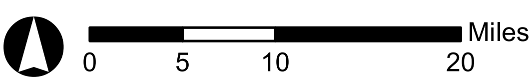
High

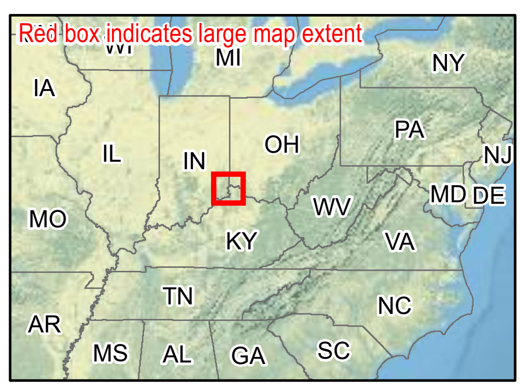
Medium

Low

Middle Ohio-Laughery Management Unit







Selected Stream

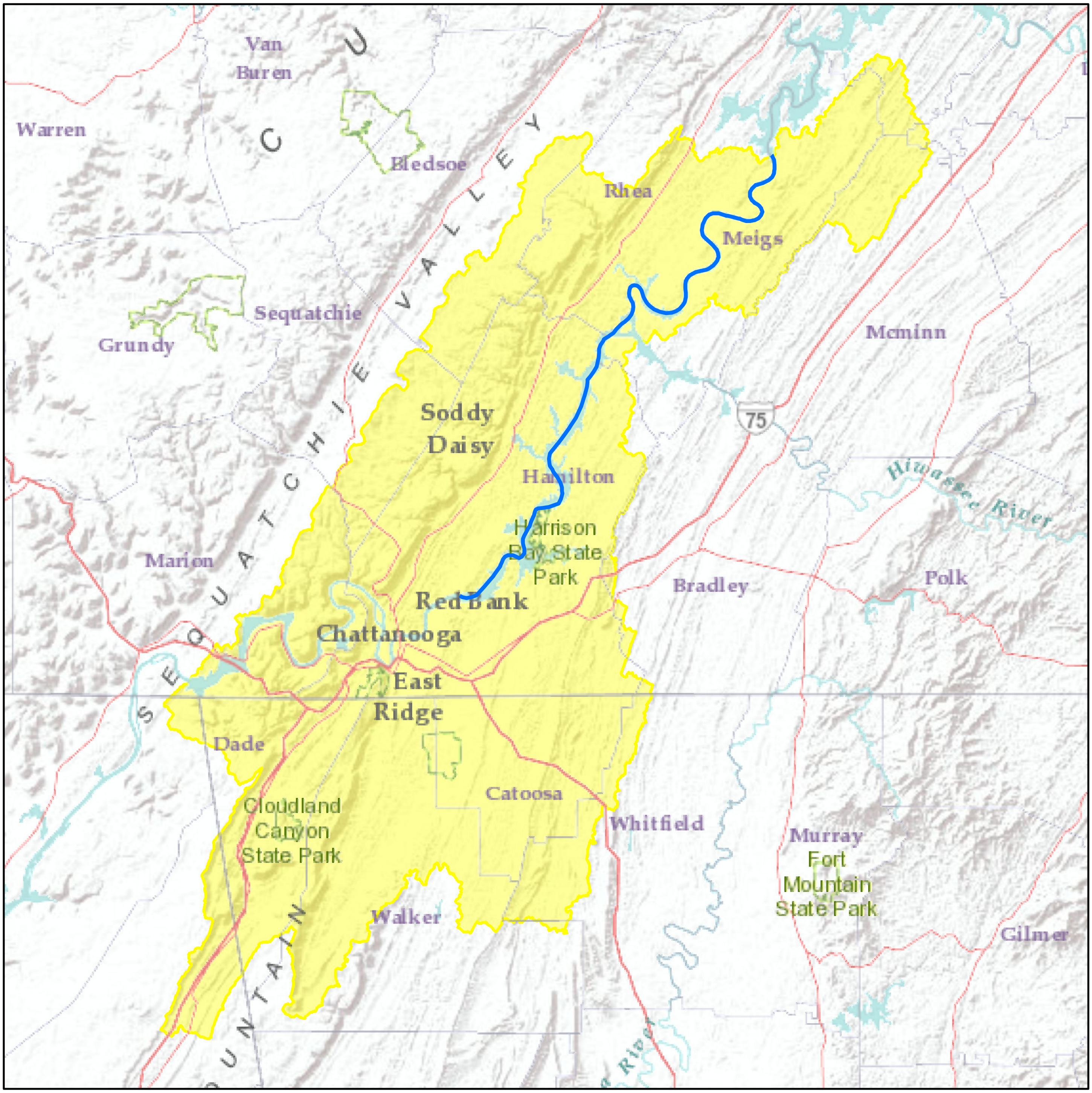
Management Unit Condition

High

Medium

Low

Middle Tennessee-Chickamauga Management Unit

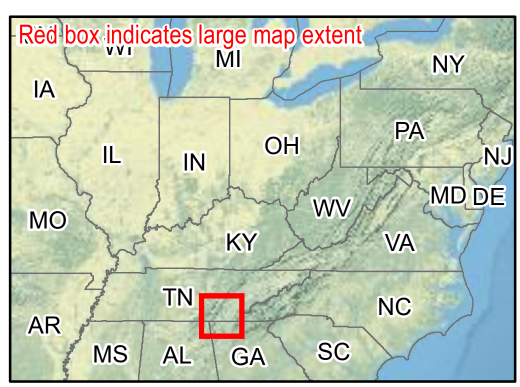


Miles
0 5 10 20

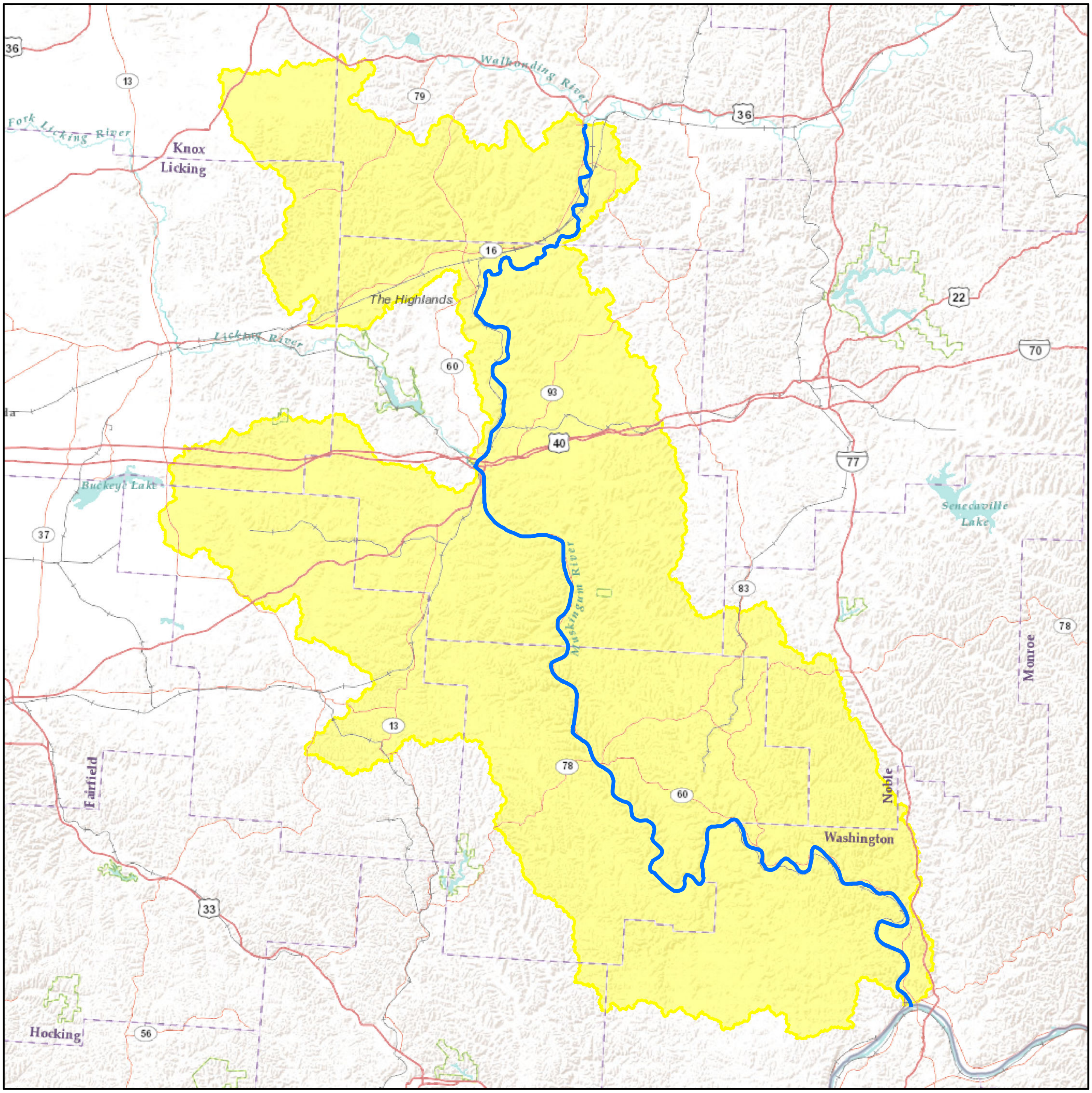
Selected Stream

Management Unit Condition

- High
- Medium
- Low



Muskingum Management Unit



Miles
0 5 10 20

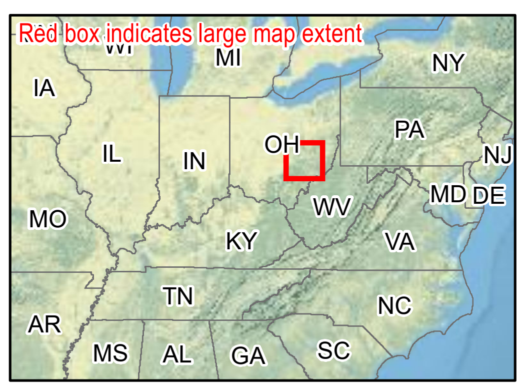
Selected Stream

Management Unit Condition

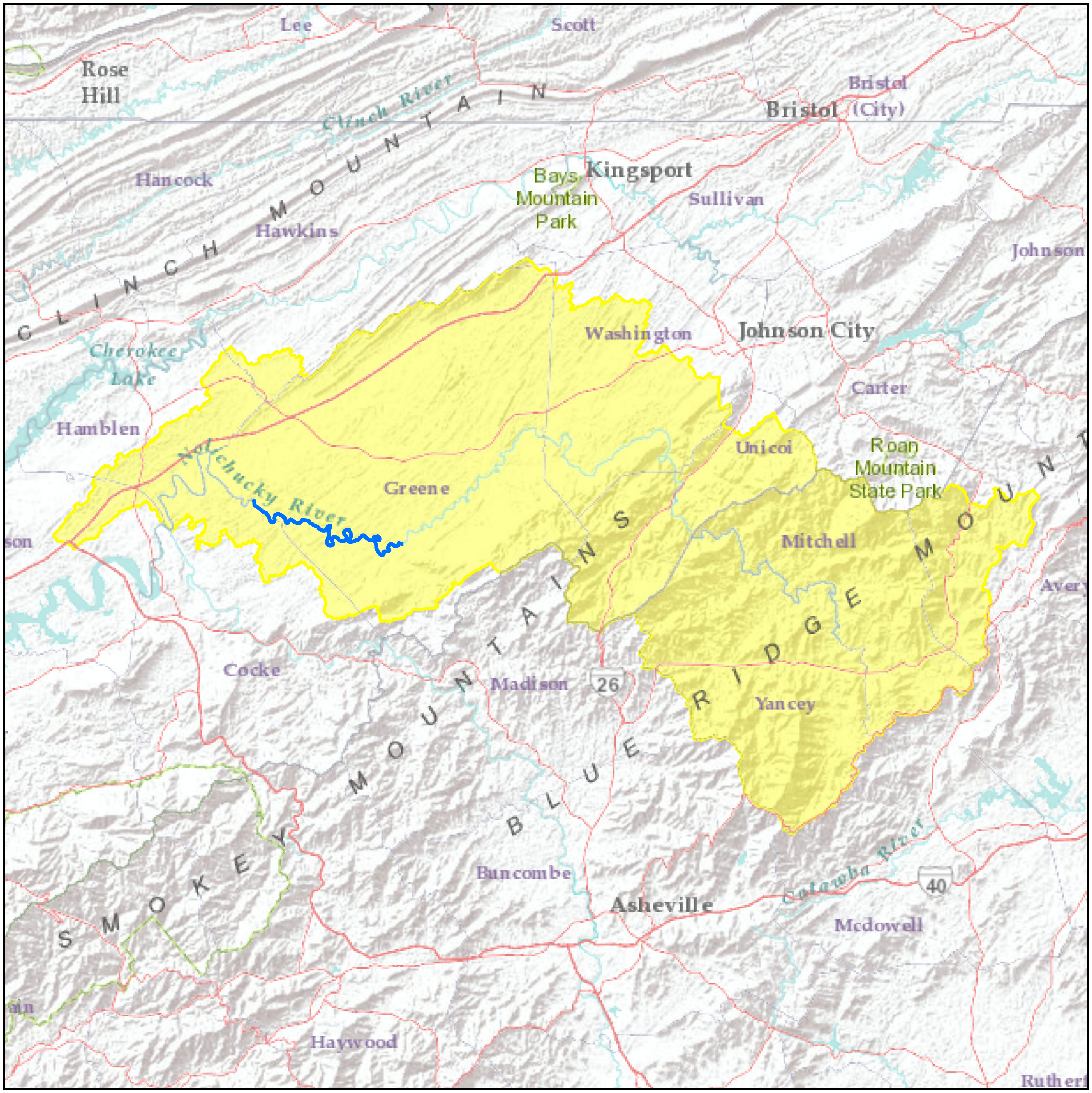
High

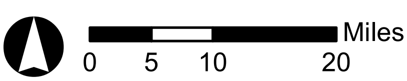
Medium

Low



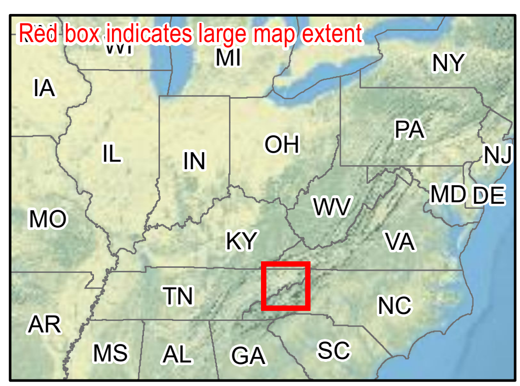
Nolichucky Management Unit





Management Unit Condition

- High
- Medium
- Low



North Fork Kentucky Management Unit

Miles

0 5 10 20

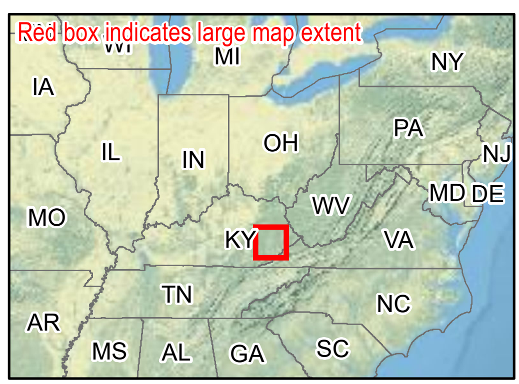
Selected Stream

Management Unit Condition

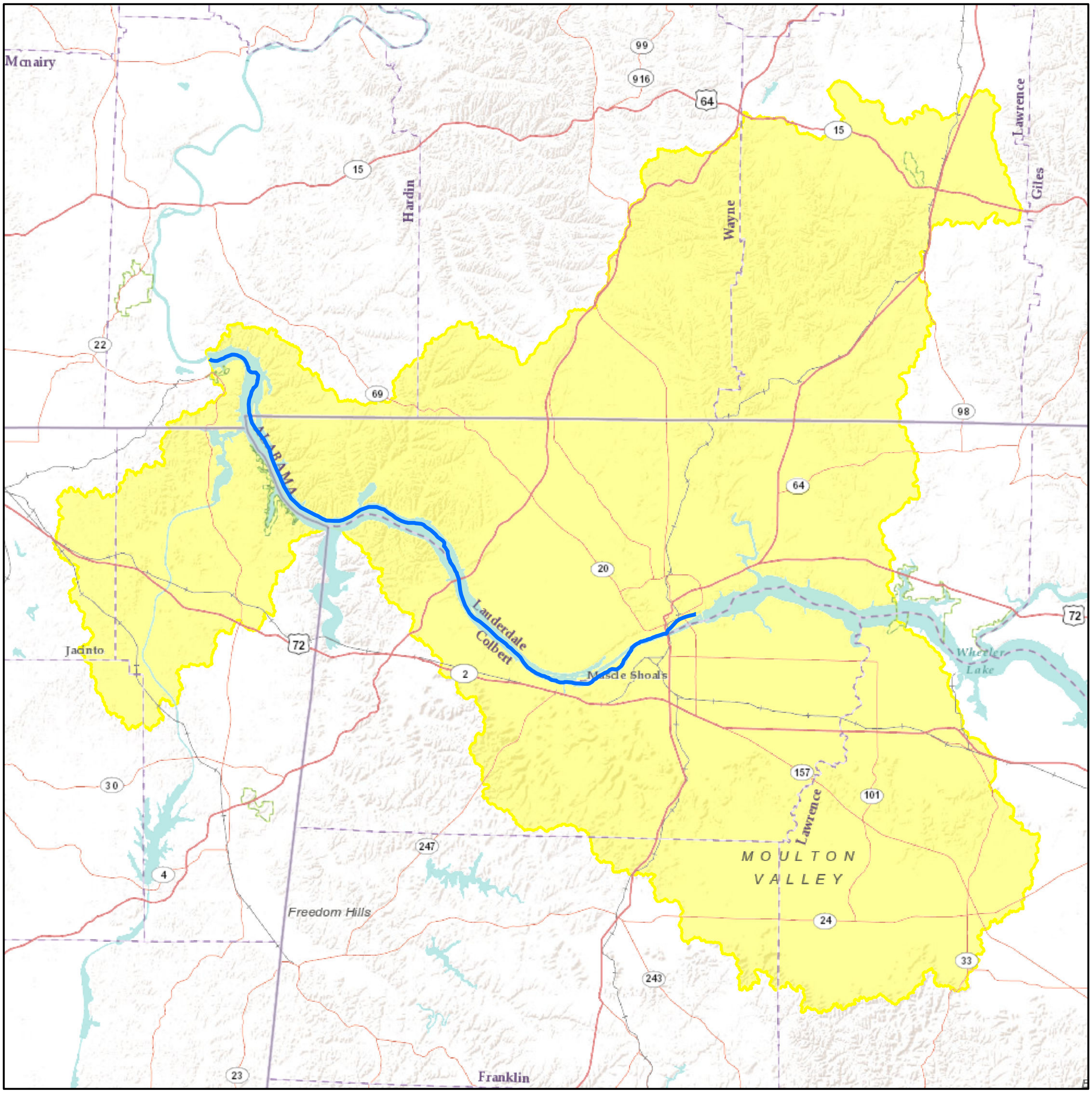
High

Medium

Low



Pickwick Lake Management Unit



Miles

0 5 10 20

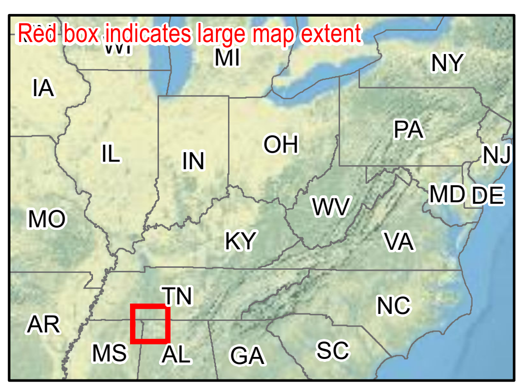
Selected Stream

Management Unit Condition

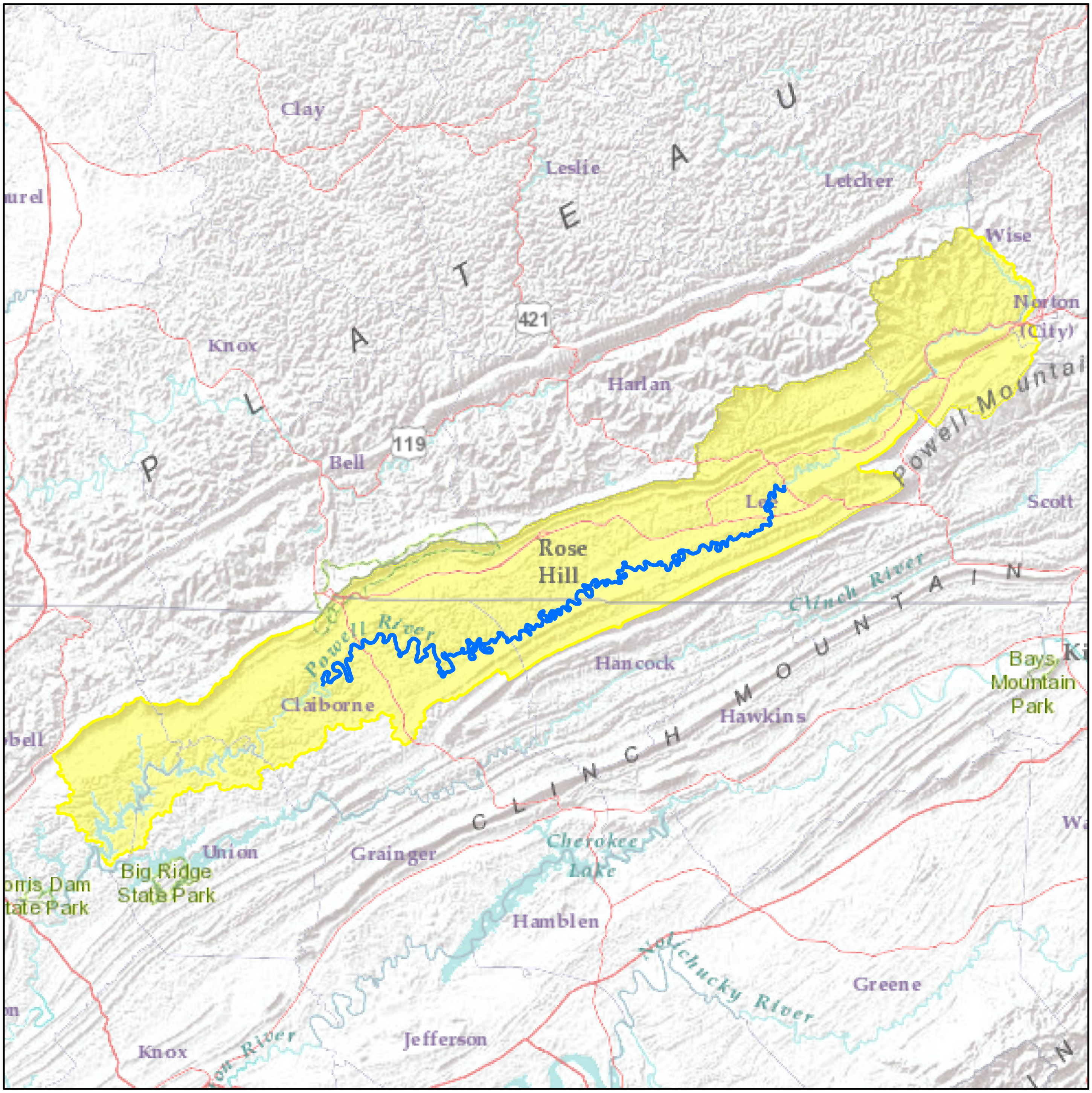
High

Medium

Low



Powell Management Unit



Miles
0 5 10 20

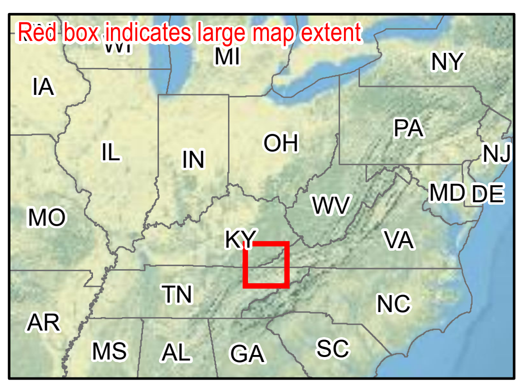
Selected Stream

Management Unit Condition

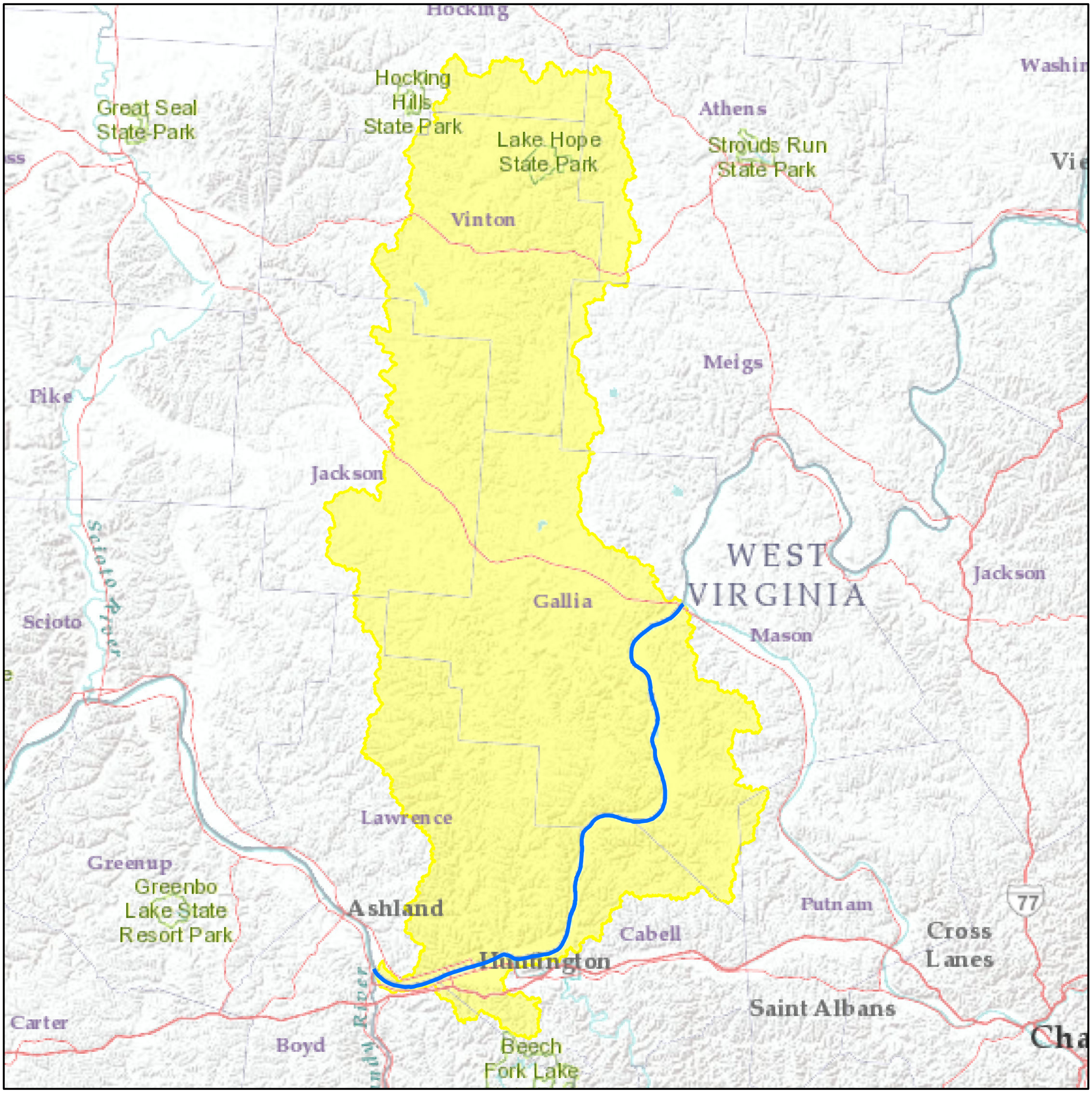
High

Medium

Low



Raccoon-Symmes Management Unit



Miles
0 5 10 20

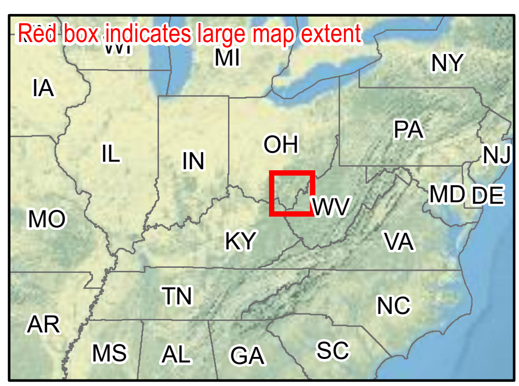
Selected Stream

Management Unit Condition

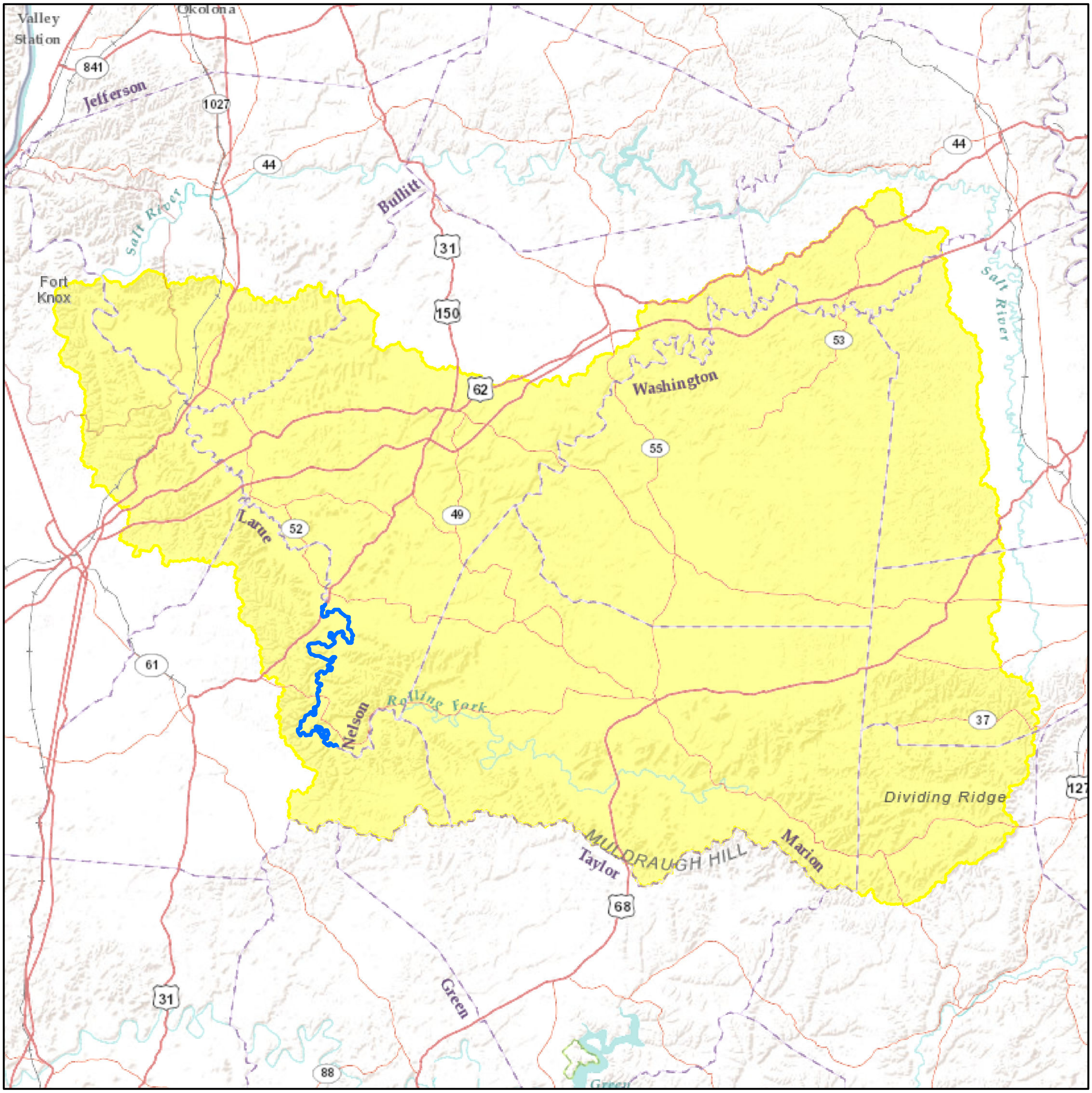
High

Medium

Low



Rolling Fork Management Unit



Miles
0 5 10 20

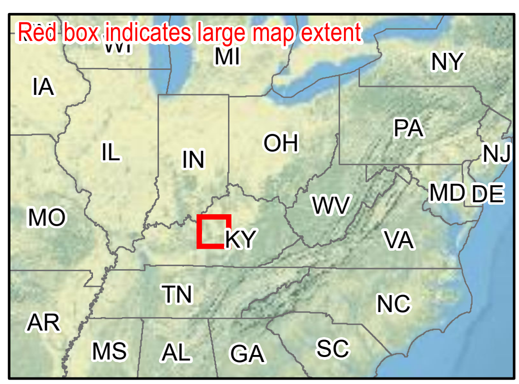
Selected Stream

Management Unit Condition

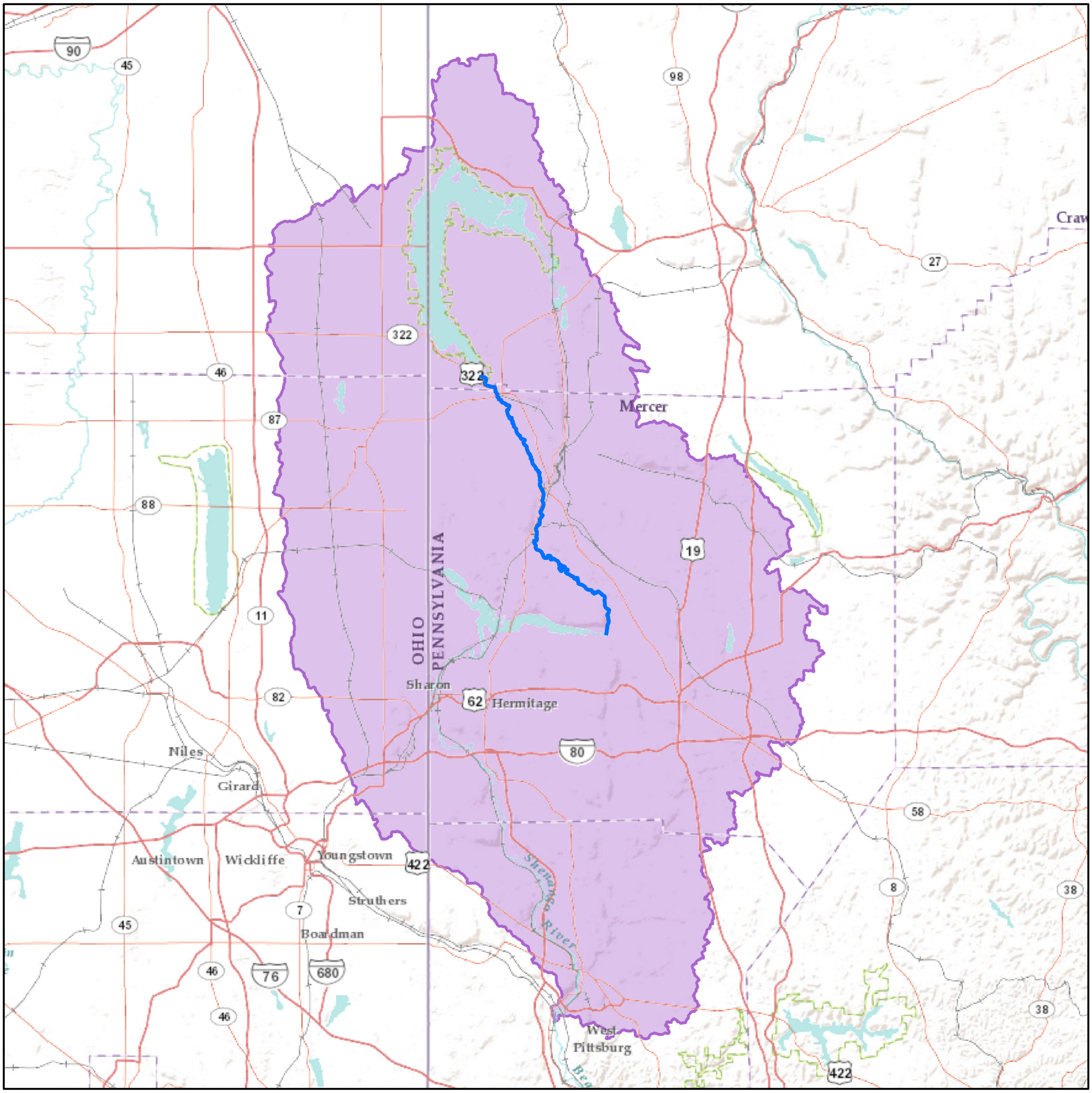
High

Medium

Low



Shenango Management Unit



Miles
0 5 10 20

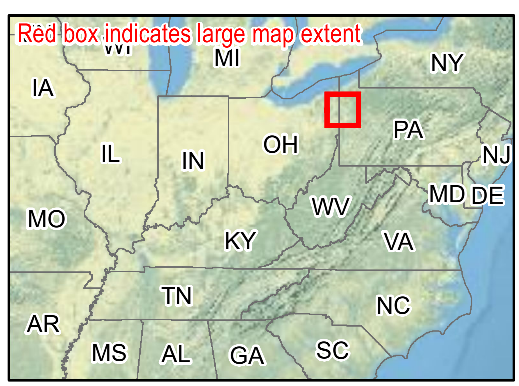
Selected Stream

Management Unit Condition

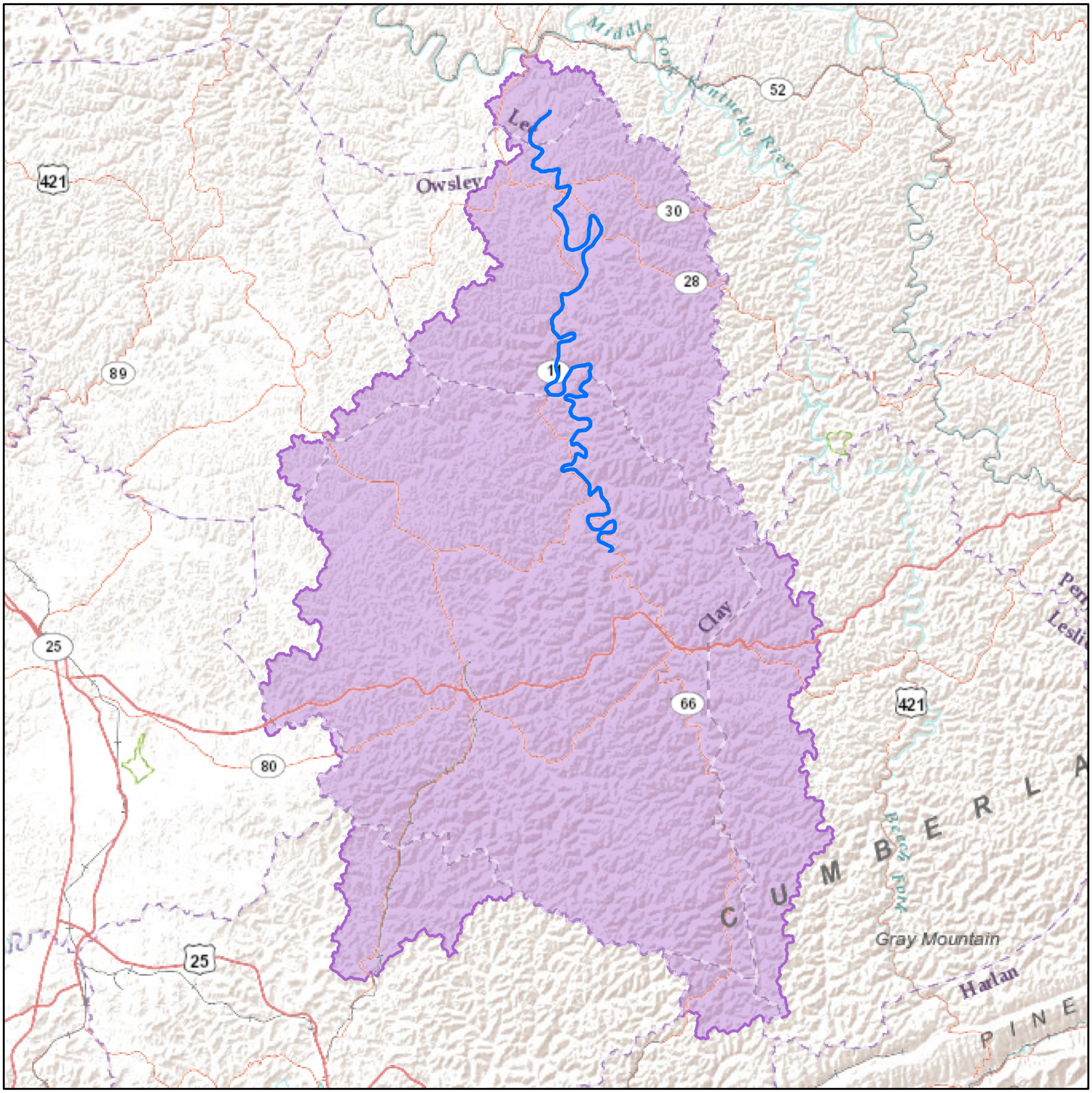
High

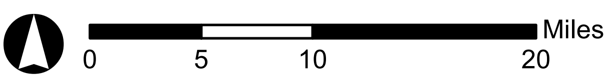
Medium

Low



South Fork Kentucky Management Unit





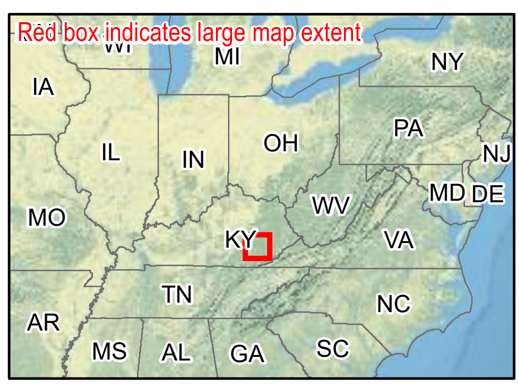
Selected Stream

Management Unit Condition

High

Medium

Low



Tuscarawas Management Unit

Miles
0 5 10 20

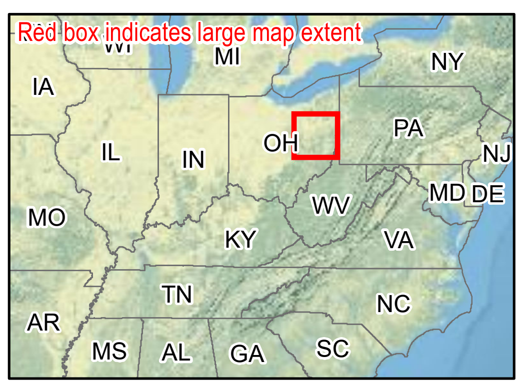
Selected Stream

Management Unit Condition

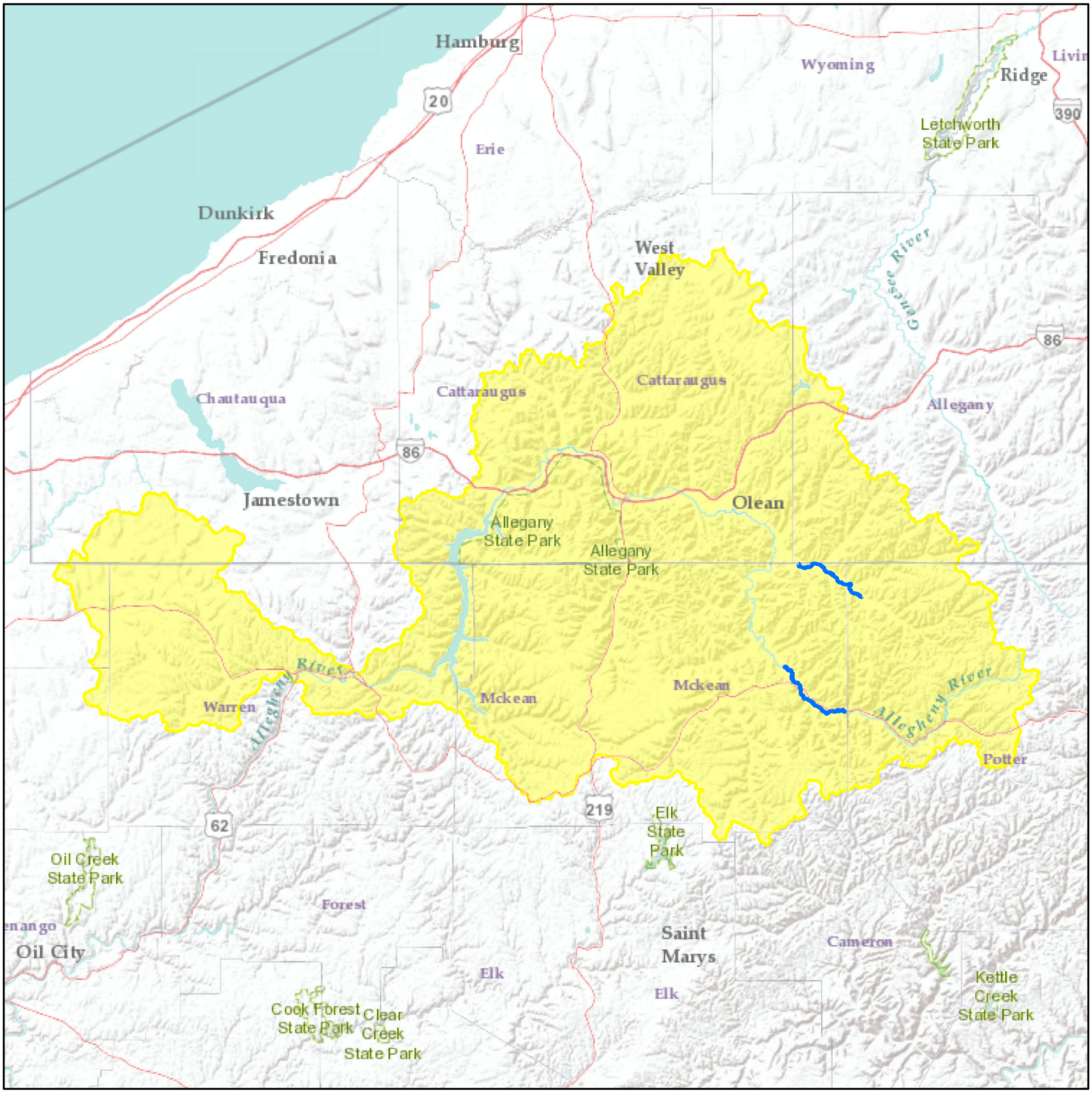
High

Medium

Low



Upper Allegheny Management Unit

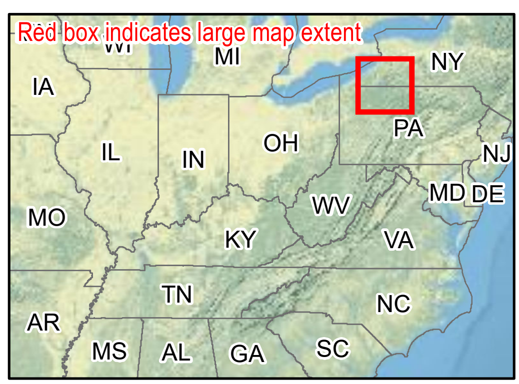


Miles
0 10 20 40

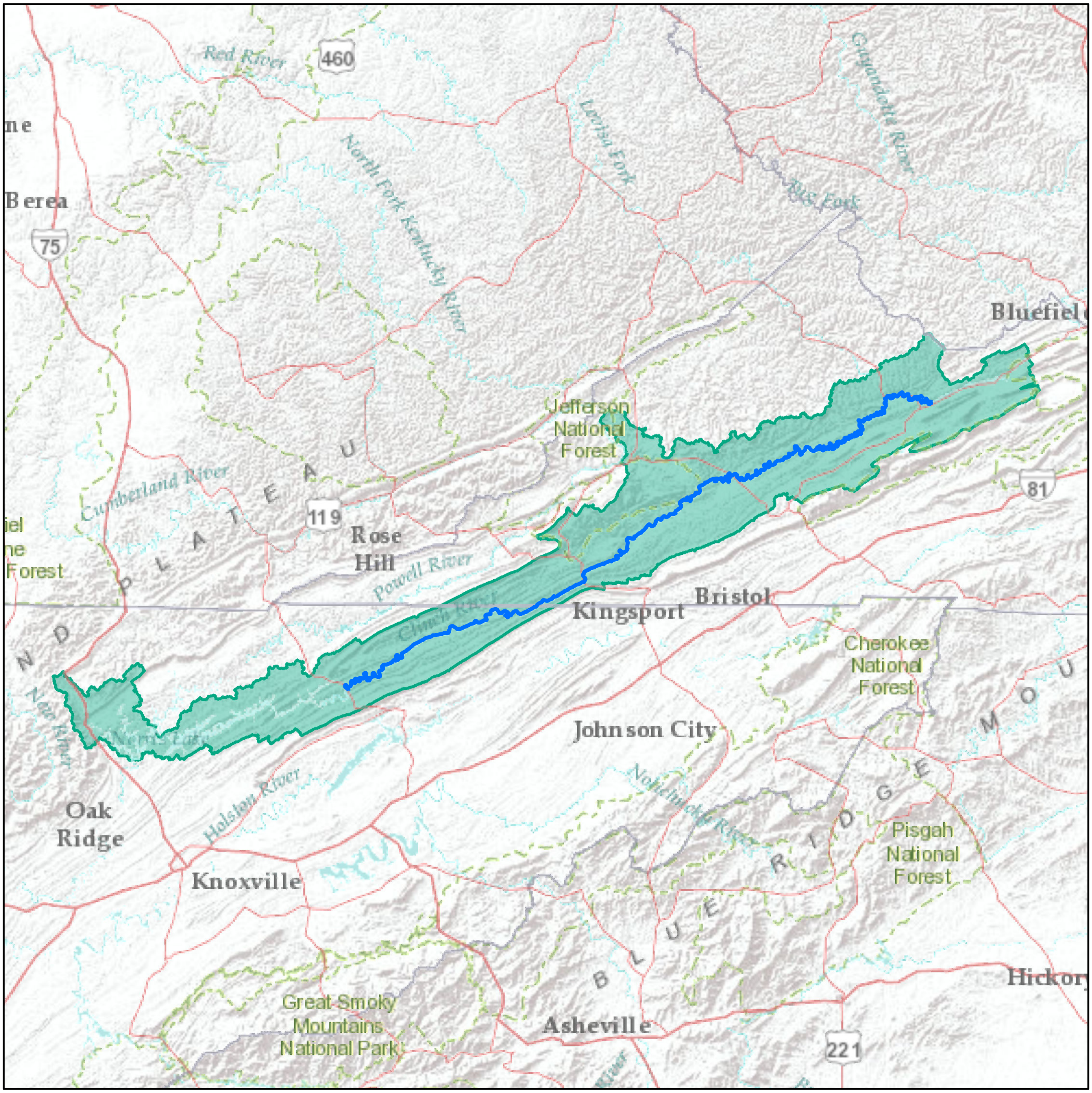
Selected Stream

Management Unit Condition

- High
- Medium
- Low



Upper Clinch, Tennessee, Virginia Management Unit



Miles

0 15 30 60

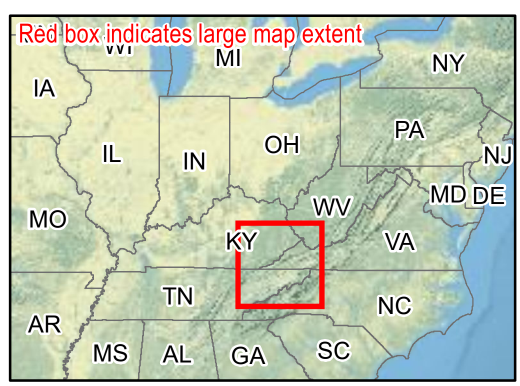
Selected Stream

Management Unit Condition

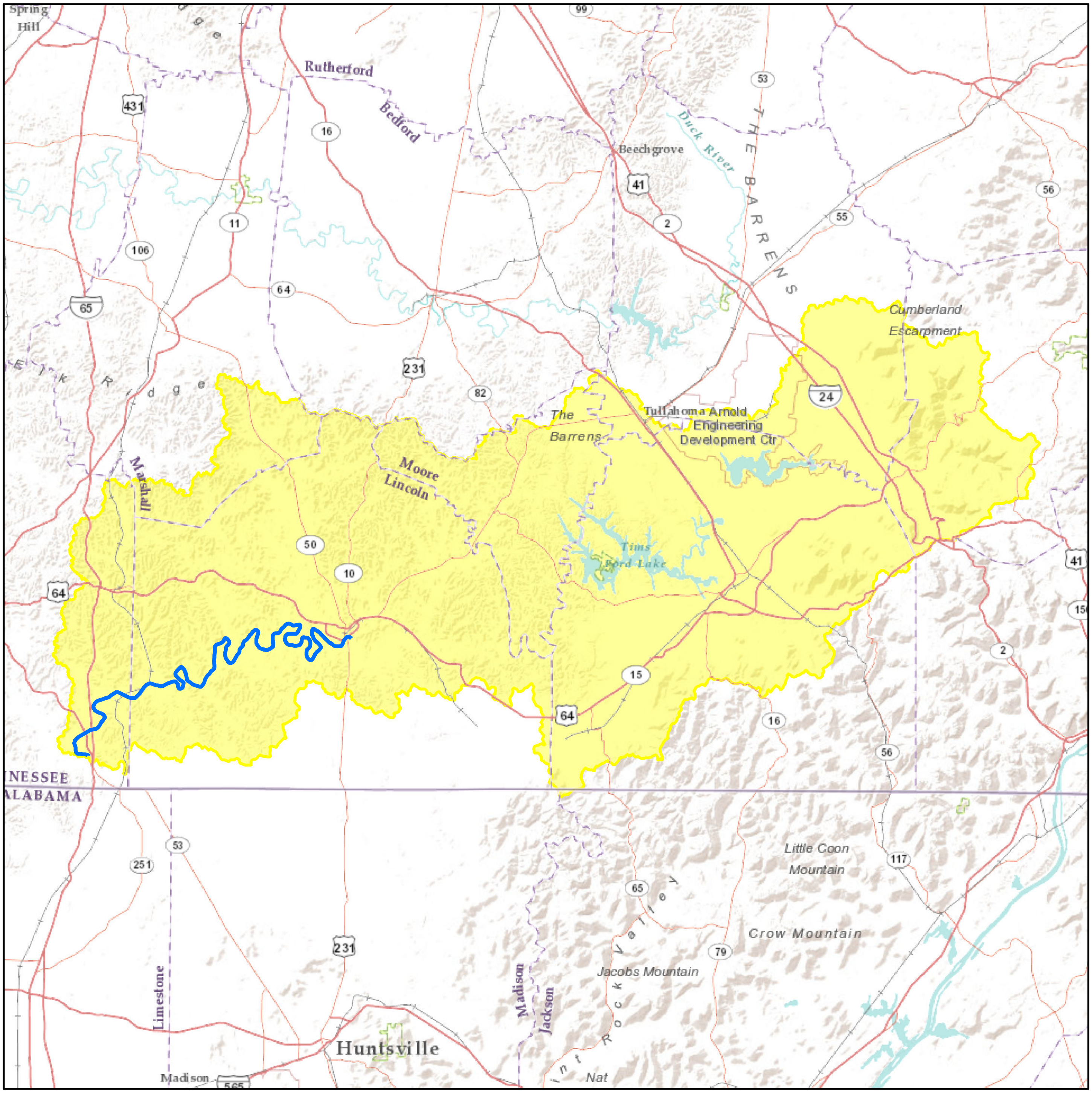
High

Medium

Low



Upper Elk Management Unit



Miles
0 5 10 20

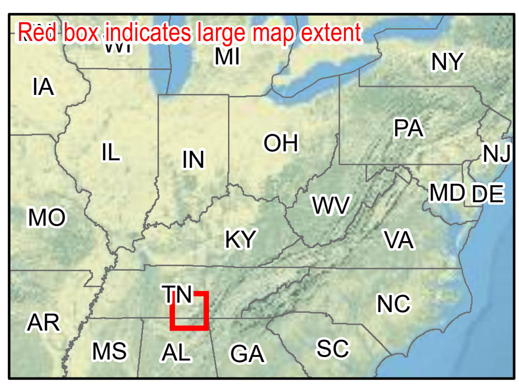
Selected Stream

Management Unit Condition

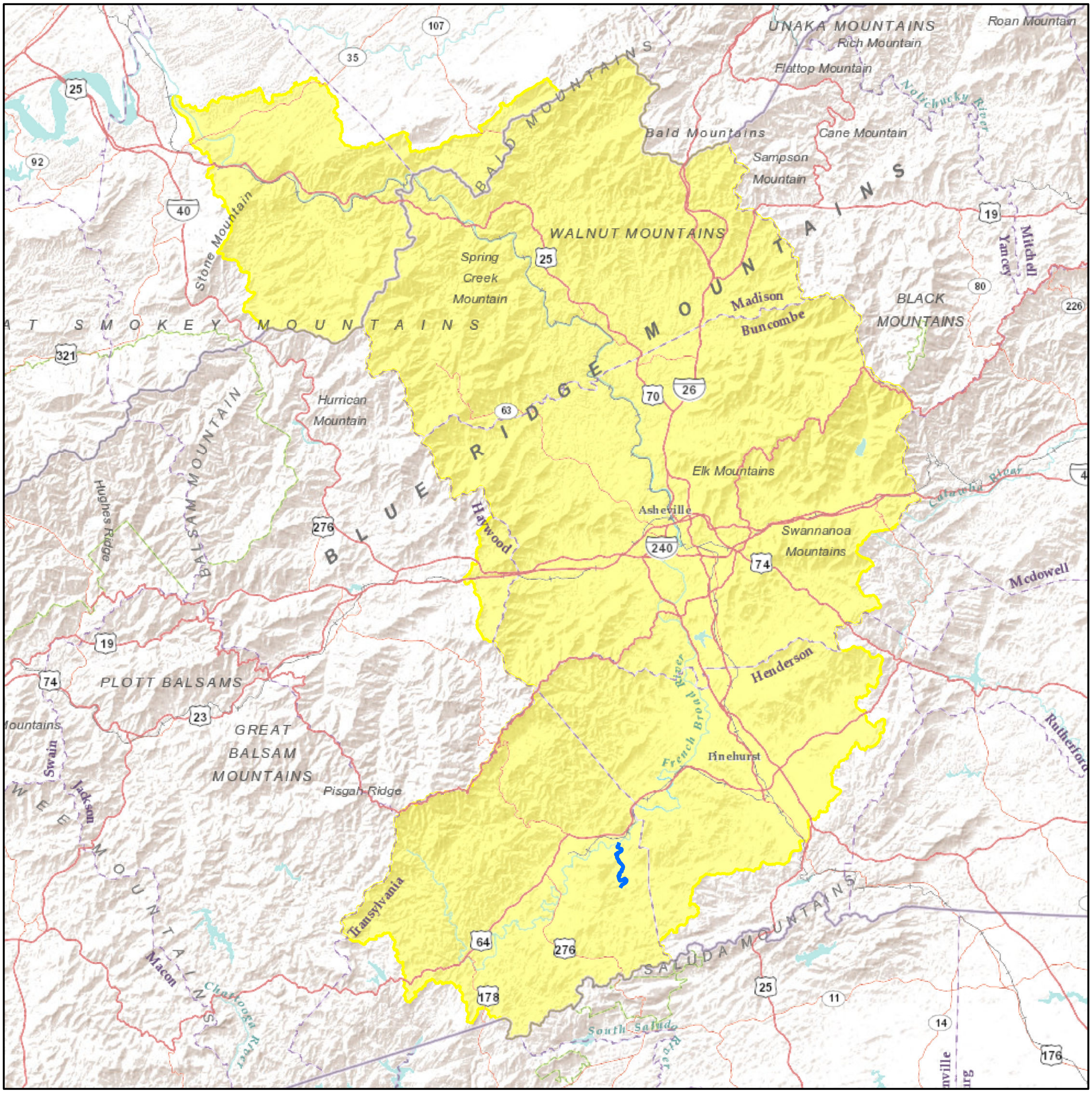
High

Medium

Low



Upper French Broad Management Unit

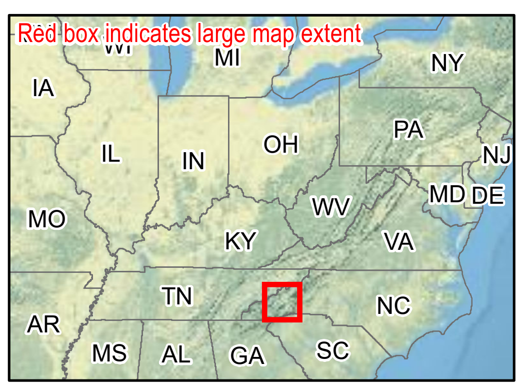


0 5 10 20 Miles

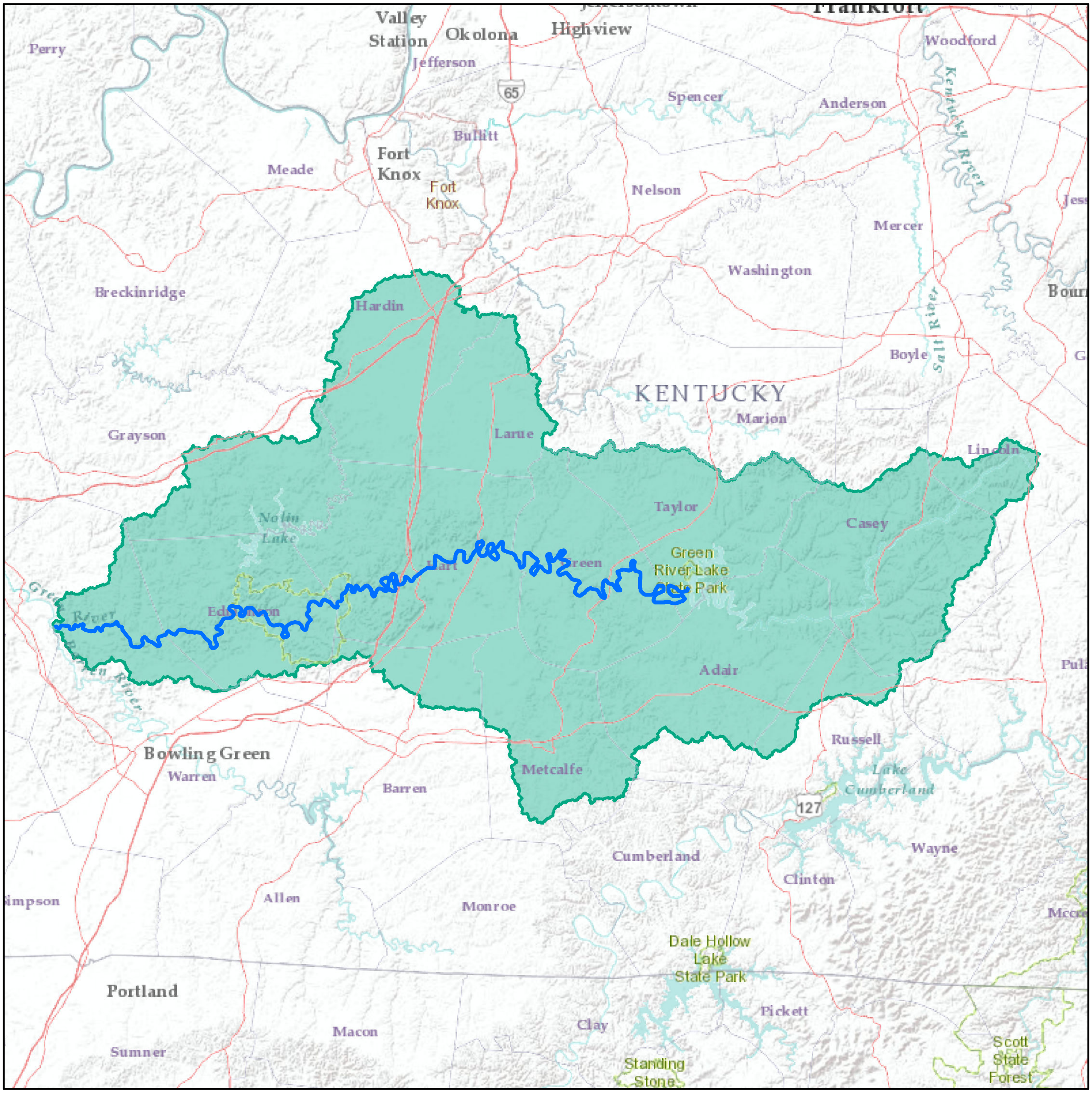
Selected Stream

Management Unit Condition

- High
- Medium
- Low



Upper Green Management Unit



Miles

0 12.5 25 50

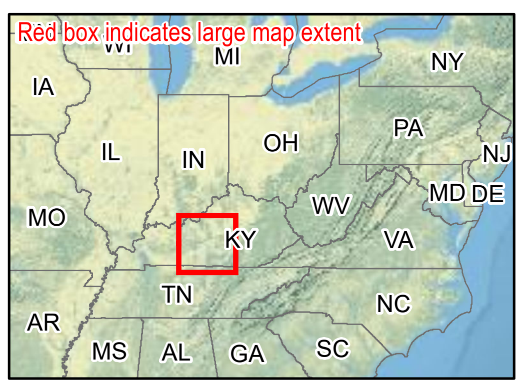
Selected Stream

Management Unit Condition

High

Medium

Low



Upper Kanawha Management Unit

Miles
0 4.5 9 18

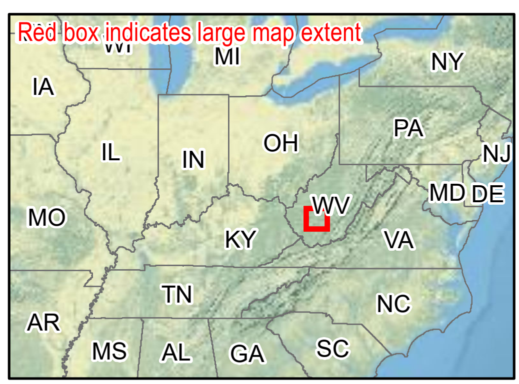
Selected Stream

Management Unit Condition

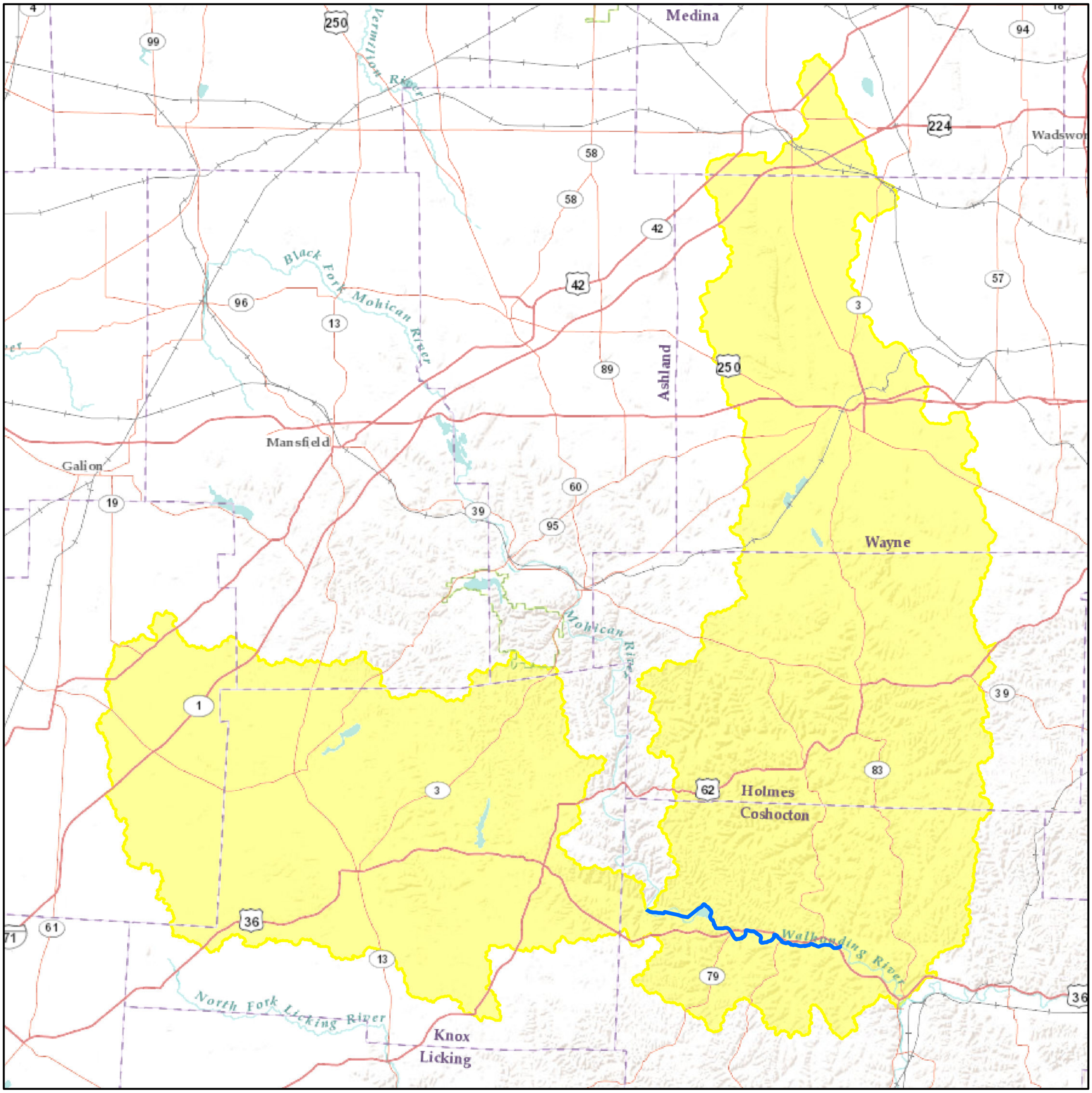
High

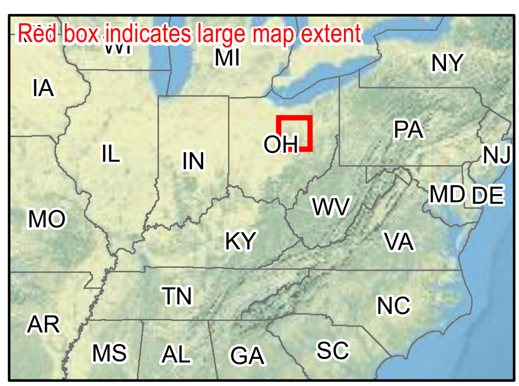
Medium

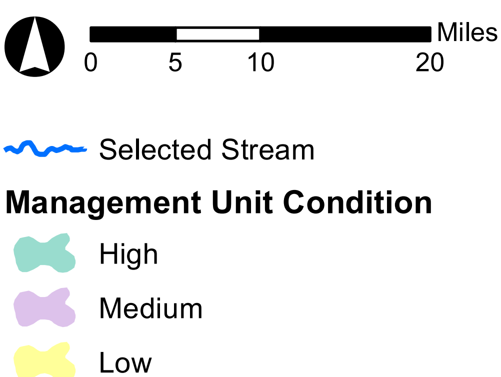
Low



Walhonding Management Unit







Wheeler Lake Management Unit

Miles
0 5 10 20

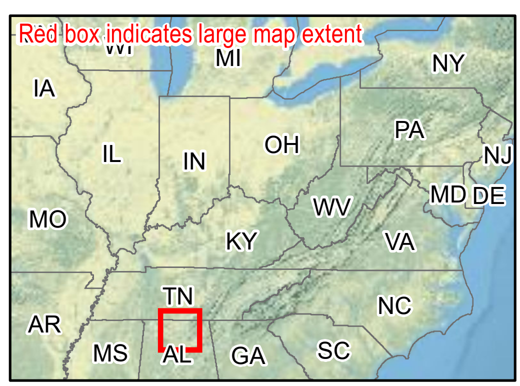
Selected Stream

Management Unit Condition

High

Medium

Low



APPENDIX D—ESTIMATES OF MAGNITUDE AND IMMEDIACY OF POTENTIAL THREATS NEGATIVELY INFLUENCING THE VIABILITY OF LONGSOLID.

Population	Threat Level Category	Threats	References
OHIO RIVER BASIN			
(1) Allegheny River	Moderate	Habitat loss & fragmentation; genetic isolation due to impoundment; climate change; potential hydropower development; nonnative species (Zebra mussel)	This population is isolated from other populations further downstream in the Allegheny river by reservoirs, nine locks and dams were constructed on the lower Allegheny River over a 72 RM reach from Armstrong County to Pittsburgh that disrupted extensive historical riverine habitat for mussels. Kinzua Dam on the upper main stem (forming Allegheny Reservoir) likely affected the Longsolid populations in the Upper Allegheny River. Channel maintenance, sedimentation & transportation & development, and silvicultural activities (Butler 2005). Furedi 2013, p. 14 ranked the species in PA as Extremely Vulnerable to climate change (Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050). Also, specifically see pages 43-44 for species account, which cites flooding and potential hydropower development.
(2) Oswayo Creek	Moderate	genetic isolation due to impoundment	This population is isolated from other populations further downstream in the Allegheny river by reservoirs. Furedi (2013, p. 14) ranked the species in PA as Extremely Vulnerable to climate change (Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050). Also, specifically see pp. 43-44 for species account, which cites flooding and potential hydropower development.
(3) Conewango Creek	Moderate	zebra mussels; genetic isolation	This population is isolated from other populations further downstream in the Allegheny river by reservoirs. Approx. 20 RMs of Conewango Creek was channelized and straightened in the first half of the last century, and the resulting dredge had no riffle or run habitat (Crabtree 2010, p.19), additionally Zebra mussels are present in the lower reaches of Conewango Creek.
(4) Allegheny River	High	Navigation impacts, including dredging in lower reaches; Habitat fragmentation & Loss due to impoundment. Water quality degradation and sedimentation related to Oil &	It is a linear population with a highly developed riparian zone. Current threats to unionids in the Allegheny River likely include channel maintenance activities, sedimentation, additional bridge replacement projects, and silvicultural activities (Butler 2007). Oil and gas extraction is accelerating in the watershed, and a large refinery in Warren is a potential source for pollutants. Zebra mussels are dense in Chautauqua Lake, a natural headwater lake in New York. There is a possibility that they will move down the system, or upstream through the navigation channel. Furedi (2013, p. 1) ranked the species in PA as Extremely Vulnerable to climate change

Population	Threat Level Category	Threats	References
		Gas Development; nonnative species (Zebra Mussel); climate change; potential hydropower development	(Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050). Also, specifically see pp. 43-44 for species account, which cites flooding and potential hydropower development.
(5) Tionesta Creek	Low	Habitat l Loss and fragmentation due to impoundment	This small, medium gradient river is located primarily within Allegheny National Forest land, but is fragmented by downstream impoundments on Tionesta Creek and the Allegheny River. Furedi (2013, p. 14) ranked the species in PA as Extremely Vulnerable to climate change (Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050). Also, specifically see pp. 43-44 for species account, which cites flooding and potential hydropower development.
(6) French Creek	Low	siltation and water quality pollution from agricultural impacts, domestic pollution, oil and gas development	Threats to the Longsolid in French Creek include nuffients from agriculture, aging septic systems, sedimentation, and municipal runoff and effluents. Oil and gas development wastes (e.g., brines, organics) are a concern in parts of the watershed. From Smith and Crabtree (2010, p. 388): Threats to the mussel pop in the watershed include siltation and pollution due to improper agriculture and timbering practices, mineral extraction, water extraction, development, and wastewater treatment plants. Other threats to the viability of freshwater mussels include dams and stream channel alteration and invasive species such as Zebra Mussels, which occur in Edinboro Lake. Low numbers of mussels in certain portions of the stream may partially be due to poor in-stream and land-use practices. According to the EPA, second to abandoned mine drainage, the major source of impairment to Pennsylvania streams is agriculture, which causes increased nutrients, siltation, and low dissolved oxygen levels. Furedi (2013, p. 14) ranked the species in PA as Extremely Vulnerable to climate change (Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050). Also, specifically see pp. 43-44 for species account, which cites flooding and potential hydropower development.
(7) Muddy Creek	Low	land development	From Mohler *et al.* 2006: Even though the mussel community in the immediate portion of Muddy Creek we sampled is afforded some level of protection

Population	Threat Level Category	Threats	References
			due to its location in the Erie NWR, there are still threats to the integrity of the aquatic community from regional land development, commerce, and other influences (Mohler *et al.* 2006). Furedi (2013, p. 14) ranked the species in PA as Extremely Vulnerable to climate change (Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050). Also, specifically see pp. 43-44 for species account, which cites flooding and potential hydropower development.
(8) Allegheny River	High	impoundment, nonnative species	This population is isolated from other populations further downstream in the Allegheny river by reservoirs; Smith and Meyer (2010, p. 555): The lock-and-dam structures on the Allegheny River have altered the river from free-flowing, well-oxygenated riffles and runs into a series of deep, slower-fl owing pools or lakes (Ortmann 1909a). Furthermore, the impoundments provide habitat for invasive species such as Zebra Mussels, which are a documented threat to freshwater mussels (Ricciardi *et al.* 1998, Strayer and Malcom 2012) and were present in this study. Furedi (2013, p. 14) ranked the species in PA as Extremely Vulnerable to climate change (Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050). Also, specifically see pages 43-44 for species account, which cites flooding and potential hydropower development.
(9) Allegheny River	High	dredging, impoundment	This population is isolated from other populations further upstream and downstream in the Allegheny river by reservoirs. Furedi (2013, p. 14) ranked the species in PA as Extremely Vulnerable to climate change (Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050). Also, specifically see pp. 43-44 for species account, which cites flooding and potential hydropower development. Smith and Meyer (2010) indicate 2 large older individuals found at RM 26 & 27. Few individuals encountered with large search effort, little evidence of reproduction, threatened immediately by dredging with high potential for extirpation.
(10) Shenango River	Moderate	impoundment, genetic isolation	Bursey (1987, p. 43) cites domestic and industrial pollution and fertilizer and pesticide run-off as probably reasons for decline in Shenango River. Bursey (1987, p. 43) states A significant change in the Shenango river was brought by the construction of Pymatuning Dam in 1934, the flood control dams reduced mussel habitat by completely inundating Pymatuning Creek. Furedi (2013, p. 14) ranked the species in PA as Extremely Vulnerable to climate change (Abundance and/or range extent within

Population	Threat Level Category	Threats	References
			geographical area assessed extremely likely to substantially decrease or disappear by 2050). Also, specifically see pages 43-44 for species account, which cites flooding and potential hydropower development. The completion of the Pymatuning Reservoir dam (near Jamestown) in 1934 eliminated 27.4 km (17 miles) of free-flowing river habitat and inundated adjacent swamplands. The completion of the Shenango River Lake dam in 1965 (near Sharpsville) inundated 17.7 km (11 miles) of historically occupied habitat, including an occupied portion of Pymatuning Creek (Ortmann 1909a). Pollution from the steel mills at Sharon and Farrell likely contributed to the demise of this species downstream of these communities.
(11) Slippery Rock Creek	High	habitat and water quality degradation due to oil and gas exploration, climate change (flooding)	Oil and Gas production is dense in the Slippery Rock Creek watershed; Furedi (2013, p. 14) ranked the species in PA as Extremely Vulnerable to climate change (Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050). Also, specifically see pages 43-44 for species account, which cites flooding and potential hydropower development. There is a Slippery Rock Creek Watershed Coalition working to address issues.
(12) Ohio River (Willow Island & Hannibal Pools)	High	habitat loss and fragmentation due to impoundment, dredging, nonnative species (Zebra mussel)	Uppermost known extant occurrence in the Ohio River. All threats to Ohio River in other HUCS. Willow Island Pool is beginning to recover in mussel diversity and density. It is believed the dams restricted host fish and lack of broodstock within the pool slowed recolonization post Clean Water Act. Hannibal Pool as well is recovering at a slower pace and maybe further impacted by mercury contamination.
(13) Middle Island Creek	Moderate	sedimentation - logging and oil and gas exploration	Water quality was considered good by Taylor and Spurlock (1981, p. 157), but interestingly, the species was not reported from the drainage at that time. Land use is in forest, with scattered towns and sparse industry. At least one mill dam persists on the stream.
(14) Meathouse Fork	High	sedimentation - logging and oil and gas exploration	Due to significant habitat degradation from oil and gas drilling, meathouse Fork no longer has habitat to support freshwater mussels and existing populations are imperiled (Clayton, 2018, pers. comm.).
(15) Little Kanawha River	Moderate	sedimentation - logging and oil and gas exploration, inadequate wastewater treatment	High - From Schmidt *et al* (1983, p. 132): The streams and rivers of the basin are turbid the majority of the year. While water quality is considered good, major problems include sedimentation due to soil conditions aggravated by timbering and oil and gas exploration and elevated fecal coliforms due to inadequate domestic wastewater treatment. Also, Rail and vehicular transportation routes

Population	Threat Level Category	Threats	References
		(domestic pollution)	follow the meandering streams, occupying most of the level land of the narrow stream flood plains. Threats in the Little Kanawha River system, summarized by Schmidt *et al.* (1983), primarily included oil and gas exploration and inadequate wastewater treatment (no WWTPs were located in the watershed during the survey), with secondary threats being coal mining (coal fines were noted in most streams) and silvicultural activities.
(16) North Fork Hughes River	Moderate	impoundment, oil & gas activities	From Miller and Payne (2000, p. 2): The North Fork Hughes River lies in the Little Kanawha River Basin, which is within the Appalachian Plateau Physiographic Province. This province is characterized by steep hills, narrow ravines, and ridges. Valleys consist of broad bottoms and terraces of gravel, sand, silt, and clay. Water quality has been described as good, although sedimentation from eroding soils is often a problem (Schmidt *et al.* 1983). ESI (1993, p. 19) cite water quality problems in the river associated with land use (Ag runoff, livestock in and near stream, oil development and sewage treatment) as potential reasons for lack of unionids at survey sites.
(17) Hughes River	unknown	habitat and water quality degradation due to resource extraction activities	This province is characterized by steep hills, narrow ravines, and ridges. Valleys consist of broad bottoms and terraces of gravel, sand, silt, and clay. Water quality has been described as good, although sedimentation from eroding soils is often a problem (Schmidt *et al.* 1983).
(18) Tuscawaras River	High	Non-native species (Corbicula), habitat loss and fragmentation due to impoundment, agricultural impacts, climate change (drought)	EnviroScience (2007, p. 5): The stream and especially its tributaries suffer a number of water quality impacts including habitat alterations, mercury and PCB contamination, municipal and industrial discharge, and others. P. 10: Increased use of agricultural chemicals, CSO releases, toxic spills and other sources may be a cause of the loss of native mussel fauna in the Tuscawaras. Another possible problem is that the immense numbers of Asian clams found in the prime mussel habitat of the study site (and most probably other parts of the Tuscarawas River) may produce competition with indigenous freshwater mussel species. Interestingly, Sterki (1892, p. 135) commented on finding dead specimens in shell in their "natural positions" as a result of drought or perennialy low water. and associated stressful water quality conditions on multiple occasions.
(19) Muskingum River	High	hydropower, impoundment, dredging, past threats include	The occupied reach of the Muskingum river is highly fragmented by impoundments, and Watters and Dunn (1993-94, p. 258) state: It is foreseeable that a single major environmental accident upstream, such as an oil or

Population	Threat Level Category	Threats	References
		commercial harvest	pesticide spill, could irreparably damage or even eliminate this fauna. One such spill, although apparently minor and well contained occurred in 1992. They also cite potential dam removal and associated silt and sediment loads, dredging activities and harvesting pressure as long-term impacts on the mussel fauna in the Muskingum River. Additionally, ESI 2012, did extensive surveys related to proposed hydropower development at existing dams, and cite changes in shear velocity as potentially affecting substrate and unionid communities. Eleven L&Ds have been constructed on the Muskingum from Zanesville downstream.
(20) Walhonding River	High	Impoundment, gravel mining, small, linear population limited in extent susceptible to stochastic events	From Butler 2007: Six Mile Dam is a low-head dam at approximately RM 9 that impounds a 0.5 mile reach of the Walhonding. Gravel mining also occurs in the lower portion of river below Six Mile Dam. Removal of Six Mile Dam brings opportunity for increased density and minor expansion of this population, however, measures to reduce sediment loads will need to be taken to prevent harm to mussels downstream of the dam. An upstream impoundment on the Walhonding River, Mohawk Dam (~RM 17.5), was built on the main stem in 1936 and operates as a "dry dam" to temporarily control flood waters. Some developmental and agricultural pressure occurs, particularly upstream of Mohawk Dam.
(21) Kanawha River	High	Chemical releases, development, Corbicula	Morris and Taylor (1978, p. 153) state that timbering and surface mining in the upper Kanawaha river contributes sizable sediment loads, and that the river for decades has had low water quality resulting from industrial, urban organic sewage, and acid mine runoff pollution. P. 155: Limiting factors for absence of unionids at lower sites may include industrial wastes, urban organic enrichment, and habitat destruction resulting from navigational impoundment, as well as the presence of the introduced Asian Clam, Corbicula. Threats to the Longsolid include sedimentation, mine runoff, and developmental activities in the narrow band of bottomlands along the deeply entrenched Kanawha River. Chemical spills are an ongoing threat with the concentrations of railroad and highway rights-of-ways that lie immediately parallel to the river. On 12 June 2014, a closed fly ash landfill discharged ash into the Kanawha River at Deepwater, London Pool, Fayette County, West Virginia. The potential for chronic impacts associated with the ash spill to mussel resources continues, and fly ash still covers the Kanawha River substrate (WVDNR 2015). The Kanawha River valley contains significant deposits of coal and natural gas, and is dredged for navigation.
(22) Elk River	Moderate	1. Abandoned	Butler (2007): Land use is primarily in forest,

Population	Threat Level Category	Threats	References
		mines (metals associated with mining runoff) 2. inadequate sewage treatment (unionized ammonia) 3. erosion in the watershed - ESI 2009 Water quality and habitat changes (erosion and subsequent sedimentation, scour) caused by sewage treatment problems and abandoned mine facilities, as well as, lack of best management practices during instream and riparian corridor construction and land use. Exposed pipeline construction led to localized changes in hydraulics which affected substrate stability.	agriculture, and occasional towns. Primary threats include silvicultural activities, coal mining, and natural gas exploration and production (ESI 2009). Riparian and floodplain roads and development raise concerns with contaminant runoff. Straight piping, sedimentation (especially from Big Sandy Creek in northeastern Kanawha County), and localized channel alterations are also threats. Sutton Dam impounds ~15 RMs and impacts tailwater habitat. ESI (2009, p. 19) cite abandoned mine lands, inadequate sewage treatment and erosion as being the primary factors currently affecting the Elk River unionid fauna, but also Cold water releases from Sutton Dam between 1960-1980 contributed to lack of mussel recruitment and population densities. ESI (2009, p. 21): The changes in unionid abundances and distribution and lack of recruitment (cause of declines) seems to be water quality and habitat changes caused by sewage treatment problems and abandoned mine facility, as well as, lack of best management practices during instream and riparian corridor construction and land use.
(23) Levisa Fork	Moderate	water quality degradation	Haag and Cicerello (2016 p. 20): Water quality in nearly the entire watershed is seriously and profoundly degraded by coal mining. Water quality also is degraded by oil drilling, and domestic and municipal pollution.
(24) Ohio River (lower Gallapolis Pool, upper Greenup Pool)	High	Zebra Mussels, Navigation Impacts, Habitat Fragmentation	Threats include the non-native zebra mussels, Corbicula, industrial pollution, excessive sedimentation, municipal wastewater overflows, channelization, dredging for navigation channel, barge traffic (scour and wave disturbance from tows). From Butler (2002, p. 14): Navigational improvements on the Ohio River began in 1830 (Cicerello *et al.* 1991), leading to the construction of 53 locks and dams by the 1960s. Since that time, several high level locks and dams were constructed and replaced all but the two lowermost older and smaller structures (Williams and Schuster 1989). Today, 18 (16 high and 2 low) locks and dams impound nearly the

Population	Threat Level Category	Threats	References
			entire 981 mile length of river (all but the lowermost portion near the Mississippi River confluence). Threats, such as chemical spills that cause major mussel kills, Chemical Contaminants, maintenance dredging, and the zebra mussel invasion are primary threats in the Ohio River. Although the zebra mussel population growth appears to have slowed, damage to existing mussel beds was realized and continue to impact native mussels over time.
(25) Ohio River (Markland Pool)	High	Zebra Mussels, Navigation Impacts, Habitat Fragmentation	Threats include the non-native zebra mussels, Corbicula, industrial pollution, excessive sedimentation, municipal wastewater overflows, channelization, dredging for navigation channel, barge traffic (scour and wave disturbance from tows). On Monday 18 August, 2014, an inadvertent discharge of diesel fuel was released on land and drained into Markland Pool of the Ohio River at Duke Energy's W.C. Beckjord Station (Beckjord) in Clermont County, Ohio (Figure 1). It is estimated that 9,000 gallons were released during a transfer of fluids near Ohio River mile (ORM) 452.6. (ESI 2015, p. 6)
(26) Licking River	Moderate	impoundment - habitat loss	A linear population distributed below Cave Run Lake Dam. Water quality problems in the Licking River drainage are nutrients, bacteria, and sediments. Also, lack of stream buffers, channelization, wastewater discharge are cited as contributing to water quality problems (KYDW 1998). Hardison and Layzer (2001, p. 79) indicate hydrological instability and specifically high shear stress and scour from high flows limits mussel distribution and recruitment in the Licking River, KY, where *F. subrotund*a is known to occur below a flood control dam operated by the USACE. Constructed in 1974, Cave Run Reservoir impounded 38 RMs of the upper Licking which impacted mussel habitat, and spikes in cold tailwater releases continue to impact the river. Other threats include sedimentation, agricultural runoff, and sewage pollution. (Butler 2007, p. 53).
(27) Slate Creek	Moderate	water quality, impoundment	Water quality problems in the Licking River drainage are nutrients, bacteria, and sediments. Also, lack of stream buffers, channelization, wastewater discharge are cited as contributing to water quality problems (KYDW 1998). Sedimentation, agricultural runoff, and several mill dams which continue to impound stream habitat.
(28) Rolling Fork River	Moderate	water quality	Most of the watershed is in agriculture. Threats include sedimentation, and agricultural and municipal runoff (Burr and Warren 1986).

Population	Threat Level Category	Threats	References
(29) North Fork Kentucky River	Moderate	impoundment/habitat fragmentation	Haag and Cicerello (2016, p. 18) cite coal mining and municipal impacts.
(30) South Fork Kentucky River	Moderate	water quality degradation from agricultural and mining impacts; however, population extent is almost entirely contained within Daniel Boone National Forest	Evans (2010): Threats observed to the mollusk fauna in the South Fork Kentucky basin are numerous. Overall, perturbations to the mollusk fauna of the basin likely stem from water quality and habitat conditions as opposed to a net hydrological alteration in the basin. In the Goose Creek watershed, coal mining and floodplain agriculture has taken a visible toll on the mussel fauna. Coal deposits, in the form of coal fines and coal pieces, were visible at many sites in mainstem Goose Creek. Further, several areas examined in Goose Creek were scoured down to bedrock, possibly as a result of long-term hydrological alterations in the watershed and a complete lack of riparian area along several stretches of the mainstem. Lower sections of Collins Fork (RK 4.0 to 10.5), is listed on the KY DOW 303(d) list as being impaired due to sedimentation (KY DOW 2008). Acid drainage was noted on the South Fork Kentucky coming out of several tributaries; namely the confluences of Indian Creek, Fish Creek, Matton Creek, and in Booneville above KY 28 bridge. Coal and coal fines was present in the river in the Chestnut Gap area upstream of Booneville and acid seeps were seen coming into the river in the area west of Eversole in this river reach. At one of the lowermost sites on the Redbird River a new surface mining operation upstream of Laurel Branch was beginning operation during this study. From Butler (2005, p. 41): Threats in the system include coal mining, sedimentation, sraight piping of untreated domestic effluents, municipal wastewater, and runoffof various other pollutants in the steep terrain characteristic of this Cumberland Plateau watershed.
(31) Redbird River	Low	mining, habitat degradation	Threats include coal mining, oil exploration and impacts associated with population growth in the narrow stream valleys (Haag and Cicerello 2016).
(32) Kentucky River	Moderate	impoundment - habitat loss	Listed as of commercial importance for button industry "good value" Danglade (1922, p. 5): Indicates overharvest as a past threat. From Haag and Cicerello p. 19: Domestic and Municipal pollution, coal mining , oil drilling (259 RMs) was pooled behind 14 locks and dams, with habitat that he characterized as “for the most part, a soft mud bottom.” He also mentioned that the narrow bottomlands were “extensively cultivated.” The fact that the main stem has been impounded and its free-flowing habitats disrupted.
(33) Green River	Low	impoundment - habitat loss	Although there are multiple dams on the Green River mainstem, there is a large amount of riverine habitat

Population	Threat Level Category	Threats	References
			available in numerous reaches. The KY CWCS (2015) lists the following as threats to the species: Aquatic habitat degradation, loss of fish hosts, point and non-point source pollution, siltation and increased turbidity. Cochran and Layzer (1993, p. 64) determined that mussels in the middle Green and Lower Barren Rivers selected habitats that were less impacted by commercial harvest activities, although harvest was lighter in the Barren than the Green.
(34) Barren River	Moderate	impoundment - habitat loss	There are multiple dams on the Barren River mainstem. The KY CWCS (2015) lists the following as threats to the species: Aquatic habitat degradation, loss of fish hosts, point and non-point source pollution, siltation and increased turbidity. Cochran and Layzer (1993, p. 64) determined that mussels in the middle Green and Lower Barren Rivers selected habitats that were less impacted by commercial harvest activities although harvest was lighter in the Barren than the Green.
(35) Green River	Moderate	impoundment - habitat loss	Although there are multiple dams on the Green River mainstem, there is a large amount of riverine habitat available in numerous reaches. Oil drilling has affected the Green watershed. The KY CWCS (2015) lists the following as threats to the species: Aquatic habitat degradation, loss of fish hosts, point and non-point source pollution, siltation and increased turbidity.
(36) Green River	Moderate	impoundment - habitat loss	There are multiple dams on the Green River mainstem, and there is the least amount of riverine habitat available in the lowermost reaches. The KY CWCS (2015) lists the following as threats to the species: Aquatic habitat degradation, loss of fish hosts, point and non-point source pollution, siltation and increased turbidity. This reach of the river was more heavily impacted by towboats before reduced commercial traffic. Miller *et al.* (1994, p. 53) also cite hypolimnetic discharges as an impact to the lower Green River mussel fauna.
(37) Ohio River	High	Non-native species, navigation impacts, impoundment	Mller and Payne (1998, p. 188): Extended periods of extreme low water can define the inner extent of a mussel bed in the lower Ohio River and structure Corbicula populations. Substantial erosion can result from propeller wash as tows negotiate tight turns in the channel, enter and exit lock chambers, and while awaiting lockage along shorelines. These areas may have been subjected to severe propeller wash creating an environment too hostile for mussel colonization. Barges sometimes ground for a number of reasons including running into unknown shoals in the navigation channel, operating outside of the navigation channel in shallow water. Spills of contaminants and cargo from

Population	Threat Level Category	Threats	References
			commercial tows may have impacted freshwater mussels by direct mortality and by chronic effects. Benthic organisms are sensitive to a wide range of contaminants including ammonium, pesticides, and petroleum products, all of which are commonly transported via barges.
(38) Ohio River (Newburgh Pool)	High	Non-native species, navigation impacts, impoundment	Mller and Payne (1998, p. 188): Extended periods of extreme low water can define the inner extent of a mussel bed in the lower Ohio River and structure Corbicula populations. Substantial erosion can result from propeller wash as tows negotiate tight turns in the channel, enter and exit lock chambers, and while awaiting lockage along shorelines. These areas may have been subjected to severe propeller wash creating an environment too hostile for mussel colonization. Barges sometimes ground for a number of reasons including running into unknown shoals in the navigation channel, operating outside of the navigation channel in shallow water. Spills of contaminants and cargo from commercial tows may have impacted fres hwater mussels by direct mortality and by chronic effects. Benthic organisms are sensitive to a wide range of contaminants including ammonium, pesticides, and petroleum products, all of which are commonly transported via barges.
(39) Ohio River	High	Non-native species, navigation impacts, impoundment	Mller and Payne (1998, p. 188): Extended periods of extreme low water can define the inner extent of a mussel bed in the lower Ohio River and structure Corbicula populations. Substantial erosion can result from propeller wash as tows negotiate tight turns in the channel, enter and exit lock chambers, and while awaiting lockage along shorelines. These areas may have been subjected to severe propeller wash creating an environment too hostile for mussel colonization. Barges sometimes ground for a number of reasons including running into unknown shoals in the navigation channel, operating outside of the navigation channel in shallow water. Spills of contaminants and cargo from commercial tows may have impacted freshwater mussels by direct mortality and by chronic effects. Benthic organisms are sensitive to a wide range of contaminants including ammonium, pesticides, and petroleum products, all of which are commonly transported via barges.
CUMBERLAND RIVER BASIN			
(40) Cumberland River	High	Habitat fragmentation, hypolimnetic	From Hubbs (2012, p. 3): Historically the Cumberland River contained a diverse mussel fauna with approximately 80 species reported from the drainage

Population	Threat Level Category	Threats	References
		discharges	(Wilson and Clark 1914); however habitat alteration from impoundment and maintenance dredging of the navigation channel has substantially reduced the species richness and abundance. Mussel habitat is highly fragmented in the main channel throughout the 310 mile reach in the Tennessee portion of the Cumberland River from the KY/TN state line (mile 385) near Celina, TN downstream to the TN/KY state line near Tobaccoport (mile 75). The upper reach of Old Hickory Reservoir located between Carthage and Lebanon, runs 49 river miles and contains much of the physical habitat favorable to mussel colonization and still holds approximately 33 species including 13 state GCN and five federally endangered. Mussel recruitment in this reach of the Cumberland River has long been suppressed by cold water resulting from the hypo limnetic releases from upstream reservoirs (Wolf Creek, Dale Hollow, and Center Hill).
TENNESSEE RIVER BASIN			
(41) Holston River	High	Habitat Fragmentation, hypolimnetic discharges	Parmalee and Faust 2006, p. 77, state: Since construction of Cherokee Dam in 1941 until 2006, approximately 75% of the naiad taxa have been extirpated in the lower Holston River downstream from the Dam. Primary impacts from the dam include large fluctuations in discharges, water temperatures, and water depth.
(42) Little River	Moderate	impoundment, agricultural activities	The man-made water supply dam - Cascade Lake - holds back considerable Little River sediments that provide for good habitat conditions immediately downstream of the dam, but the species is limited to a short reach of less than 1 km. From Schwartzman (2008, p. 406): Flooding in September 2004, associated with the remnants of Hurricanes Ivan, Frances, and Jeanne, was particularly severe in the French Broad and the Catawba River Basins. NCWRC biologists conducted mussel surveys in these basins before and after the 2004 floods to characterize the effects on mussel populations (Fraley and Simmons 2006). Stream habitat heterogeneity, presence of flow refuges, and natural channel design with a functioning floodplain all appear to contribute to habitat preservation, and therefore, mussel survival during severe flooding. The floodplain along the Little River Aquatic Habitat is quite broad and mostly used for sod farming and pasture.
(43) Nolichucky River	High	impoundment, agricultural activities	TVA (2006 p. 11) state that threats to the aquatic fauna in the Nolichucky River include residual sediment in the river bed and continuing local sedimentation and other non-point source problems, primarily of agricultural

Population	Threat Level Category	Threats	References
			origin, entering the main river from certain tributaries. As the reservoir pool has filled, its ability to trap sediment has declined dramatically, and it has become easier for high flows to carry sand over the top of the dam. Intensive row-crop agriculture has led to increased pesticides and herbicide application and removal of stream/river buffers.
(44) Clinch River	Moderate	logging, deep and surface coal mining, agricultural activities, dams, overharvest, 100-year floods and prolonged drought. Point and nonpoint source contaminants from coal mine activities, agricultural uses, and urban areas Non–point-source inputs of agricultural pesticides	Contaminant Spills have been particularly detrimental and are an ongoing threat to this population Ahlstedt *et al.* (2016a, p. 8). Ahlstedt *et al.* (2017a, p. 224), state that the mussel fauna of the Clinch River downstream of the Appalachia Power Company's Steam Plant at Carbo, Virginia, was severely affected by a fly ash spill in 1967 and a sulfuric acid spill in 1970. Jones *et al.*, (2001, p. 20) reference a 1,400 gallon spill of rubber accelerator into the upper Clinch River just above Cedar Bluff, Virginia (CRM 323) in August 1998, which killed at least 7,000 mussels of 16 species, the species has been documented to occur within the affected reach (Jones *et al.*, 2001, p. 22). High concentration levels of the toxic metals zinc and copper in sediments present below a coal processing plant resulted in reduced survival of juvenile mussels in the Clinch River, Virginia (Ahlstedt and Tuberville, 1997, p. 75). Ahlstedt *et al.* (2016a, p. 8) give a chronology of significant perturbations that have occurred in the Clinch and Powell rivers. These include: logging of the landscape, resulting in increased sedimentation, deep and surface coal mining; including discharges of industrial and mine wastes, mine blowouts, black water release events and fly-ash spills from mining activities, soil erosion from agricultural activities, construction of impoundments, overharvest, sulfuric acid spills, 100-year floods. Mussel die-offs of unknown origin have been and continue to be a significant threat, mussel die-offs and were documented in the Clinch (1986-1988) and recently (2016) in the Clinch River, VA. Longsolid were observed dead with meat inside their shells in the Clinch River from 2001-2004 with no direct cause for mortality, however, black-water release events associated with mining activity were documented in the same drainage in 2002-2003 (Ahlstedt *et al.*, 2016a, p. 9). Ninety-six specimens of *F. subrotunda* were collected from muskrat middens in the Clinch River at Slant, VA, 1984-1985, indicating that this species is vulnerable to mammal predation (Bruenderman 1989, p. 11). The Clinch River in Virginia and Tennessee has significant chronic threats including concentrated agricultural and mining activities and transportation corridors, as well as acute threats such as wastewater treatment effluents and chemical spills (Zipper *et al.* 2014, p. 810). From Diamond *et al.* (2002, p. 1,153):

Population	Threat Level Category	Threats	References
			Point and nonpoint source contaminants from coal mine activities, agricultural uses, and urban areas are also likely to be limiting aquatic fauna distribution. Non–point-source inputs of agricultural pesticides, particularly in the more fertile bottomlands and valleys, also are a potential source of toxic stress on native fish and mussels in this watershed. The Clinch River in Virginia and Tennessee, which has perhaps one of the best remaining population of the species, has significant chronic threats including concentrated agricultural and mining activities and transportation corridors, as well as acute threats such as wastewater treatment effluents and chemical spills (Zipper *et al.* 2014, p. 810).
(45) Indian Creek	High	agricultural impacts, chemical spills	Jones and Neves (2004, p. 1, 2) state that water quality degradation as a result of residential development as a primary threat. Also muskrat predation, logging, contaminant spills & coal mining were cited as ongoing threats, specifically coal mining & recent discharged wastes associated with coal mines are primary threat.
(46) Powell River	High	water quality degradation due to Chemical spills, Mining impacts, also separated from Clinch River population by Norris Reservoir	From Johnson *et al.* (2012, p. 84): Mussel declines in the Powell River have largely been attributed to habitat degradation caused by agricultural practices, urban development, and coal mining (Dennis 1981; Ahlstedt and Tuberville 1997; Diamond *et al.* 2002; Ahlstedt *et al.* 2005b). Additional studies have shown that runoff of sediments contaminated with by-products from coal mining activities is a potential factor leading to mussel declines (McCann and Neves 1992). Black-water events activities) have occurred frequently over the last 100 y in this watershed (Ahlstedt *et al.* 2005b). From Diamond *et al.* (2002, p. 1,153): sedimentation and other forms of habitat degradation from urban uses, mining, and agricultural areas are likely to be limiting aquatic fauna in this watershed. Sedimentation due to accumulation of coal fines (fine particulate coal and refuse rock material) has been reported in many areas downstream of active coal mines and coal slurry ponds in the upper Powell River drainage. Non–point-source inputs of agricultural pesticides, particularly in the more fertile bottomlands and valleys, also are a potential source of toxic stress on native fish and mussels in this watershed.
(47) Tennessee River (Chicamauga Reservoir)	High	Habitat fragmentation	Hundreds of miles of large river habitat on the Tennessee main stem has been lost under nine reservoirs. Operation of Watts Bar Nuclear Plant and Watts Bar dam directly impact this population (Olson 2010, p. 6).
(48) Paint Rock River	Low	agricultural impacts	The Paint Rock River drainage was severely affected in past decades by small impoundments, stream channelization, erosion, and agricultural runoff. A major

Population	Threat Level Category	Threats	References
			detrimental impact on habitat occurred with the channelization and removal of snags and riverbank timber in the upper drainage and the lower reaches of Larkin and Estill forks and Hurricane Creek by the US Army Corps of Engineers during the 1960s (Ahlstedt 1995). This direct headwater habitat manipulation was probably a large contributor to freshwater mussel loss in the drainage. Wheeler Dam was completed by the TVA in 1936, resulting in loss of most of the mussel fauna and riverine habitat in the lower 21 km of the Paint Rock River (Ahlstedt 1995).
(49) Estill Fork	Low	agricultural impacts	Continuing threats to the watershed include siltation and erosion from poor farming practices along with commercial and residential development (Godwin 2002).
(50) Hurricane Creek	Low	agricultural impacts	Continuing threats to the watershed include siltation and erosion from poor farming practices along with commercial and residential development (Godwin 2002).
(51) Tennessee River (Wheeler Reservoir)	High	impoundment, habitat degradation from flow releases	From Ahlstedt and McDonough (1995): Beginning in the early 1950's, the Japanese discovered that freshwater mussel shells from the united States were ideal material for implantation in oysters to form the nucleus for cultured pearls. The mussel shells were cut into small blocks, which were then tumbled and polished into smooth, round beads for surgical implanting in the oysters. This development resulted in a sudden, rapid demand for shells and was a tremendous economic boost for the declining American musseling industry. The mainstream reservoirs of the Tennessee River became the nation's most important source of shell for shipment to Japan. The annual shell harvest from the Tennessee River exceeded 10,000 tons for a number of years (lsom 1969). Although a past threat, this is a considerable contributor to the decline of freshwater mussels in Wheeler Reservoir. Additional threats are the continued operation of Guntersville Dam and Browns Ferry Nuclear Plant.
(52) Elk River	Moderate	cold water discharges, agricultural impacts to habitat and water quality	The Elk River in Tennessee, which has significant agricultural activity throughout the watershed, supports a recruiting population (Hoos *et al.* 2000). Additionally, construction and operation of Tims Ford Dam has impacted the fauna considerably above Harms Mill dam. Although the operations have changed, the lack of mussel recruitment above Harms Mill indicates that translocation or propagation for population restoration is likely needed.
(53) Hiwassee River	High	cold water discharges from hydropower	This is a small population that is subject to hypolimnetic releases from Mission Dam and Chatuge Dam upstream (NC SWAP 2015, p. 370).

Population	Threat Level Category	Threats	References
		dams; habitat fragmentation	
(54) Valley River	Moderate	chemical releases, agricultural impacts	Favrot and Kwak 2018, p. 205, indicate the lower portion of the watershed is surrounded by agricultural land. A recent wastewater treatment plant spill on the Valley River mainstem continued for several days before being repaired (Service 2018a, unpublished data).
(55) Hiwassee River	Moderate	hypolimnetic discharges from hydropower dams	The reach of Hiwassee River between Apalachia Dam and the powerhouse is referred to as the "Apalachia Cutoff", where water is mostly derived from inflows from tributary streams, leakage from the dam, minimum flow releases of 25 cfs, and dam spillage during storm events and reservoir level management. Although buffered by National Forest, the minimum flows that do not vary seasonally restrict the capability to move and flush fine sediment and aquatic vegetation from the river channel. Cold water and low dissolved oxygen likely inhibit the species ability to expand further downstream (Ahlstedt et al. 2016b).
(56) Tennessee River (Pickwick Reservoir)	High	impoundment, dredging/navigation impacts	Isom (1969, p. 410) reported the species from the Seven mile Island Area Muscle Shoals, Wilson Dam tailwater (TRM 247-253). Also, reported the species to be of some commercial importance (p. 402). The 53 RM reach of the Tennessee River in northwestern AL collectively referred to as Muscle Shoals historically harbored 69 species of mussels, making it the most diverse mussel fauna ever known from a single river reach (Garner and McGregor 2001). The construction of three dams (i.e., Wilson in 1925, Wheeler in 1930,Pickwick Landing in 1940) inundated most of the historical mussel habitat, leaving approximately 13 RMs of riverine habitat. The largest remnant habitat remaining is the Wilson Dam tailwaters, a several mile reach adjacent to, and downstream from, Florence, Alabama (Garner and McGregor 2001). The zebra mussel populations in the TN River have dramatically increased in recent years (Garner 2018, pers.comm.).
(57) Tennessee River (Kentucky Reservoir)	High	impoundment, dredging/navigation impacts	From Hubbs (2015): Commercial sand and gravel dredging, conducted on the Lower Tennessee River since at least the 1920's, and currently permitted on approximately 48 of the 95 river miles in this reach has degraded a significant portion of the available aquatic habitat. Significantly lower mussel abundance and diversity values have been observed at dredge sites indicating bottom substrates altered by dredging and resource extraction operations do not provide suitable habitat to support mussel populations similar to those found inhabiting non-dredged reaches (Hubbs *et al.*

Population	Threat Level Category	Threats	References
			2006).
(58) Buffalo River	Moderate	agricultural impacts	Reed (2014, p. 13) cites increases in human population and associated municipal effluent as the primary source of degradation in Buffalo River tributaries. Additional increased herbicide and pesticide use and changes to hydrology were also cited as contributors to mussel decline in the river.
(59) Tennessee River (Kentucky Reservoir & 5km of tailwater)	High	impoundment	Dredging for navigation, tows. From Sickel and Burnett (2005): Downstream from the sanctuary, the river provides a valuable source of mussel shell for the cultured pearl industry. During the pearl button days from the late 1800's until the mid 1950's, the river was a source of valuable shells for the button industry. With the construction of Kentucky Lock and Dam completed in 1944, major changes occurred in the aquatic habitat upstream from the dam in Kentucky Lake, with sediment accumulation in deeper areas, while the tailwater area remained riverine and retains its original gravel bottom. In July 1998, the USACE, Nashville District, began construction of a new 1,200-ft (366-m) long navigation lock at Kentucky Lock and Dam to help alleviate the bottleneck in river traffic caused by the existing single 600 ft (183 m) lock. This addition accommodates increased commercial river traffic. Also, new industries are being added and established industries are expanding in the tailwater area.
(60) Tennessee River	High	impoundment, dredging, exotic species	Dredging for navigation, tows. From Sickel and Burnett (2005): Downstream from the sanctuary, the river provides a valuable source of mussel shell for the cultured pearl industry. During the pearl button days from the late 1800's until the mid 1950's, the river was a source of valuable shells for the button industry. With the construction of Kentucky Lock and Dam completed in 1944, major changes occurred in the aquatic habitat upstream from the dam in Kentucky Lake, with sediment accumulation in deeper areas, while the tailwater area remained riverine and retains its original gravel bottom. In July 1998, the USACE, Nashville District, began construction of a new 1,200-ft (366-m) long navigation lock at Kentucky Lock and Dam to help alleviate the bottleneck in river traffic caused by the existing single 600 ft (183 m) lock. This addition accommodates increased commercial river traffic. Also, new industries are being added and established industries are expanding in the tailwater area. The entire length of the 650-mi (198-m) long Tennessee River main stem has been impounded, destroying hundreds of miles of riverine habitat for the Longsolid. The main stem is currently maintained as a navigational channel. Thus maintenance

Population	Threat Level Category	Threats	References
			activities and impacts associated with barge traffic are continued threats.