Species Status Assessment Report

for the

Nashville Crayfish (*Orconectes shoupi*)

Version 1.0

7-25-2018

U.S. Fish and Wildlife Service

Region 4

Atlanta, GA

EXECUTIVE SUMMARY

The Species Status Assessment (SSA) reports the results of the comprehensive status review for the Nashville crayfish (*Orconectes shoupi)*. For the purpose of this assessment, we generally define viability as the ability of the Nashville crayfish to sustain resilient populations in the natural ecosystems within the Mill Creek watershed over time. Using the SSA framework, we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (USFWS 2016, entire; Wolf et al. 2015, entire). This SSA provides a thorough assessment of biology and natural history and assesses demographic risks, stressors, and limiting factors in the context of determining the viability for the species. This process used the best available information to characterize viability as the ability of a species to sustain populations in the wild over time.

The Nashville crayfish is a relatively large crayfish endemic to the Mill Creek watershed in Davidson and Williamson Counties, Tennessee. The Nashville crayfish has been found in a wide range of environments including gravel and cobble runs, pools where the flow was intermittent, and under slab rocks and other cover. The species has also been found in other unique areas, such as storm water detention ponds, indicating the species may be more of a generalist than previously thought (USFWS 2017).

For the Nashville crayfish to maintain viability, its populations or some portion thereof must be resilient. Stochastic factors that have the potential to affect Nashville crayfish include impacts to water quality via runoff and catastrophic spills, particularly phosphorus loading, sedimentation, and significant alterations to dissolved oxygen. Other factors that influence the resiliency of Nashville crayfish populations include population size and presence of slab rock. Influencing those factors are elements of Nashville crayfish ecology that determine whether populations can grow to maximize habitat occupancy (e.g. dispersal, reproductive success), thereby increasing resiliency of populations.

Because there is insufficient information on dispersal and genetics to accurately delineate demographic populations for Nashville crayfish, we delineated populations segments, which are the basis for resilience estimates. Ten population segments were delineated based on habitat quality and species occurrence data from Tennessee Department of Environment and Conservation (TDEC) Natural Heritage Data and species expert opinions.

Three feasible future scenarios representing status quo, worst case, and conservation scenarios were developed to assess viability out to the year 2040. The two primary stressors examined included impacts to water quality via human population growth and subsequent increases in impervious cover, and catastrophic spill risk as a function of increasing road density and development.

Given the species' current condition and the impacts that the species is expected to experience under the future scenarios, some reductions in resilience are anticipated under a status quo and worst case scenarios, but redundancy and representation are unaffected under all scenarios. The results of the SSA highlight that Nashville crayfish exhibits a high degree of resistance to disturbance, indicating the species has a low susceptibility to threats and a high degree of stability.

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INTRODUCTION

The Nashville crayfish is a species endemic to the Mill Creek watershed in Davidson and Williamson Counties, Tennessee. The Nashville crayfish has been listed as endangered under the Endangered Species Act of 1973, as amended (Act), since 1986 (51 FR 34410). The SSA framework (USFWS 2016, entire) is intended to support an in-depth review of the 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 intent is for the SSA to be 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.

This SSA for the Nashville crayfish is intended to provide the biological support for the decision on whether or not to reclassify the species and for potential future ESA actions. Importantly, the SSA does not result in a decision by the Service on whether this species should be proposed for reclassification under the Act. Instead, this SSA provides a review of the available information strictly related to the biological status of the Nashville crayfish. The reclassification decision will be made by the Service 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. For the purpose of this assessment, we generally define viability as the ability of the Nashville crayfish to sustain populations in natural river systems over time. Using the SSA framework (Figure 1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf *et al.* 2015, entire).

- **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.

- **Representation** describes the ability of a species to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species is capable of adapting to environmental changes. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the geographical range.
- **Redundancy** describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can return from catastrophic events (such as a rare destructive natural event or episode involving many populations).

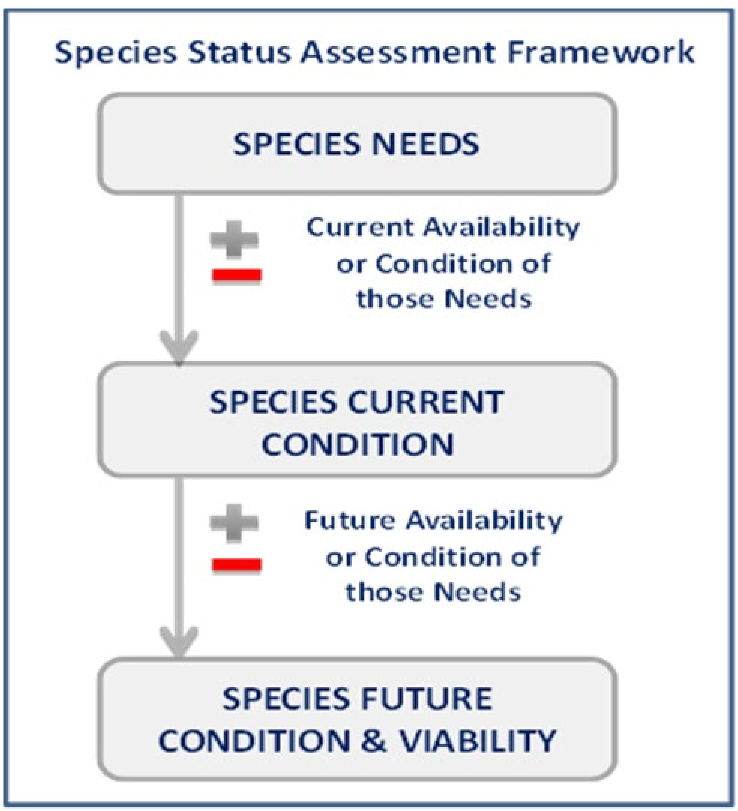


Figure 1- Species Status Assessment Framework

To evaluate the biological status of the Nashville crayfish both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). This SSA Report provides a thorough assessment of biology and natural history and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the species.

The format for this SSA includes: (1) Species Biology (2) Species Distribution and Needs for Viability (3) Current Conditions (4) Influences on Viability and (5) Future Conditions. This document is a compilation of the best available scientific and commercial information and a description of past, present, and likely future risk factors to the Nashville crayfish.

SPECIES BIOLOGY:

In this chapter we provide basic biological information about the Nashville crayfish, including its taxonomic history, species description, distribution, life history traits, and habitat characteristics. We then use this information to outline the resource needs within various life stages of Nashville crayfish. Here we report those aspects of the life history of the Nashville crayfish that are important to our analysis.

Taxonomy and species description

Orconectes shoupi Hobbs 1948 is the recognized classification of the Nashville crayfish. Hobbs described *O. shoupi* following close examination of a series of crayfishes from the Nashville area (Bouchard, 1984, from Barrociere, 1986). No other changes in nomenclature have occurred. Many authors have addressed the particular characters that distinguish the Nashville crayfish from others in Mill Creek and the region (Hobbs 1948; O'Bara et al. 1985; USFWS 1989; Williams 2001). The most distinguishing features include elongate pincers with red tips and adjacent narrow black banding, a usually light-colored "saddle" on the carapace extending from the posterior to the anterior and terminating as lateral stripes on both side, and distinctive gonopods markedly different from any of its congeners. Larger females can be identified easily by the sigmoidal cleft of the annulus ventralis (AV or sperm receptacle) under minimal magnification, and occasionally by the naked eye.

The Nashville crayfish is a relatively large crayfish, ranging from young-of-the-year (YOY) at ~0.6 cm (.24 in) total length (TL) to adults ~17.8 (7 in) cm (TDNA 2009, O'Bara et al., 1985). Other *Orconectes* reported from the Mill Creek watershed, including *O. rhoadesi* and *O. durelli*, can easily be distinguished from *O. shoupi* by gonopod structure and body coloration. As noted by Bouchard (1984), *O. placidus*, a Central Basin species strongly resembling *O. shoupi*, never has been reported from the Mill Creek watershed. As such, even YOY crayfish from the Mill Creek drainage often can be identified as *O. shoupi*, as no other saddle-bearing species are present in the system. That idea was borne out during a contemporary distributional survey (TDNA 2009), as the only adult *Orconectes* from the Mill Creek system with the characteristic saddle was *O. shoupi*. Saddled YOY observed in the Mill Creek drainage, by inference, are likely *O. shoupi* as well (TDNA 2009).

Distribution

The Nashville crayfish is endemic to the Mill Creek watershed in Davidson and Williamson counties, Tennessee. The species was thought to occur historically in a few locations outside of the Mill Creek watershed, including Big Creek in Giles County (Elk River drainage), the South Harpeth River in Davidson County (Harpeth River drainage), and Richland Creek in Davidson County (Cumberland River drainage) (USFWS 1987). The Big Creek and South Harpeth River records are believed to be the result of "bait bucket" introductions. The species was thought to be native to Richland Creek and displaced by a more competitive crayfish species, the bigclaw crayfish (*O. placidus*). However, specimens of Nashville crayfish (*O. shoupi*) collected from Richland Creek were misidentified and the collections were annotated as the bigclaw crayfish (USWFS 1989).

Biologists conducting the pre-listing status survey for the species surveyed 148 streams in central Tennessee (Korgi and O'Bara 1985). Streams surveyed were located in the Collins River drainage, Stones River drainage, Caney Fork River drainage, Cumberland River drainage, Red River drainage, Mill Creek drainage, Harpeth River drainage, and Elk River drainage. Nashville crayfish were only found in Mill Creek and its tributaries.

In 1999, a study was done to determine the current status of the Nashville crayfish in the Mill Creek watershed and to identify potential habitat in stream systems adjacent to Mill Creek (O'Bara 2000). The species was found in Mill Creek, except in the lower 0.8-mile reach which is influenced by water level fluctuations in the Cumberland River and in the upper 2.5-mile reach which undergoes seasonal dewatering. The species was found to be evenly distributed in the remaining 23.5 miles of Mill Creek and in eight of the 15 tributaries to Mill Creek.

There has been no change in the distribution of the species within its historical range (USFWS unpublished data). The species is currently known to occur in Mill Creek and its tributaries, including Collins Creek, Owl Creek, Edmonson Branch, Sims Branch, Sevenmile Creek, Sorghum Branch, Whittemore Branch, Turkey Creek, Indian Creek, Holt Creek, four unnamed tributaries to Mill Creek, and one unnamed tributary to Owl Creek (Figure 2).

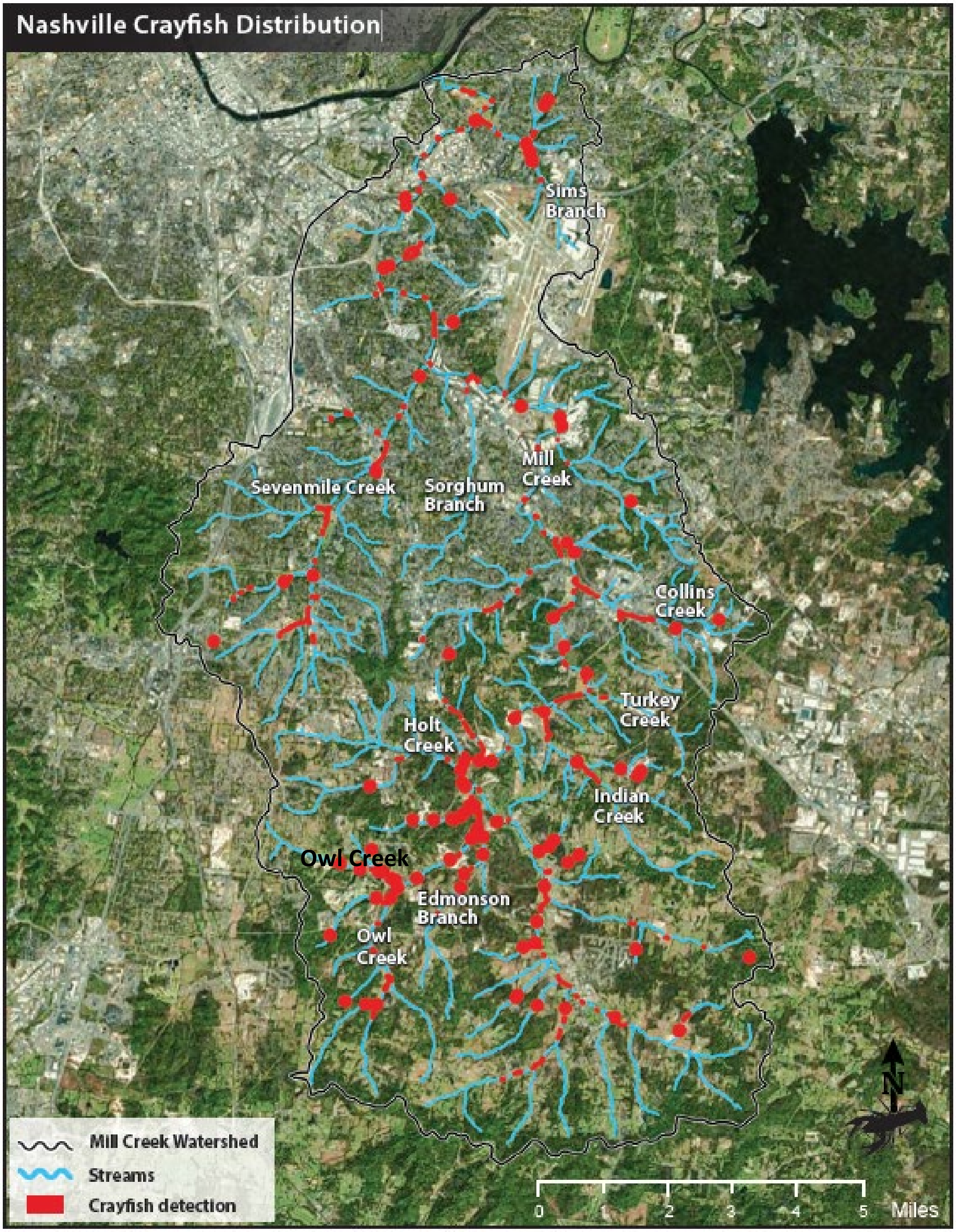


Figure 2—Nashville crayfish distribution based on detections in Davidson and Williamson counties, Tennessee

Life History

Little is known about the life history of the Nashville crayfish (Table 1). We assumed that their life history traits are similar to other crayfish species (Figure 3). Most common stream-dwelling species of crayfish (non-burrowing and non-cave-dwelling species) live an average of four to five years (Bergey et al. 2005). Raccoons, fish and reptiles are the primary crayfish predators. Crayfish are omnivorous, feeding on a variety of plant and animal material, including algae, insects, worms, fish eggs, snails and mussels.

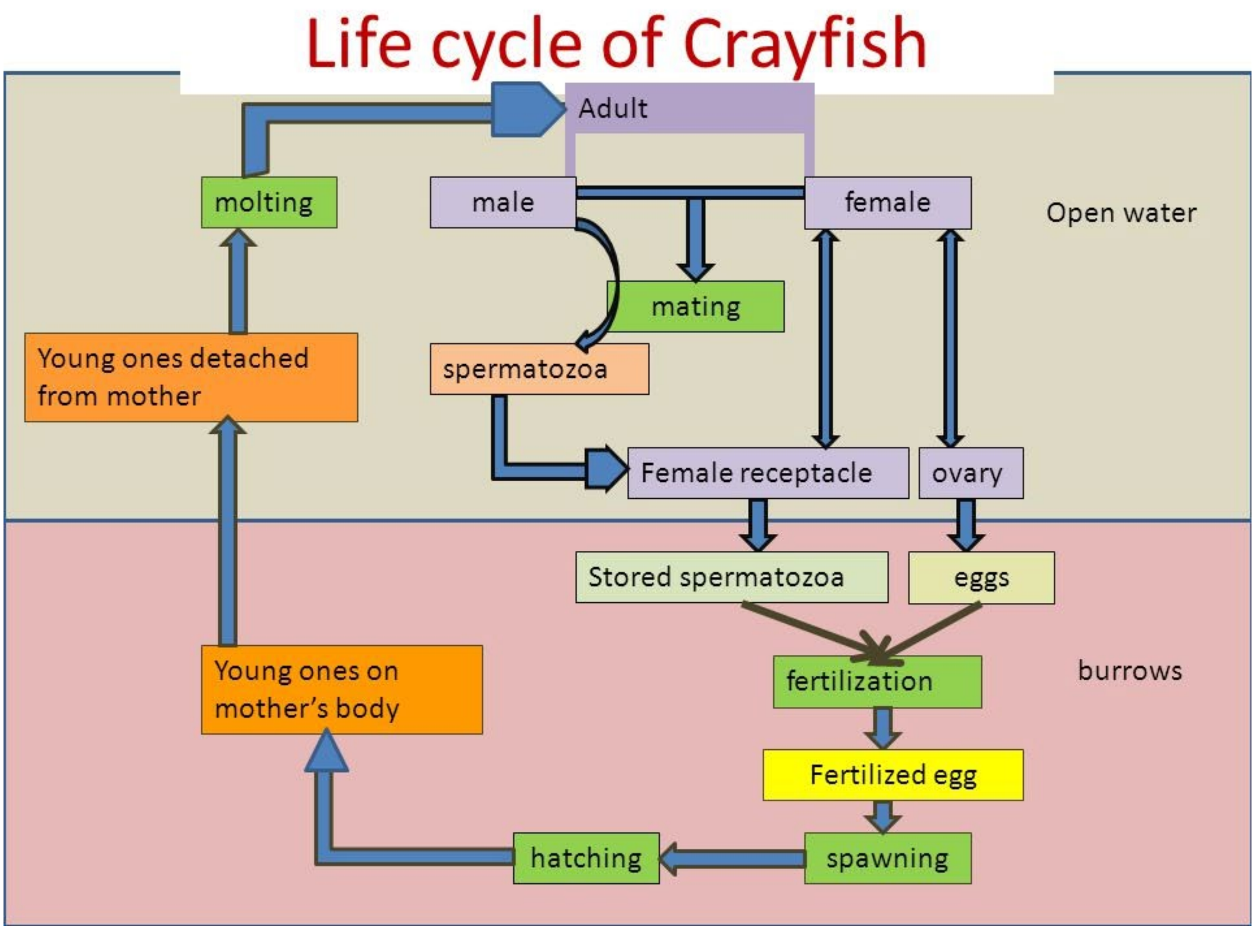


Figure 3—General life history diagram for crayfish.

Reproductive females are typically found under large slab rocks. Ovigerous females (i.e. females carrying/bearing eggs) have been found in isolated areas near banks during spring, in preparation for brood hatching. Cover rocks of at least 0.02 m^2 (2.15 ft^2) may be important habitats for females releasing broods and for protection during molting after releasing broods

(USFWS 1987). Nashville crayfish were found at least 50% of the time in runs, using cover rocks with a surface area of 0.05m^2 (0.54 ft^2), and at least 50% of the time in pools, when cover rock area increased to 0.10 m^2 (1.1 ft^2). Larger rock areas may be needed in pools to decrease risk of predation, whereas smaller rock areas would provide adequate protection in runs (Cook and Walton 2008). Instream cover is also important for Nashville crayfish during the time when they are molting. Cover is aggressively defended; larger individuals drive smaller crayfish from their selected cover. Juveniles tend to inhabit areas along stream margins (Pennington 2007, personal communication).

Male crayfish, and possibly females, have an unusual pattern of molting after reaching adulthood. Crayfish typically molt six or seven times during their first year of life and once or twice a year for the remainder of their lives. Males molt back and forth between a reproductive form (Form I) and a non-reproductive form (Form II). Reproduction begins when males change from Form II to Form I. The primary differences between Form I and Form II males are development of the claws and the shape of the reproductive organ which is known as the first pleopod, or gonopod on Form I individuals. In juvenile and Form II males, the gonopod appears to be the same color and consistency throughout its length and has more blunt and rounded features. In Form I males, at least one of the terminal elements is corneous (appears yellowish and brittle) (Georgia College 2012). According to Barrociere (1986), Nashville crayfish reach sexual maturity during early spring of the year following their hatching; Withers (2012a, personal communication) has further indicated that earlier hatched Nashville crayfish likely reach sexual maturity within their first year of life, while those hatched later in the year would be expected to reach sexual maturity during their second year of life.

The Nashville crayfish reproductive period, which includes mating, spawning, egg release, egg incubation and hatching, occurs from approximately October 1 to May 31 (Barrociere 1986). We assumed mating in Nashville crayfish to be similar to that of other crayfish species, consisting of short exchanges of tactile and olfactory signals, after which males grasp females by their claws, turn them on their backs, and release spermatophores, which attach to the thoracic sternites (ventral surface of body segments) of the females. Fertilization occurs externally, and occurs a few days or weeks after mating (Acquistapace et al. 2002). Eggs developing under the female crayfish's abdomen are guarded, a period during which females typically do not eat (Galeotti et al. 2006). Withers (2012b, personal communication) estimated the average clutch size for the Nashville crayfish at approximately 100 eggs per female. Nashville crayfish egg-laying occurs during late winter and early spring. Smart (1962) found that the female, *Cambarus longulus longulus*, a crayfish species closely related to the Nashville crayfish, carried eggs approximately 35 days from late April through late May. Barrociere (1986) noted that the period of egg laying and embryonic development of Nashville crayfish in Mill Creek occurred from late March through mid-May (Barrociere 1986).

When female crayfish are ready to lay eggs, they usually find a secure hiding place and, hence, are rarely encountered. Like other crayfish species, when the female Nashville crayfish releases her eggs, she attaches them to her swimmerets (pleopods) and is said to be 'in berry" (Georgia College 2012). Embryos develop in approximately three weeks, and the young remain attached to the pleopods of the mother for approximately another two weeks (Barrociere 1986). Upon hatching, the hatchling crayfish remain attached to the mother by the "telson thread". The telson is defined as the terminal segment of an arthropod, and in Nashville crayfish, there is a thread which hatchlings stay attached during early development. Throughout this period, besides providing protection, females continuously fan and groom the eggs and hatchlings (Reynolds 2002). After the juveniles molt for the second time, they are free of the mother, but stay close and cling to the mother's abdomen for several weeks through late spring until they move off on their own (Georgia College 2012).

Table 1—Life history table for Nashville crayfish

Life Stage	Resource Needs (habitat)	Source
Reproduction-- ***Gravid females*** ***Juveniles***	• Juveniles are most often found along the margins of the stream in slower flow where beds of aquatic vegetation provide cover. • Females seek out large slab rocks when they are carrying eggs and young • Algae can be a significant variable in predicting the presence of females, especially during egg laying and brooding	• Cook and Walton (2008) • U.S. Fish and Wildlife Service 1987 • Whitledge and Rabeni 1997 • U.S. Fish and Wildlife Service 1987 • Stark 1986, Miller and Hartfield 1985

	• Cover rocks of at least 0.02 m^2 may be important habitats for females releasing broods • Gravel-cobble substrate provides good cover for juveniles	
Adults	• Adults tend to be solitary, seeking cover under large rocks, logs, debris, or rubble • They feed on a variety of plant and animal material • Males were more often found between depths of 0.05 and 0.15 meters • Females were more often found in depths greater than 0.30 m • The species is highly photosensitive and is usually found under cover during the day • Canopy cover of 60 to 90 percent appears important	• U.S. Fish and Wildlife Service 1987 • U.S. Fish and Wildlife Service 1987 • Cook and Walton (2008) • Cook and Walton (2008) • Bouchard 1976 • O'Bara et al. (1985)
Molting	• Secluded places such as large slab rocks are needed for molting • Cover rocks of at least 0.02 m^2 may be important habitats for protection during molting • Instream cover is important during the time when they are molting	• Stark 1986, Miller and Hartfield 1985 • U.S. Fish and Wildlife Service 1987 • Stark 1986, Miller and Hartfield 1985

Habitat

The Nashville crayfish has been found in a wide range of environments including gravel and cobble runs, pools with up to 10 cm (3.9 in) of settled sediment, and under slab rocks and other cover (largest crayfish are usually under cover). The species has also been found in small pools where the flow was intermittent (Stark 1986, Miller and Hartfield 1985). They have been found to select large stones for cover and tend to inhabit non-flowing, rather than flowing, water (Cook and Walton 2008).

Nashville crayfish have been found in other unique areas, such as storm water detention ponds, indicating the species may be more of a generalist than previously thought (USFWS 2017). Gravel-cobble substrate provides good cover for juveniles (Stark 1986, Miller and Hartfield 1985). Adults tend to be solitary, seeking cover under large rocks, logs, debris, or rubble; the largest individuals generally select the largest cover available (USFWS 1987). Females seek out large slab rocks when they are carrying eggs and young, and these secluded places are also needed for molting. The species is highly photosensitive and is usually found under cover during the day (Bouchard 1976). Canopy cover appears important, as O'Bara et al. (1985) reported that all sites they sampled had canopy cover of 60 to 90 percent.

Cook and Walton (2008) attempted to describe habitats used by the species, but because of a severe drought during their 2007 study, their models may only reflect habitats used during stress periods. Their study indicated habitat variables important to Nashville crayfish include cover (rock area) and depth, and that the most important microhabitat variables for the species are habitat unit type (riffle, run, pools, and cascades) and area. Males were more often found between depths of 0.05 and 0.15 m, whereas females were more often found in depths greater than 0.30 m. Males occurred most often at greater depths (over 0.2 m) when seasons were averaged together than during spring (0.05 m and 0.15 m). Algae can be a significant variable in predicting the presence of females, especially during egg laying and brooding (Whitledge and Rabeni 1997). The probability of finding a female increased when canopy was absent, aquatic vegetation cover was 30 % or more within a depth of 0.25 m, and with cover rocks greater than 0.02 m^2.

In its 2009 report, the Tennessee Division of Natural Areas (TDNA) identified preferred habitat that includes slab rock over bedrock or cobble substrates in free-flowing streams (Carpenter 2004; DNA Biotics 2009; Walton 2008). Although they primarily utilize riffle habitat, they are typically found in areas with slower flow velocities (i.e., riffle/runs, pools). Juveniles are most often found along the margins of the stream in slower flow where beds of aquatic vegetation provide cover. At least four exceptions involving small impoundments have been reported (Carpenter 2004; DNA Biotics 2009; Walton 2008). Nashville crayfish recently collected from impoundments, overflow pools adjacent to Mill Creek and small, intermittent tributaries in the Mill Creek watershed include: (1) 809 Nashville crayfish found in a small five acre impoundment with rock habitat on a tributary to Mill Creek (U.S. Fish and Wildlife Service 2011); (2) a live Nashville crayfish collected from a rock outcropping along the shoreline of a 5-acre (ac) impoundment on a Mill Creek tributary that was drained for a residential development (USFWS 2011); (3) four Nashville crayfish collected from a limestone slab shoreline of a retention pond adjacent to Owl Creek (Cook and Walton 2008); and (4) Nashville crayfish (number unknown) collected from a pond with rock armoring on Sims Branch (Withers, 2009, personal communication).

Fifty-two streams in the adjacent Harpeth River, Cumberland River, and Stones River watersheds were evaluated as potential habitats for the species. Several streams provided good to excellent habitat for the species; however, it was not known that Nashville crayfish would use non-riverine habitat types in the watershed.

Surveys for the species are primarily conducted in relation to pre-construction survey requirements for Clean Water Act (CWA) permits, as well as state and local authorizations. Based on analyses of TDEC Natural Heritage Data, CWA permit reviews, and other data sources, the Service and Tennessee Division of Natural Heritage ranked habitat quality and species occurrence data to develop guidance for future recovery efforts. We used these data to characterize Nashville crayfish population segments and identify the status of crayfish populations throughout the Mill Creek watershed (Figure 4).

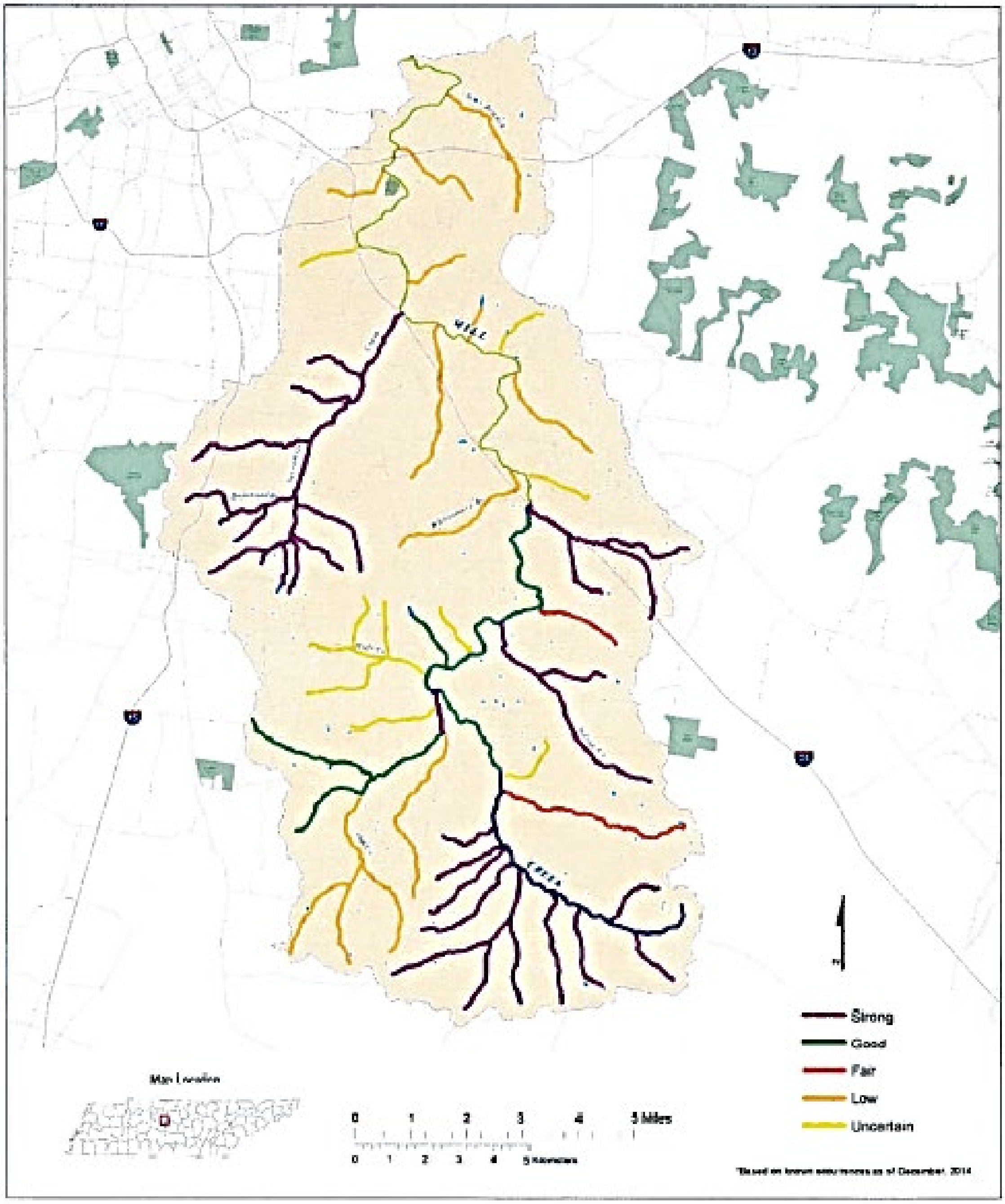


Figure 4—Assumed status of Nashville crayfish within Mill Creek watershed in 2014.

SPECIES DISTRIBUTION AND NEEDS FOR VIABILITY

In this chapter we consider the Nashville crayfish's historical distribution, current distribution, and what the species needs for viability. We first review the historical and current information on the range and distribution of the species. We next review the conceptual needs of the species, including population resiliency, redundancy, and representation to support viability and reduce the likelihood of extinction.

Historical Range and Distribution

As discussed in the previous section, Nashville crayfish were once thought to occur not only in the Mill Creek watershed, but also in a few locations outside of the Mill Creek watershed (Elk River drainage and Harpeth River drainage). However, these detections outside of the Mill Creek watershed have been found to be misidentifications (Harpeth River drainage) or the result of "bait bucket" introductions. In summary, the available information and experts we solicited agreed Nashville crayfish only occurs in the Mill Creek watershed in Davidson and Williamson counties, and it likely never occurred naturally outside of this watershed.

Current Range and Distribution

There has been no change in the distribution of the species within its confirmed historical range (USFWS unpublished data). The species is currently known to occur in Mill Creek and its tributaries, including Collins Creek, Owl Creek, Edmonson Branch, Sims Branch, Sevenmile Creek, Sorghum Branch, Whittemore Branch, Turkey Creek, Indian Creek, Holt Creek, four unnamed tributaries to Mill Creek, and one unnamed tributary to Owl Creek.

Characteristics of the Mill Creek Watershed

Mill Creek originates in Williamson County, Tennessee, and flows in a northerly direction for approximately 27 mi. It crosses into Davidson County at approximately Mill Creek river mile (RM) 20.8 and continues to flow north for approximately 20.8 mi before joining the Cumberland River at Cumberland RM 194.5. The drainage area is 172 mi^2 and it is located within the Central Basin Physiographic Region, an area of approximately 7,000 mi^2, which is comprised predominately of Ordovician limestones and shales (Jones 2006). Mill Creek is within the Inner Nashville Basin subecoregion, which TDEC characterizes as having thin soil, karst limestone, intermittent surface streams, and cedar glades. Five major tributaries contribute to the system, including Owl Creek, Indian Creek, Turkey Creek, Sorghum Branch, and Sevenmile Creek.

Mill Creek is a 4th order stream that drains an area of 172 mi^2. Jones (2006) studied the physical hydrology of Mill Creek and suggested splitting the watershed into three main subwatersheds: MCW-A, MCW-B, and MCW-C based on hydrology, stream characteristics, and surrounding land use (Figure 5). We used these hydrological delineations to help refine our population segments, as discussed in the **Delineating Population Segments and Resilience Categories** section, and to delineate our units of representation.

The unit MCW-A encompasses the headwaters and all drainage area of the watershed east-southeast of Edmonson Branch and west-southwest of Indian Creek. This hydrologic unit has a stream order of 2, it is approximately 6.8 mi. long, and covers an area of 35.4 $mi.^2$. It is a predominantly agricultural region, with pasture land and some dairy farms, although development has begun to encroach into some areas, particularly near Nolensville.

The unit MCW-B begins .15 mi. south of the confluence of Owl and Mill Creeks, and drains areas east of Sevenmile Creek. Major tributaries in MCW-B are Owl Creek and Indian Creek. MCW-B has an area of 77 $mi.^2$ and the reach of Mill Creek is 10.5 mi. long. The MCW-B unit drains the watershed northward to the Cumberland River, and includes Owl Creek which drains a suburban community located in the town of Brentwood in Williamson County. This region is predominantly suburban, with development increasing in the northern and eastern sections of this subwatershed.

The unit MCW-C drains a highly urbanized area, including the Nashville International Airport. The subwatershed encompasses an area of industrial businesses, freight train yards, densely packed urban communities and a sewage outfall managed by the City of Nashville. The confluence of Mill Creek with the Cumberland River is adjacent to an industrial park. Its major tributaries are Sevenmile Creek and Sims Branch. It drains and area of 60 $mi.^2$ and is 9.9 mi. long.

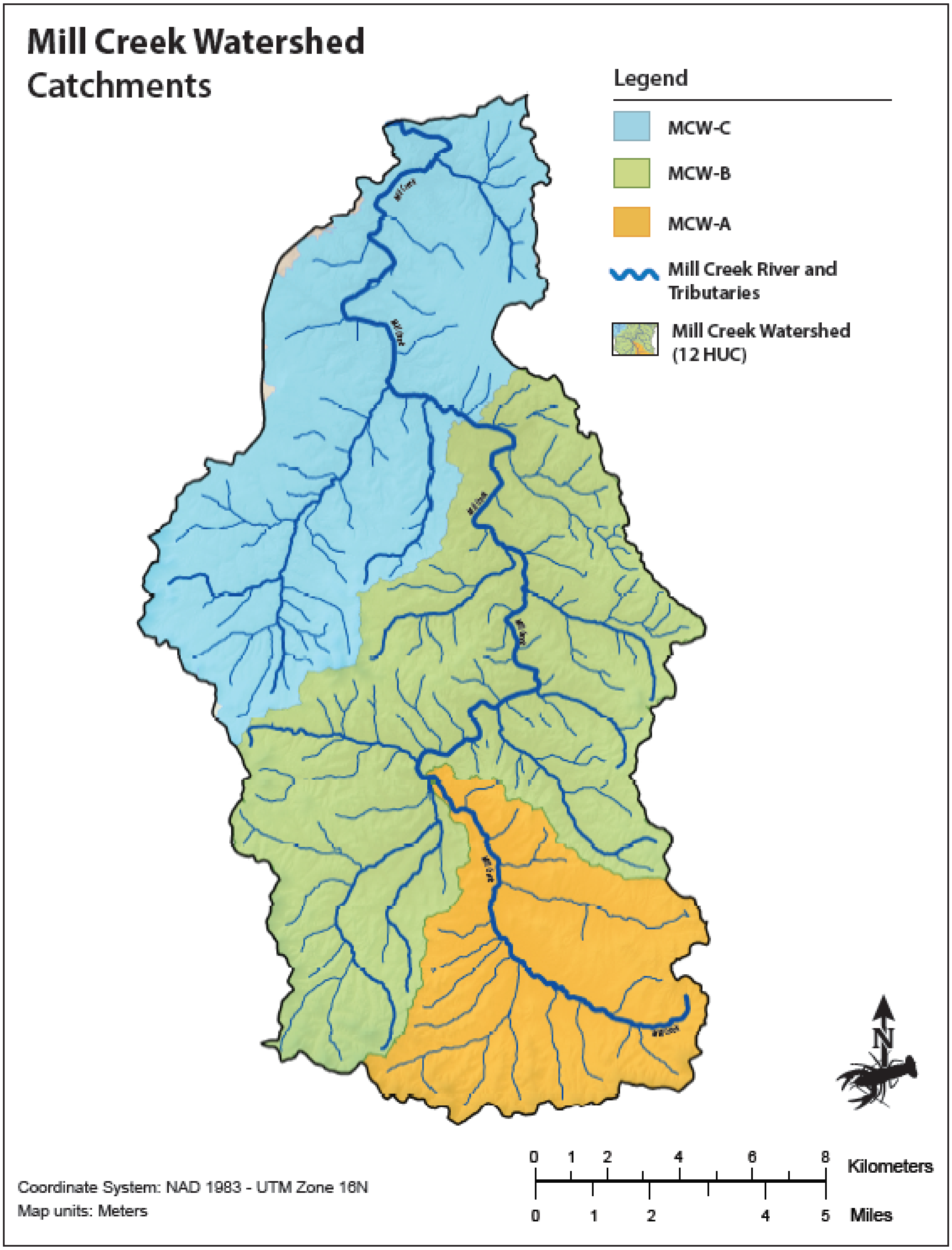


Figure 5--Mill Creek hydrology. The three catchments were classified by using flow direction, flow accumulation, and a 3 meter digital elevation model, following Jones 2006.

Needs of the Nashville Crayfish

For the purpose of this report, we define viability as the ability of the species to sustain populations in the wild over time. Species with greater numbers (redundancy) of healthy populations (resiliency), encompassing a broad array of ecological and genetic diversity in a spatial arrangement that maintains adequate gene flow (representation), are more likely to be viable. Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation.

Delineating Population Segments and Resilience Categories

Because resilience is a population level attribute, key to assessing resiliency is the ability to delineate populations. Because there is insufficient information on dispersal and genetics to accurately delineate demographic populations for Nashville crayfish, we delineated population segments (Figure 6), which will be the basis for resilience estimates. Population segments were delineated based on habitat quality (i.e. presence of slab rock and qualitative assessments of water quality) and species occurrence data from TDEC Natural Heritage Data and species expert opinions. Population resilience was characterized through a combination of "resilience ranking rules" and species expert opinion, as described below.

Expert input was critical at many stages throughout the writing and analysis of this SSA, including the delineation of population segments, our unit of measure for resilience. David Withers (TDEC), Emily Weller (USFWS), and Steven Alexander (USFWS), all have extensive experience with Nashville crayfish, and were heavily relied on to provide input into the process. They answered a series of elicitation questions ranging from delineating population segments, categorizing resilience, identifying key current threats, and assessing scenarios and future condition. They provided review of each section, and their input was integrated into this assessment.

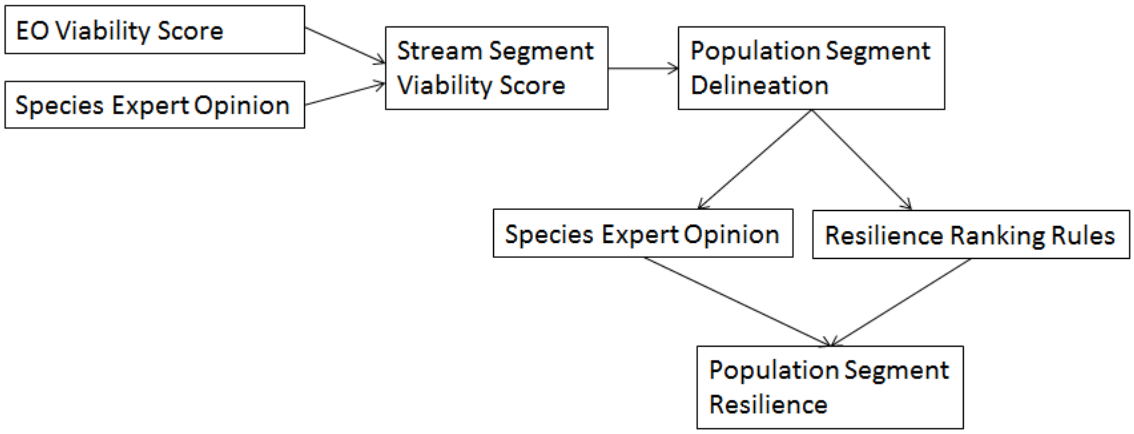


Figure 6—Flow chart depicting the process for delineating population segments and resilience

Element Occurrence Viability Scores and Stream Segment Viability

Element Occurrence (EO) data was available through TDEC Natural Heritage Data shapefiles. These data represent survey detections for Nashville crayfish conducted since 1985, and each EO has an associated EO viability score. The EO viability scores provide a succinct assessment of the estimated viability of the species, or an estimation of the likelihood that, if current conditions prevail, a species occurrence will persist for a period of time. The EO viability scores for Nashville crayfish are delineated following NatureServe descriptions (Hammerson et al. 2008) as follows:

- Excellent—species occurrence exhibits **optimal** or at least **exceptionally favorable** characteristics with respect to population size and/or quantity and quality of occupied habitat, and if current conditions prevail, the occurrence is very likely to persist for the foreseeable future (i.e. at least 20-30 years)
- Good—species occurrence exhibits **favorable** characteristics with respect to population size and/or quantity and quality of occupied habitat, and if current conditions prevail, the occurrence is very likely to persist for the foreseeable future (i.e. at least 20-30 years)

- Fair—species occurrence characteristics (size, condition, and landscape context) are **non-optimal** such that occurrence persistence is uncertain under current conditions, but may persist for the foreseeable future with appropriate management or protection.
- Poor—If current conditions prevail, occurrence has a **high risk of extirpation** because of small population size or area of occupancy, deteriorated habitat, poor conditions for reproduction, or other factors.

Stream Segment and Population Segment Delineations

The EO data, combined with other survey efforts and expert opinion resulted in the delineation of 174 stream segments with stream segment viability scores of excellent, good, fair, poor, and uncertain (i.e. no survey data, and presence in these areas is unknown). These stream segments were scaled up to the population segment scale based on watershed features such as physical hydrology and stream characteristics, and species expert opinion. This resulted in ten populations segments as depicted in Figure 7. Three of the delineated population segments are collections of several smaller streams within delineated representative units (Upper Mill Creek Streams within MC-A; Middle Mill Creek Streams within MC-B; Lower Mill Creek Streams within MC-C). We combined these streams in this fashion because 1) they were not part of larger tributary systems 2) they were too small to be delineated as a separate population segment, and 3) using representative units to combine smaller streams ensured these streams were hydrologically similar.

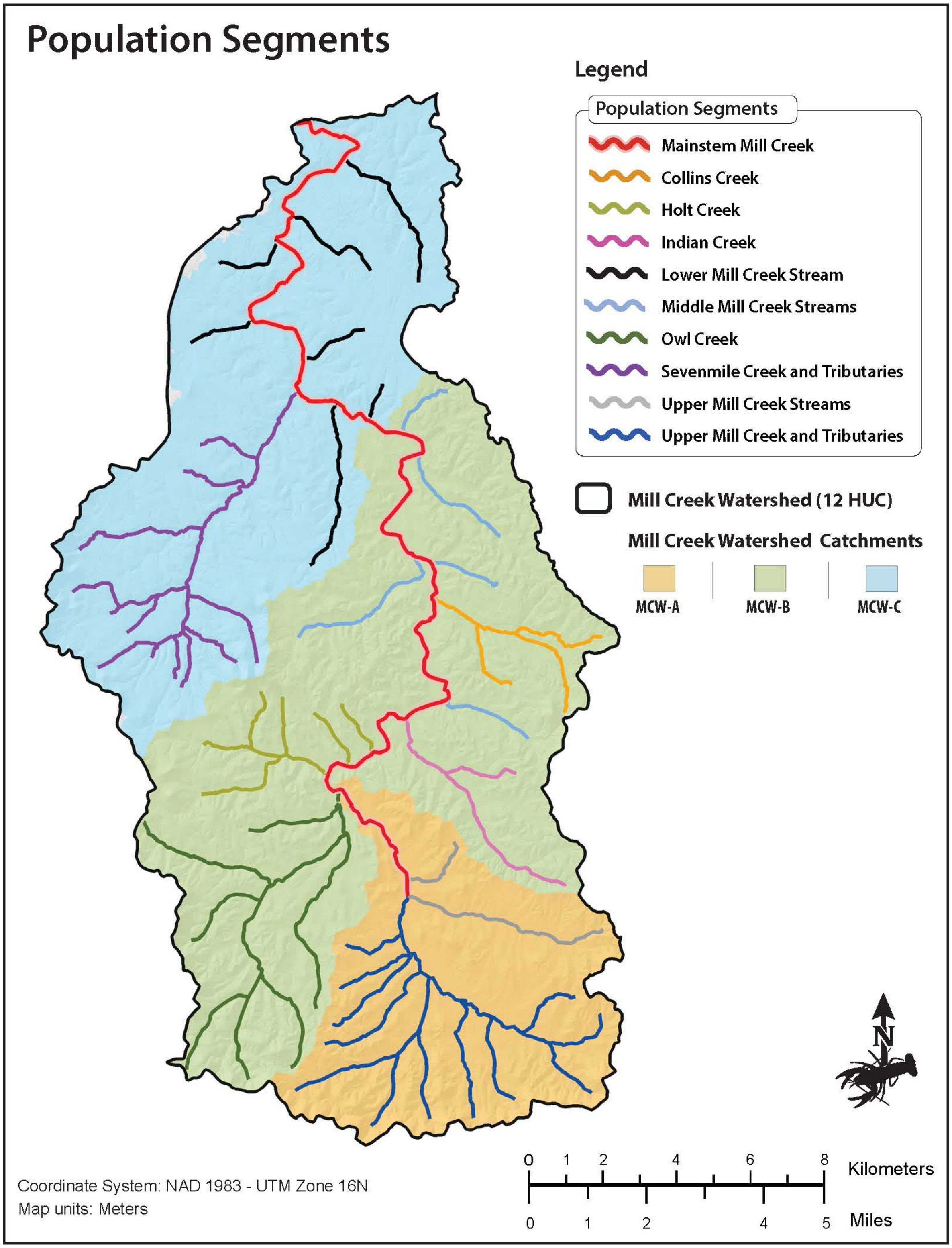


Figure 7--Nashville crayfish population segments within the Mill Creek Watershed.

Resilience Ranking Rules and Population Segment Resilience

We categorized resilience for each of the ten population segments using stream segment viability scores (e.g., excellent, good, fair, poor, and uncertain) and expert opinion. We considered stream segment viability scores of excellent and good as a single category, with fair, poor, and uncertain being the other three stream viability scores used in the resilience categorization. Within each of the ten population segments, we calculated the total stream miles within each stream segment viability category (e.g. excellent + good, fair, poor, and uncertain), to determine the proportion of various viability ranks represented in each population segment. Table 2 summarizes how stream segment viability scores were converted to population segment resilience ranks. If a stream segment viability score represented 50% or more of the total stream mileage in a given population segment, we categorized that population segment at that resilience level. If no stream segment viability score was represented as 50% or more of the total stream mileage in a given population segment, or if 50% or greater of the total stream mileage was uncertain, we looked at EO viability scores within the element occurrence data, and elicited Nashville crayfish experts as to how we should characterize resilience of that population segment.

Table 2—Description of the conversion of stream segment viability ranks to population segment viability scores.

Stream Segment Viability Scores	Population Segment Resilience Rank
>50% excellent + good	High
>50% fair	Moderate
>50% poor	Low
No ranks >50%	EO ranks + Expert Opinion
> 50% uncertain	EO ranks + Expert Opinion

Population Resiliency

For the Nashville crayfish to maintain viability, its populations or some portion thereof must be resilient. Stochastic factors that have the potential to affect Nashville crayfish include impacts to water quality, particularly phosphorus loading, sedimentation, and significant alterations to dissolved oxygen. Other factors that influence the resiliency of Nashville crayfish populations include population size and presence of slab rock. Influencing those factors are elements of Nashville crayfish ecology (e.g. dispersal and reproductive success) that determine whether populations can grow to maximize habitat occupancy, thereby increasing resiliency of populations. These factors and habitat elements are discussed below.

Population Factors

Presence of Nashville Crayfish-- The influence of stochastic variation in demographic (reproductive and mortality) rates is much higher for small populations than large ones. Stochastic variation in demographic rates causes small populations to fluctuate randomly in size. In general, the smaller the population, the greater the probability that fluctuations will lead to extinction. There are also genetic concerns with small populations, including reduced availability of compatible mates, genetic drift, and inbreeding depression. Small populations of Nashville crayfish have low resilience, leaving them particularly vulnerable to stochastic events. Large populations of Nashville crayfish have higher resilience, as they are better able to return to pre-disturbance numbers after stochastic events. Large populations also have increased availability of mates and have reduced risk of genetic drift and inbreeding depression.

The Nashville crayfish population sizes in the Mill Creek drainage cannot be accurately estimated at this time because: a) Nashville crayfish do not occur in all stream reaches within the Mill Creek drainage, b) the number of individuals occupying suitable habitat varies among stream reaches where they are known to occur, c) the most recent population estimates are based on data collected more than a decade ago (Carpenter 2002), and d) many stream reaches have never been or have not recently been surveyed. However, numerous surveys since 1985 have confirmed the presence of Nashville crayfish throughout the watershed (Figure 8).

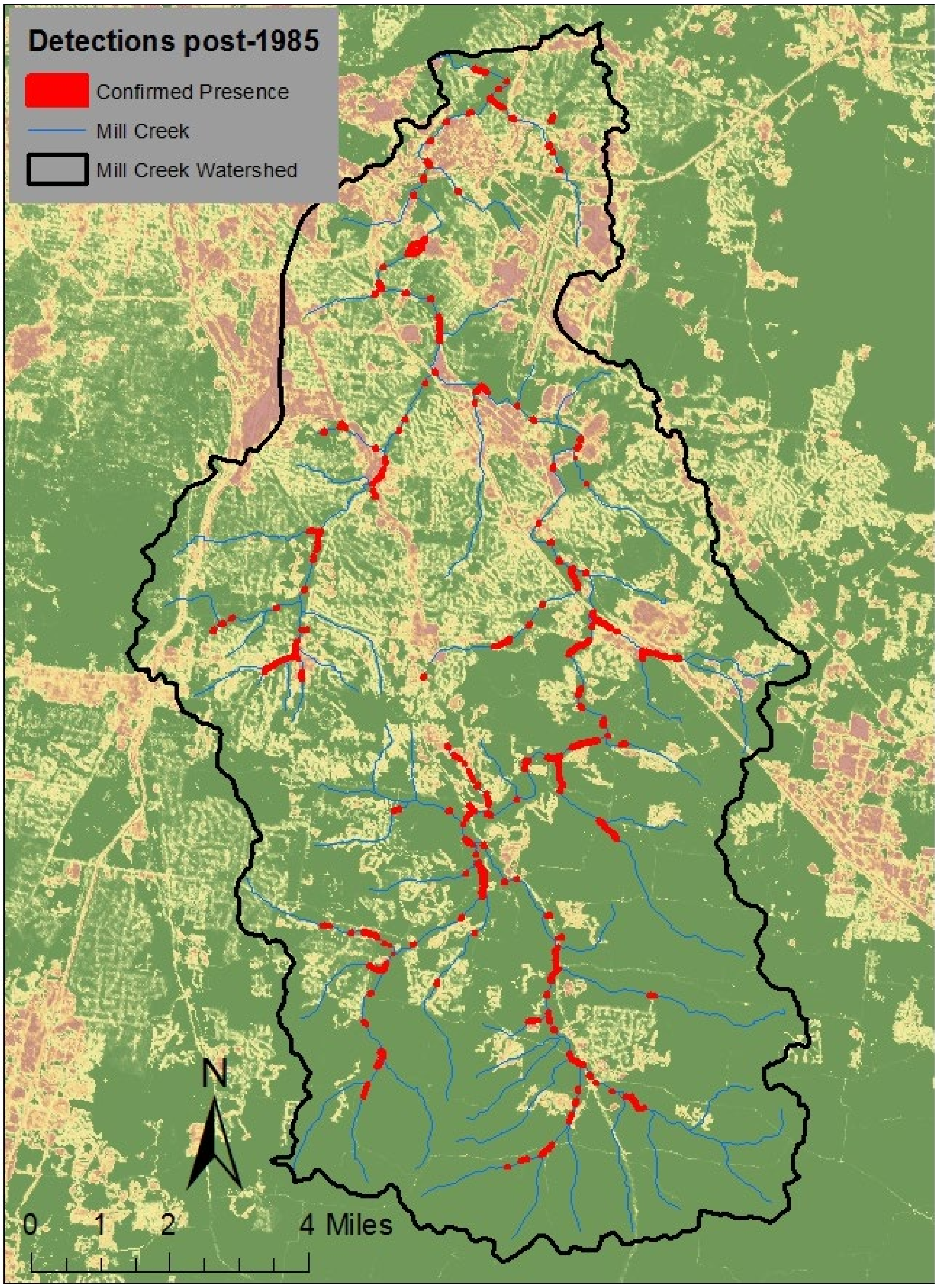


Figure 8--Element occurrence records for Nashville crayfish (1985-present) overlaid on impervious cover.

Habitat Factors

Water Quality-- Mill Creek is currently listed as an impaired stream with the EPA. This means that many streams within the Mill Creek watershed are considered too polluted or otherwise degraded to meet the water quality standards set by Tennessee under section 303(d) of the Clean

Water Act. As of 2014, 17 stream reaches in Mill Creek and its tributaries were listed as impaired on the State of Tennessee's 303(d) list (TDEC 2014). Impairment of stream reaches in the drainage is the result of low dissolved oxygen (DO), siltation, removal of riparian vegetation, nutrient enrichment and high bacteria levels from stormwater discharges, sewage collection system failures, land development and unrestricted cattle access (TDEC 2014). However, Nashville crayfish persist despite these water quality impairments (Figure 9).

Silt deposition in streams contributes to several of the impairments in the Mill Creek watershed, and can also be a risk factor for crayfish. Stream channelization and silt deposition has been reported to be directly responsible for the permanent loss of some crayfish populations (Reynolds et al. 2013). As crayfish are primarily active at night, the chief requirement of all size classes is for hiding spaces during the daytime. Where loss of hiding spaces occurs through bank reconstruction or siltation from natural or human causes, the habitat's carrying capacity for crayfish diminishes (Reynolds et al. 2013). Therefore, good quality habitat for Nashville crayfish has minimal silt deposition such that availability of vital hiding spaces, and thus carrying capacity, are maximized.

Dissolved oxygen levels are an important water quality parameter for all aquatic life, including crayfish. Oxygen is dissolved into the water in streams through diffusion, aeration, and as the waste product of plants that are photosynthesizing. The amount of DO found in water can vary due to several factors including water temperature, level of pollutants and water velocity. Extended periods of supersaturation can occur in highly aerated waters, often near hydropower dams and waterfalls, or due to excessive photosynthetic activity. Algae blooms can cause air saturations of over 100% due to large amounts of oxygen as a photosynthetic byproduct. This is often coupled with higher water temperatures, which also affects saturation (Fondriest 2013). High levels of DO may be stressful to crayfish because of physiological effects, such as gas bubble disease, or because higher oxygen levels allow invasion of invasive crayfish species, who better tolerate higher DO concentrations. If DO levels are very low, it is harder for individual crayfish to take in oxygen, and in extreme cases the lack of DO results in death. Although the tolerance level of Nashville crayfish for DO is not known, levels below 2.0 mg/L typically result in invertebrates abandoning the area (Fondriest 2013).

High phosphate loads contribute to Mill Creek's impairments, and are a risk factor for aquatic life in general. Phosphates could have a range of sources, including natural geologic elements, fertilizers, and domestic and industrial detergents. Forms of phosphate occur in living and decaying plant and animal remains, as free ions or weakly chemically bounded in aqueous systems, chemically bonded to sediments and soils, or as mineralized compounds in soil, rocks, and sediments. Orthophosphate forms are produced by natural processes, but major human influenced sources include: partially treated and untreated sewage, runoff from agricultural sites, and application of some lawn fertilizers (Oram 2014). Orthophosphate is readily available to the biological community and typically found in very low concentrations in unpolluted waters (Oram 2014). Phosphate will stimulate the growth of plankton and aquatic plants, and initially, this increased productivity will cause an increase in the overall biological diversity of the system. But as the phosphate loading continues and there is a build-up of phosphate in the waterbody, eutrophication can occur. Eutrophication is enhanced production of primary producers resulting in reduced stability of the ecosystem. Excessive nutrient inputs, usually nitrogen and phosphate, have been shown to be the main cause of eutrophication over the past 30 years (Oram 2014). This process can result in large fluctuations in water quality and trophic status and in some cases periodic blooms of cyanobacteria (i.e. algal blooms). Although we know phosphate loads can have an impact on aquatic organisms, we do not know what the critical levels are for the Nashville crayfish.

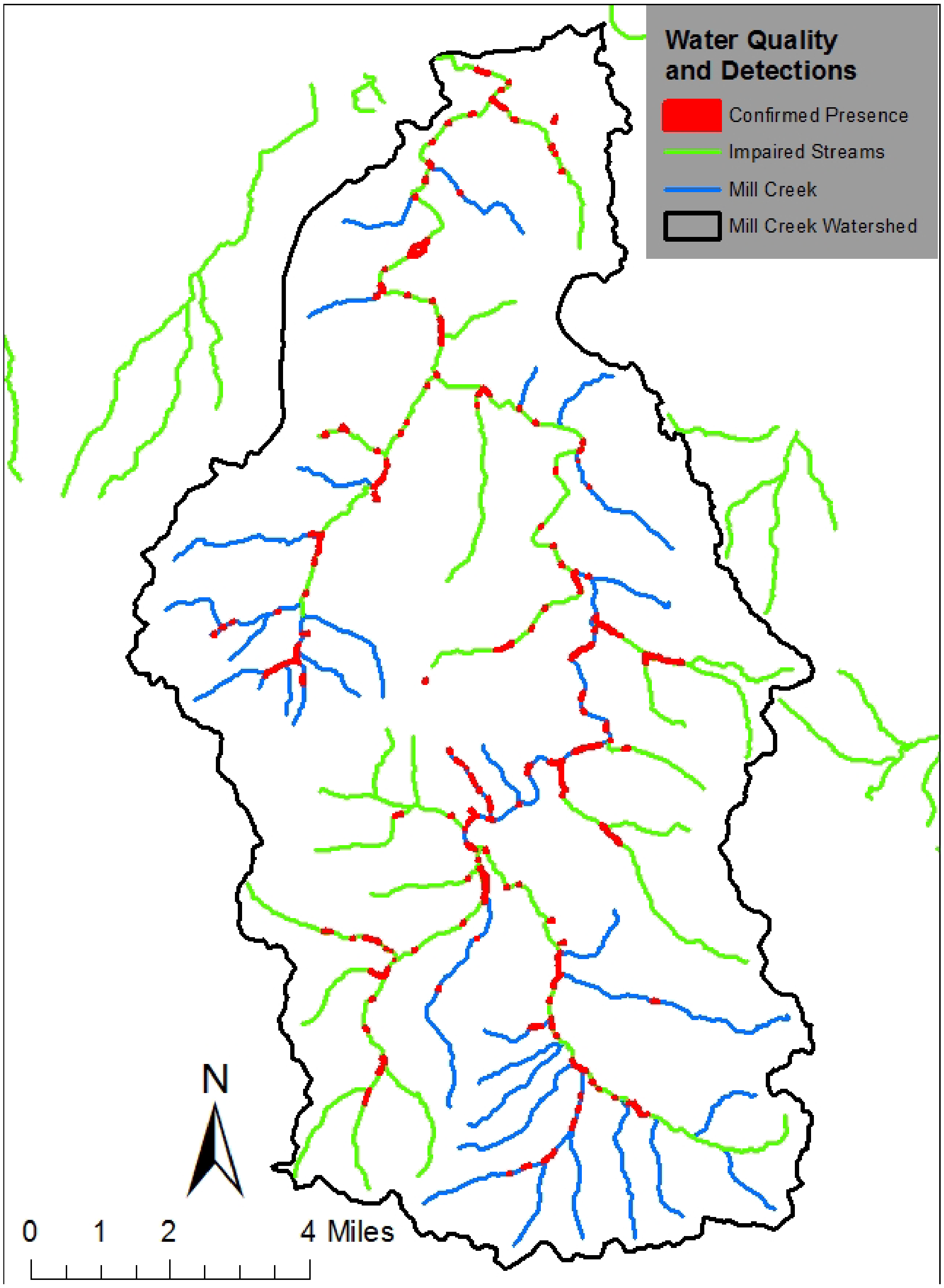


Figure 9--Overlay of Nashville crayfish detections post-1985 with impaired (green) and healthy (blue) streams based off of EPA 2014 303(d) listed streams.

Presence of Slab Rock— Slab rock, for purposes of this SSA, is defined as moderately to large sized rocks in the stream channel, typically limestone, found on top of bedrock, cobble, or gravel. Observations made by biologists during numerous pre-project surveys for the species confirmed that adult Nashville crayfish occur in various habitats in streams with slab rocks or other debris for cover. In its 2009 report, TDNA identified “preferred habitat that includes slabrock over bedrock or cobble substrates in free flowing streams”.

Adults tend to be solitary, seeking cover under large rocks, logs, debris, or rubble; the largest individuals generally selected the largest cover available (USFWS 1987). Cook and Walton (2008) attempted to describe habitats used by the species, and their study indicated a habitat variable important to Nashville crayfish to be cover, particularly presence of large rocks. Nashville crayfish were found at least 50% of the time in runs, using rocks with a surface area of $0.05 m^2$ ($0.54 ft^2$) as cover, and at least 50% of the time in pools, when cover rock area increased to $0.10 m^2$ ($1.1 ft^2$). Larger rock areas may be needed in pools to decrease risk of predation, whereas smaller rock areas would provide adequate protection in runs (Cook and Walton 2008).

Reproductive females are typically found under large slab rocks. Females seek out large slab rocks when they are carrying eggs and young, and these secluded places are also needed for molting. Cover rocks of at least $0.02 m^2$ ($2.15 ft^2$) may be important habitats for females releasing broods and for protection during molting after releasing broods (USFWS 1987). Gravel-cobble substrate provided good cover for juveniles (Stark 1986, Miller and Hartfield 1985).

Nashville crayfish have also been found in atypical habitat types such as detention ponds and other impoundments. However, slab rock seems to be an important component of these habitat types as well. For example, in 2002, a five acre impoundment on a development site was considered to be unsuitable for Nashville crayfish, but during a pre-draining survey, a small area of rock habitat was found, and subsequent surveys conducted during the draining process yielded a total of more than 800 Nashville crayfish (USFWS 2017). Individuals were found throughout the pond in areas with slab rock on mud and silt substrate.

Species Redundancy

For the Nashville crayfish to maintain viability, the species needs to exhibit some degree of redundancy. Redundancy describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or return from catastrophic events (such as a rare destructive natural event or episode involving many populations). We measure redundancy for Nashville crayfish in terms of the number and distribution of resilient populations across the range of the species. It is important to note that Nashville crayfish has a naturally limited range, so measures of redundancy reflect the distribution within a relatively small area.

Species Representation

Representation describes the ability of a species to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species is capable of adapting to environmental changes. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluated representation based on the extent and variability of habitat characteristics across the geographical range. For the Nashville crayfish, we characterized representative units by using physical stream hydrology, and measure representation as the number of resilient populations within three delineated representative units (Figure 5). The representative units are catchments created in ArcMap by using flow direction, flow accumulation, and a 3-meter resolution digital elevation model. The three units have different stream and watershed characteristics, such as stream order, surrounding drainage landscapes, depth, and flow. These differences in hydrology in these three areas could result in differences in the species to adapt to changing environmental conditions.

CURRENT CONDITION

The available information suggests that the Nashville crayfish is restricted to the Mill Creek watershed, and the species still occupies large portions of its historic range. Below we assess current resilience, representation, and redundancy as they relate to population and habitat factors known to be important for species viability.

Assessing Population and Habitat Factors within Mill Creek Watershed

At the core of assessing viability for Nashville crayfish is assessing the current state of factors acting on resilience, redundancy, and representation. Figure 10 summarizes these factors, primary stressors acting on these factors, and the relationship of these factors and stressors on resilience. Below we summarize the current information on factors across the watershed, and later we use this information to assess resilience at the population level which is scaled up to the species level for redundancy and representation.

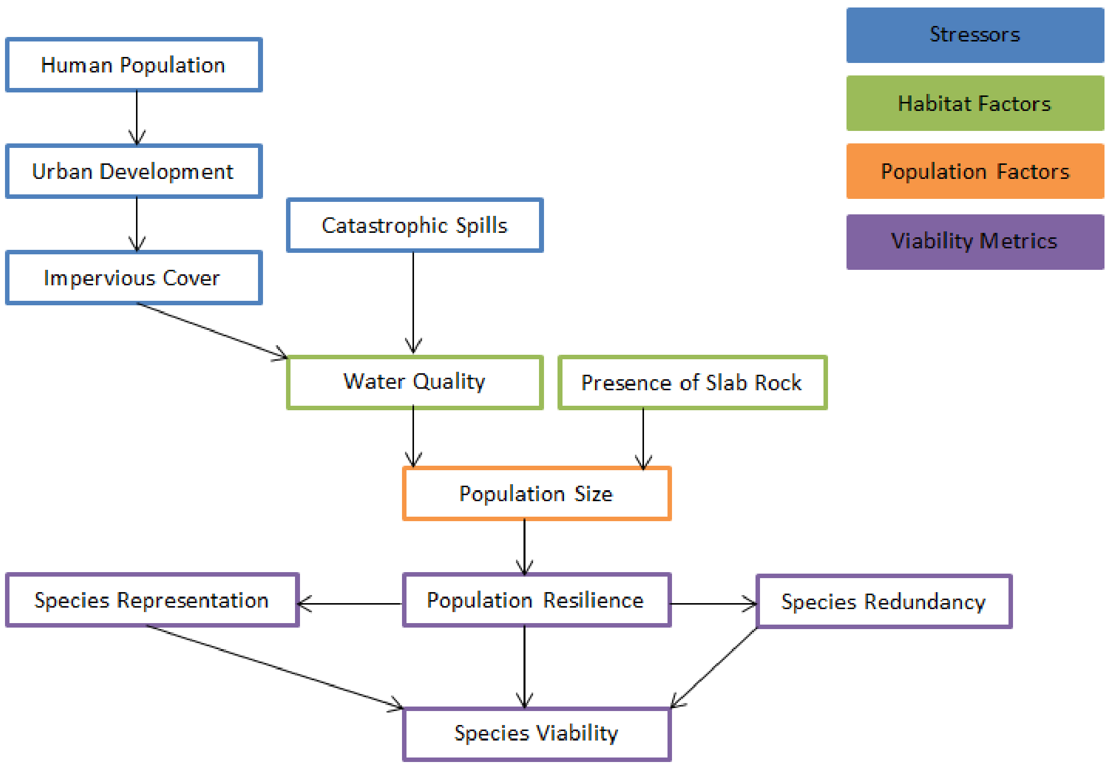


Figure 10—The effects of stressors on habitat and population factors and how these factors impact viability for Nashville crayfish.

Population size

The result of a 2002 mark/recapture study revealed population numbers of Nashville crayfish in Sevenmile Creek to be 404-1,425 individuals per 100 linear meters of stream. Estimates for Mill Creek were 1,854-3,217 individuals per linear meter. Overall, it was determined that population densities may have been as high as 1,000 to 2,000 individuals per 100 linear meters of stream (Carpenter 2002). Results of surveys conducted between 1988 and 2003 indicate that the

Nashville crayfish occurs primarily in the middle-to-upper reaches of the Mill Creek system. During that period, approximately 60 individuals were collected within the lower 5 mi of Mill Creek, while more than 5,400 individuals were collected at 16 sites between Mill Creek RM 7.5 and 20.5 (U.S. Fish and Wildlife Service 2011).

The Nashville Zoo received a Cooperative Agreement from the USFWS in 2011 to develop and implement long term monitoring protocols for the federally endangered Nashville crayfish in the Mill Creek watershed. Long-term population monitoring for this species is a recommendation in the USFWS Recovery Plan for the Nashville Crayfish, and is important to determine the status of the species over time.

The protocols were developed in collaboration with the TDEC, USFWS personnel from the Cookeville field office, and Nashville Zoo staff. In 2014, some minor changes were made to the Long Term Monitoring Protocols that included adding 2 new sampling sites in the main stem of Mill Creek. The 2 new sites were above and below a new bridge being constructed to determine its long term effects on Nashville crayfish populations. It was also decided that 2 tributary sites (Indian Creek, Sims Branch) would be removed from the protocol because Nashville crayfish were only found at very low densities at these sites. Therefore, the 2 tributary sites were not appropriate for the current methodology. Starting in 2015, Habitat Assessment Field Data Sheet-High Gradient Streams, Physical Characterization/Water Quality Data Sheet and a WPC field Survey Sheet documents were added to the Nashville Crayfish Long Term Population Monitoring Protocols. At all 5 main stem Mill Creek sampling sites surveyed, *O. shoupi* was the predominant species found, comprising more than 90% of all crayfish documented at those sites. A total of 1,763 crayfish have been documented while conducting the long term population monitoring.

As indicated in Table 3, the Service has estimated that approximately 54% (104 stream mi) of the 192 stream mi, which have the potential to support Nashville crayfish in the Mill Creek drainage, are currently occupied by the species.

Table 3. Percentages and miles of occupied crayfish habitat per stream reach designation from Figure 3.

STREAM REACH DESIGNATION	MILES OF STREAM REACH PER DESIGNATION	ESTIMATED MILES OF OCCUPIED HABITAT PER DESIGNATION (2)	ESTIMATED % OF HABITAT OCCUPIED (1)	OCCUPIED HABITAT AS % OF TOTAL DRAINAGE MILES (3)
Strong	58.3	40.8	70	21.3%
Good	73.6	44.2	60	23%
Fair	5.3	2.7	50	1.4%
Low	27	2.7	10	1.4%
Uncertain	28	14	50	7.3%
TOTALS	192	104		54%

(1) Percentage of occupancy based upon robustness and abundance.
(2) Determined from "Miles of Stream Reach by Designation" x "Estimated Percentage of Habitat Occupied" by Stream Reach Designation.
(3)Determined from "Estimated Miles of Occupied Nashville Crayfish Habitat By Stream Reach Designation" x 100% ÷ 192 total Mill Creek drainage miles.

Note: Uncertain = no survey data and presence in these areas is unknown

Water quality

As of 2014, 17 stream reaches in Mill Creek and its tributaries were listed as impaired on the State of Tennessee's 303(d) list (TDEC 2014). Impairment of stream reaches in the drainage is the result of low dissolved oxygen (DO), siltation, removal of riparian vegetation, nutrient enrichment and high bacteria levels from stormwater discharges, sewage collection system failures, land development and unrestricted cattle access (TDEC 2014). However, Nashville crayfish persist despite these water quality impairments (Figure 9).

Increases in urban and suburban development lead to increases in impervious surface, and increased impervious cover often leads to water quality degradation, including increases in phosphate and sediment loads, as well as suppression of dissolved oxygen. Impervious surfaces are unevenly distributed over the land surface and rapid development contributes to this watershed's impairment (Wang 2005). Subwatersheds dominated by urban land consistently contributed over half of the total phosphorus (TP) in Mill Creek during dry and wet weather periods. Both TP loads and concentrations increased downstream. Since runoff increases with impervious surfaces and urban runoff is a major contributor during peak discharge events, and the northern portion of the watershed has the densest distribution of single family homes and industrial settings, the source of urban inorganic orthophosphates (soluble reactive phosphorous) in downstream subwatersheds is most likely from over-fertilization of residential lawns.

Presence of slab rock

Although Nashville crayfish occupy a variety of habitat types within the Mill Creek watershed, the presence of slab rock is an important component of high quality habitat as it provides cover for individuals. Substrate in streams throughout the drainage consists of coarse gravel and bedrock in various combinations, and USFWS has estimated over 85% of the stream mileage to be potential habitat (Table 3), with the remaining 15% of stream mileage being uncertain. Surveys consistently note the presence of cobble and slab rock throughout the watershed (see population segment resilience section). Presence of slab rock and other forms of cover (e.g. cobble) does not appear to be limiting for Nashville crayfish.

Current Population Segment Resilience

Resiliency describes the ability of populations to withstand stochastic events (arising from random factors). 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.

We measured resiliency at the population segment level for this assessment. There are ten population segments across the range of the Nashville crayfish. Currently, six of these population segments display high resilience; two moderate resilience; and two low resilience (Table 4; Figure 11).

Table 4--Summary results of population segment resilience for Nashville crayfish. *Owl creek was an exception to our ranking criteria, which is explained in the population description in the next section.

Population Segment	% poor	% fair	% excellent + good	% Uncertain	Resilience Rank
Mainstem Mill Creek	0	0	38	62	High
Sevenmile Creek	0	0	100	0	High
Indian Creek	0	0	100	0	High
Holt Creek	0	0	14	86	High
Owl Creek	38	0	53	8	Moderate*
Collins Creek	0	0	100	0	High

Upper Mill Creek	0	0	100	0	High
Upper Mill Creek Streams	0	74	0	26	Moderate
Middle Mill Creek Streams	55	18	0	17	Low
Lower Mill Creek Streams	90	0	0	10	Low

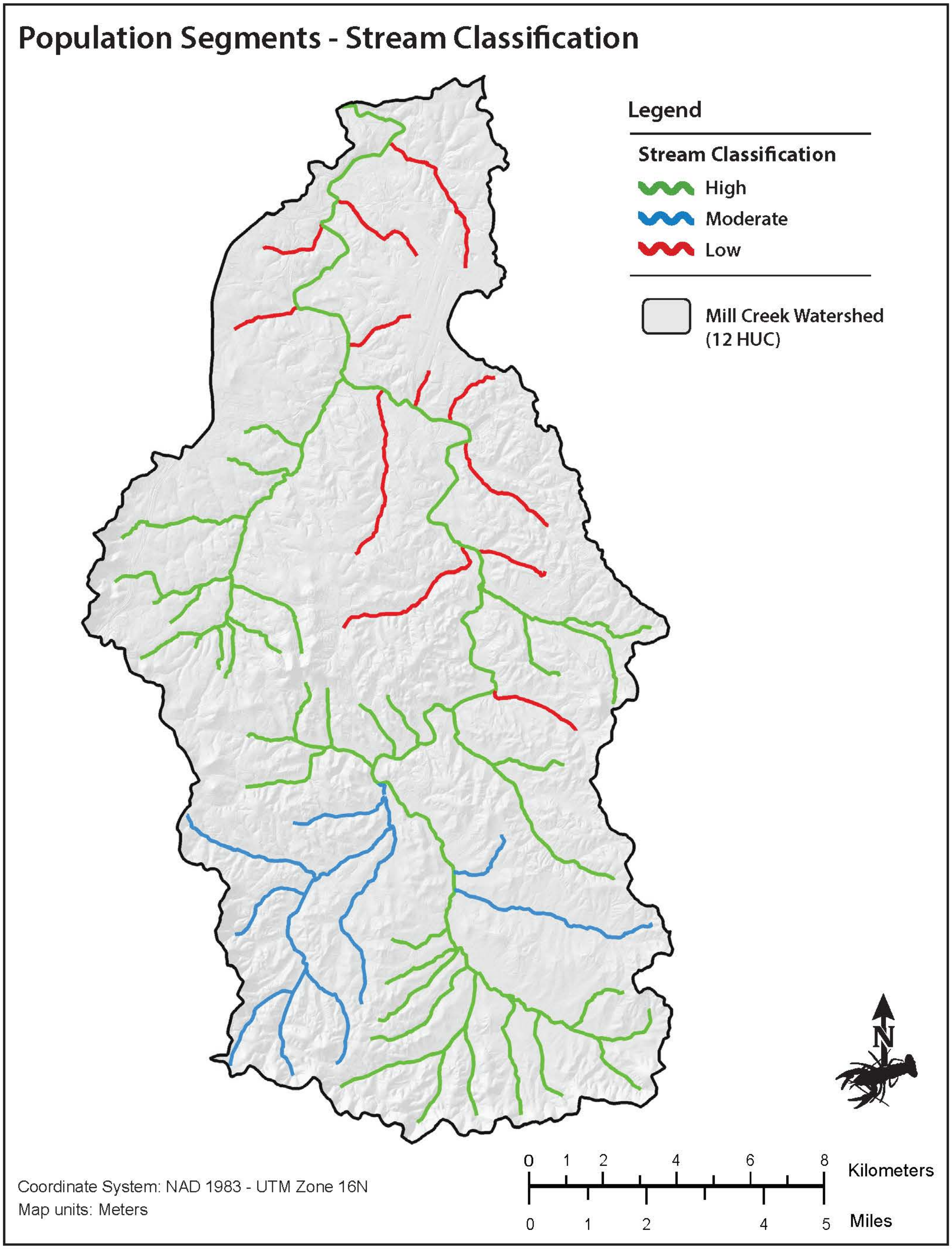


Figure 11—population segment resilience for Nashville crayfish.

Mainstem Mill Creek—

This population segment contains 22.5 miles of stream along the mainstem of Mill Creek. Surveys conducted from 1985-2014 noted 36 separate detections of Nashville crayfish. Population estimates for Nashville crayfish, based on surveys conducted from July 1999 through August 2001, ranged from 1,854 to 3,217 individuals per 100 m (328 ft) at various sites containing suitable habitat in mainstem Mill Creek.

Surveys provide some descriptions of the locations where Nashville crayfish were detected. Limestone was a common bedrock substrate and most locations were described as having adequate slabrock and/or cobble on bedrock or gravel substrate. Several sites were described as having excessive sedimentation, trash/refuse, and scrap metal. Much of the mainstem is fairly wide (10-12 meters at several locations), and is composed of several habitat types, including riffles, runs, gravel bars, and pools.

Element occurrence viability scores at the 36 detection locations (from surveys conducted between 1985-2014) included excellent (62%; n = 24), good (20%; n = 8), fair (8%; n = 3), and poor (2%; n = 1). Because 38% of stream segments were characterized as “strong” or “good”, 62% were characterized as uncertain, 82% of EO scores were either excellent or good, and experts agreed that the mainstem was some of the best habitat for Nashville crayfish, we have classified the population segment as high overall resilience.

Sevenmile Creek—

This population segment contains 40.3 miles of stream, including Sevenmile Creek, Brentwood Branch, and many other small tributaries. Because 100% of stream segments were characterized as “strong” or “good”, we have classified the population segment as high overall resilience.

Surveys conducted from 1994-2011 noted 16 separate detections of Nashville crayfish. Element occurrence viability scores at detection locations included excellent (44%; n = 7), good (38%; n = 6), and fair (18%; n = 3). Population estimates for Nashville crayfish, based on surveys conducted from July 1999 through August 2001, ranged from 404 to 1,425 individuals per 100 m at a site in Sevenmile Creek.

Surveys provided some descriptions of the locations where Nashville crayfish were detected. Most locations were described as having abundant slabrock on bedrock or cobble. A few locations were described as having excessive amounts of sediment, but most locations had moderate to no sedimentation. Most streams in this system are perennial tributaries to the mainstem of Mill Creek.

Indian Creek—

This population segment contains 11.4 miles of stream, including Indian Creek and other small tributaries. Because 100% of stream segments were characterized as "strong" or "good", we have classified the population segment as high overall resilience.

Surveys conducted from 2008-2009 noted 3 separate detections of Nashville crayfish. Element occurrence viability scores at detection locations were all excellent (100%; n = 3).

Surveys provided some descriptions of the locations where Nashville crayfish were detected. One site was described as having good physical habitat including slabrock on bedrock, but extensive algae buildup due to proximity a golf course. Another site was described as having very little vegetation with steep banks, heavy silt and cloudy water. However, large boulders and rocks were present with long linear pools and a high percentage of slabrock on bedrock.

Holt Creek— This population segment contains 8.4 miles of stream, including Holt Creek and other small tributaries. Fourteen precent of stream segments were characterized as "strong" or "good", and 86% were classified as "uncertain", so we used EO data and expert opinion to classify the population segment. As discussed below, EO data alone did not help determine a resilience classification, so we relied on species expert opinion. Habitat conditions are reported as being good throughout Holt Creek, and recent surveys have detected Nashville crayfish, so we classified Holt Creek as high resilience.

Surveys conducted from 2000-2016 noted 8 separate detections of Nashville crayfish. One of these detections was from a detention pond which was later thought to be extirpated, so we did not include in it in our ranking. Element occurrence viability scores at detection locations were excellent (29%; n = 2), good (14%; n = 1), fair (43%; n = 3), and not assessed (14%; n = 1).

Surveys provided some descriptions of the locations where Nashville crayfish were detected. One site was described as a first order tributary with good slabrock on bedrock or gravel. Other sites included: moderate sediment in quieter areas, clear in runs and glides; water in mostly pools with moderate sediment loads. The possibly extirpated site was described as a 5-acre pond impounded with significant slabrock on the eastern portion providing good habitat.

Owl Creek and Tributaries—

This population segment contains 20.3 miles of stream, including Owl Creek, Edmunson Branch and several other small tributaries. Fifty-three percent of stream segments were characterized as "good/strong", 38% were characterized as "low", and 8% as unclassified. Although greater than 50% of the stream mileage was classified as "good/strong", several other factors led us to classify the population segment as moderate overall resilience. First, a fairly high percentage of stream mileage was classified as low and uncertain (46%). Also, 17 out of 25 surveys (68%) conducted since 2005, have failed to detect Nashville crayfish. At locations where Nashville crayfish were detected, the EO viability scores were relatively high (see below). All of this, plus expert opinion resulted in classifying this population segment as moderate overall resilience.

Surveys conducted from 1999-2008 noted 13 separate detections of Nashville crayfish. Element occurrence viability scores at detection locations were excellent (15%; n = 2), good (54%; n = 7), and fair (31%; n = 4).

Surveys provided some descriptions of the locations where Nashville crayfish were detected. Habitat was described as a mix of bedrock or cobble, with many pools up to 2 feet deep, and closed canopy approaching 100% throughout. There was a detention basin estimated to be 5 acres with scattered slabrock on the margins providing habitat.

Collins Creek—

This population segment contains 13.3 miles of stream, including Collins Creek and several other small tributaries. Because 100% of stream segments were characterized as "strong" or "good", we have classified the population segment as high overall resilience.

Surveys conducted from 1994-2005 noted 7 separate detections of Nashville crayfish. Element occurrence viability scores at detection locations were excellent (14%; n = 1), good (57%; n = 4), and fair (14%; n = 1), and poor 14%; (n = 1).

Surveys provided some descriptions of the locations where Nashville crayfish were detected. Habitat was described as alternating sections of pools with cobble bottom, and slabrock on cobble or gravel. Nashville crayfish were detected in areas having little sedimentation and cobble substrates atop bedrock or in slabrock areas with reduced flow relative to the middle of the stream. One detection site was 4-6 meters wide with rock and slabrock on cobble and bedrock, with a wide slow moving pool.

Upper Mill Creek System—

This population segment contains 49.3 miles of stream, and includes the southern portion of the main stem of Mill Creek and many small tributaries. Because 100% of stream segments were characterized as "strong" or "good", we have classified the population segment as high overall resilience.

Surveys conducted from 1985-2009 noted 14 separate detections of Nashville crayfish. Element occurrence viability scores at detection locations were excellent (50%; n = 7), good (43%; n = 6), and fair (7%; n = 1).

Surveys provided some descriptions of the locations where Nashville crayfish were detected. Habitat was described as slabrock on cobble or gravel, and canopy varied from 50-75%. Several sites had apparent cattle activity (e.g. crossings), and one in particular was described as having severely eroded banks due to cattle, however the entire segment is to be restored by Tennessee Stream Mitigation Program in cooperation with the landowner.

Upper Mill Creek Streams—

This population segment is near the town of Nolensville and contains 5.01 miles of stream, including several small unnamed tributaries. Because 26% of stream segments were characterized as "uncertain", and 74% were characterized as "fair", we have classified the population segment as moderate overall resilience.

Surveys conducted from 2004-2005 noted 1 detection of Nashville crayfish. The element occurrence viability score at the detection location was fair. One other survey failed to detect any Nashville crayfish.

Surveys provided some descriptions of the locations where Nashville crayfish were surveyed. The areas surrounding one of the survey points is was agricultural pasture and the stream was full of filamentous algae. Another segment is downstream from a bridge, measured 15-20 cm deep, and pools briefly with rock and slabrock on cobble with minor amounts of cobble. Another section is 1-5 meters wide with some deeply incised channels and a substrate composition primarily bedrock with some rock and slabrock present.

Middle Mill Creek Streams

This population segment contains 9.25 miles of stream, and includes Whittemore Branch, Franklin Creek, Turkey Creek, and several other small unnamed tributaries. Because 27% of stream segments were characterized as "uncertain", 55% were characterized as "poor", and 17% were characterized as "fair", we have classified the population segment as low overall resilience.

Surveys conducted between 1985-2009 noted 8 separate detections of Nashville crayfish. Element occurrence viability scores at detection locations were good (62%; n = 5), fair (13%; n = 1), and poor (25%; n = 2).

Surveys provided some descriptions of the locations where Nashville crayfish were detected. Turkey Creek averages 1-5 meters wide, widening to 8-10 m with confluence to Mill Creek. Habitat was described as a mix of slabrock on bedrock or gravel. One segment at a confluence to Mill Creek mainstem was described as having moderate to no sedimentation but much filamentous algae, and substrate was small to medium limestone slabs. Another segment was described as having good habitat with a mix of slabrock on bedrock, but showing "urban funk" from surrounding development.

Lower Mill Creek Streams—

This population segment contains 12.2 miles of stream, and includes Sims Branch, Sorghum Branch, and several other small unnamed tributaries. Because 10% of stream segments were characterized as “uncertain”, and 90% were characterized as “poor”, we have classified the population segment as low overall resilience.

Surveys conducted from 1987-2009 noted 6 separate detections of Nashville crayfish. Element occurrence viability scores at detection locations were fair (50%; n = 3), and poor (50%; n = 3).

Surveys provided some descriptions of the locations where Nashville crayfish were detected. Habitat was described as slabrock on bedrock or gravel; shallow sections with rock and gravel and a deeper section with few rocks, reduced flow, and accumulated silt; slabrock over bedrock with some pools, riffles and glides; riffle with little to no sediment and substrate of small to medium size limestone slabs, gravel and rubble. Many sites were described as having good physical habitat but uncertain water quality, and displaying significant amounts of algae. Several sites displayed reduced flow and accumulated sediment. One site was an artificially widened stream channel in a business park with habitat consisting of slabrock on limited bedrock and mud.

Development activities have had significant impacts on these streams and have affected their aquatic communities. Although the species is still present, it is present at low densities. Small populations of Nashville crayfish have low resilience, leaving them particularly vulnerable to stochastic events.

Resilience Summary

There are 10 population segments across the range of the Nashville crayfish. Six of these population segments are highly resilient; two population segments are moderately resilient; and two population segments demonstrate low resilience (Table 5).

Table 5--Resilience summary for ten population segments of Nashville crayfish

Population Segment	Presence/Density	Water Quality	Slab Rock	Overall
Mainstem	Very High	Moderate	High	High
Sevenmile	Very High	Moderate	High	High
Indian Creek	Moderate	Low	High	High
Holt Creek	High	Low	High	High
Owl Creek	Moderate	Low	Moderate	Moderate
Collins Creek	Moderate	Low	High	High

Upper System	Moderate	High	High	High
Upper Streams	Low	High	High	Moderate
Middle Streams	Low	Low	High	Low
Lower Streams	Low	Low	High	Low

Current Species Representation

Representation describes the ability of a species to adapt to changing environmental conditions. We lack genetic and ecological diversity data to characterize representation for Nashville crayfish. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the geographical range. Thus, we characterized representative units (MC-A, MC-B, and MC-C) by using physical stream hydrology. Differences in hydrology in these three areas could result in differences in the species to adapt to changing environmental conditions. Because the mainstem population segment crosses representative unit boundaries, we report representation as the percentage of stream miles categorized as low, moderate, and high, within each representative unit. Current representation is high because the majority of stream mileage in each representative unit is of high resilience.

- MC-A: There are 61.8 total stream miles in MC-A, which is the southernmost representative unit. Of those, 49.6 miles of stream are portions of population segments classified as high resilience (80%); 12.2 miles of stream are of low resilience (20%).
- MC-B: There are 72.6 total stream miles in MC-B, the central representative unit. This includes 43.6 miles of stream are portions of population segments classified as high resilience (60%); 9.3 miles of stream are of low resilience (13%); 19.7 miles of stream are of moderate resilience (27%).
- MC-C: There are 57.1 total stream miles in MC-C, which is the northern most representative unit. This includes 52.1 miles of stream are portions of population segments classified as high resilience (91%); 5.0 miles of stream are of low resilience (9%).

Current Species Redundancy

Redundancy describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations). We report redundancy for Nashville crayfish as the total number and resilience of population segments and their distribution within and among representative units.

There are 10 population segments distributed across the range of the Nashville crayfish within all representative units. Six of these population segments are highly resilient; two population segments are moderately resilient; and two population segments are low resilience. Currently, there appears to be adequate redundancy for Nashville crayfish to withstand catastrophic events, although the species range is relatively small (i.e. limited to Mill Creek watershed).

INFLUENCES ON VIABILITY

The primary threat to the continued existence of the Nashville crayfish is still development in the Mill Creek drainage that results in destruction or alteration of the aquatic habitat. Increased development in the watershed leads to increased impervious cover, and increases in impervious cover often lead to water quality deterioration. Siltation, stream alteration, and urban runoff, particularly phosphorus, resulting from development pressures in urbanized areas surrounding Nashville, all have the potential to negatively impact Nashville crayfish. The species' limited distribution also makes it vulnerable to catastrophic events, such as chemical spills or other contamination sources. Development in the watershed has led to an increase in road density and potential contaminant sources, which in turn increase the probability of a catastrophic spill. Finally, competition with invasive crayfish species could be problematic, but as of now, this is not a known threat for the species.

Development activities in the northern part of the watershed, and the associated tributaries have had significant impacts on the streams and have affected their aquatic communities. New construction often results in the removal of riparian vegetation and disturbance to streambeds. Heavy development due to the close proximity to Nashville, as well as toxic spills due to the close proximity to Nashville International Airport, are likely factors contributing to the low resilience of the middle and lower Mill Creek stream population segments.

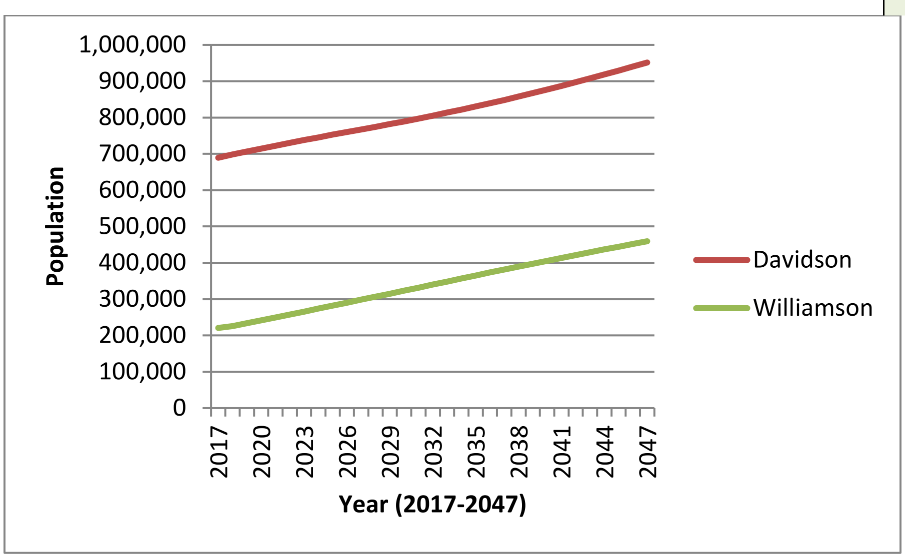
The upper reaches of the Mill Creek drainage are located in areas that were historically in agricultural production. Currently, the headwaters of Mill Creek flow primarily through rural, sparsely populated, agricultural lands. Although there have been recent increases in development throughout the watershed, the population segments near the headwaters remain on the low end of the development spectrum. There is plenty of habitat available for the Nashville crayfish in these areas, and they occupy much of the system in the upper reaches of Mill Creek. Water quality is not as degraded, and generally, Nashville crayfish have reduced threats in this area.

Increasing Human Population:

Increasing human populations drive development, and Middle Tennessee is expected to lead the state in population growth under current projections. The population of Davidson County has grown by 5.1 percent between 2010 and 2013. Adjacent Williamson County has grown by 8.6 percent in the same time period. Five of the ten counties with the highest projected growth rates through 2040—Williamson, Rutherford, Wilson, Robertson, and Sumner—are in the Nashville metropolitan area. Approximately 69% of the population growth in Tennessee from 2010 to 2040 is expected to occur in 10 counties across the state, including Davidson and Williamson counties (Boyd Center 2015). As Nashville and surrounding areas have grown, commercial and residential developments have increased within the Mill Creek drainage. Populations in both Williamson and Davidson counties are expected to increase dramatically in the next 30 years (Boyd Center 2015 Population Projections). With an increase in population, there will be an increase in conversion of

YEAR	Davidson	Williamson
2017	689,338	220,746
2018	698,061	225,526
2019	706,549	233,580
2020	714,756	241,597
2021	722,665	249,605
2022	730,404	257,635
2023	737,985	265,689
2024	745,443	273,792
2025	752,810	281,940
2026	760,080	290,153
2027	767,308	298,409
2028	774,587	306,707
2029	782,010	315,035
2030	789,590	323,389
2031	797,357	331,775
2032	805,339	340,122
2033	813,530	348,478
2034	821,939	356,786
2035	830,580	365,060
2036	839,414	373,284
2037	848,458	381,473
2038	857,753	389,600
2039	867,300	397,633
2040	877,108	405,614
2041	887,166	413,497
2042	897,438	421,310
2043	907,905	429,036
2044	918,580	436,703
2045	929,414	444,311
2046	940,410	451,878
2047	951,526	459,398

open space to more impervious cover, with a subsequent increase in roads and other associated infrastructure.



The Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade (SLEUTH) models run by Gulf Coast Prairie LCC for the Southeastern United States, predict urban growth, and reveal a few high growth areas in the Mill Creek watershed (Figure 12: urban growth by 2040). Besides further expansion of the Nashville Metropolitan area in the northern portion of the watershed, Nolensville is predicted to be an area of high urban growth in the more rural southern portion of the watershed. The Town of Nolensville, located in northeast corner of Williamson County, has historically been a rural area with a small business district on the main highway, State Route 11, Nolensville Road. From a population of 1,702 in 1990 and 2,313 in 2000, the town had grown to 5,861 by 2010 (2010 Census), a change from year 2000 to 2010 of 153%. Based on average new dwelling units built per year between October 2010-2013, the town's average population per occupied household (3.26), and assuming the same annual rate of growth, the estimated population for Nolensville in 2035 is 20,202. A key factor influencing growth in the Nolensville area is the availability of a public sewer trunk line provided by the Metro Nashville Department of Water and Sewerage Services. This trunk line is providing adequate capacity to service the area within most of the current municipal boundaries as well as the land area within the urban growth boundary. The economic attraction of Williamson County and the Nashville Metropolitan area continues to contribute heavily to the current growth and is expected to continue attracting new residents and businesses to the Nolensville area. Other high growth areas for urban growth potentially impacting Nashville crayfish include the cities of Brentwood and Franklin in and near the western portion of the watershed.

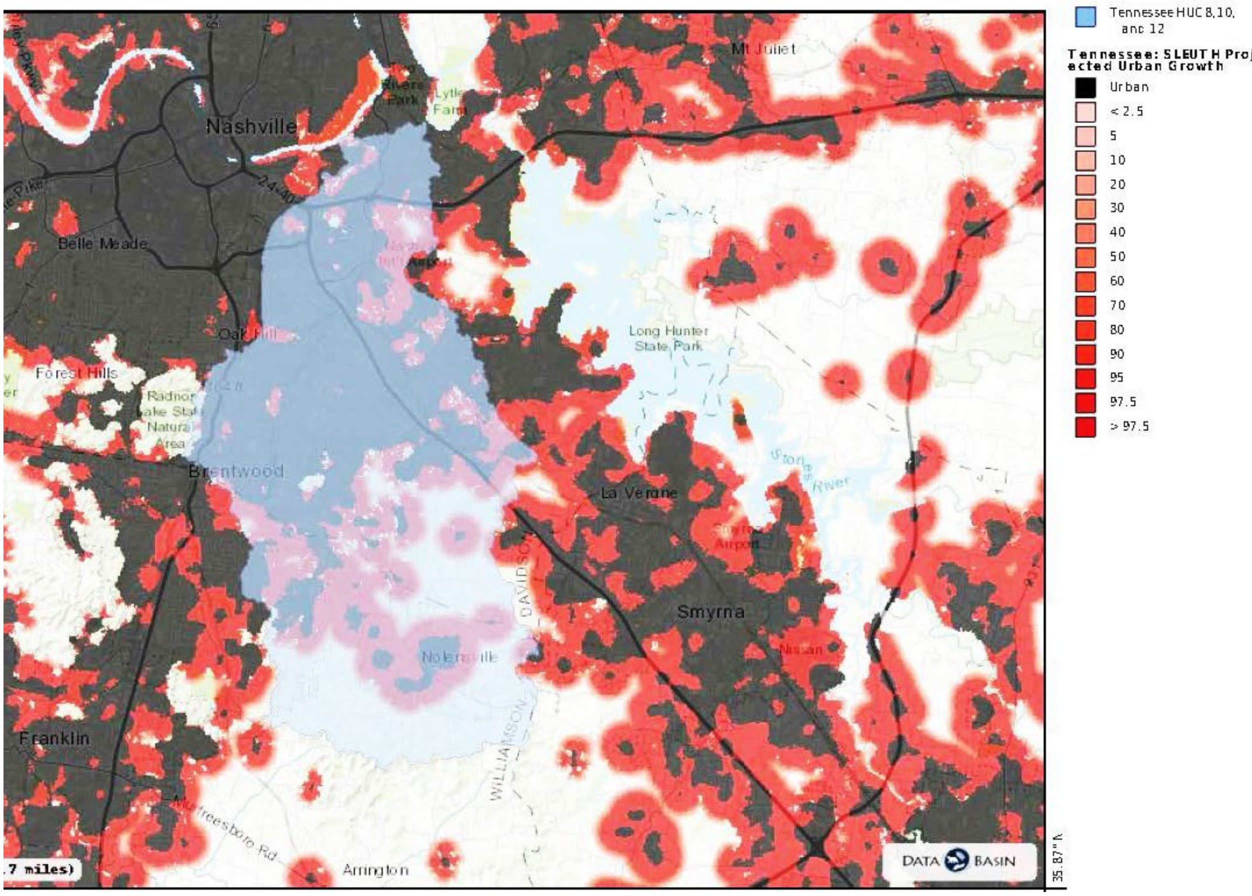


Figure 12—SLEUTH model predictions for % urban development in 2040 in the Mill Creek watershed and surrounding areas.

Increases in Impervious Cover and Impacts to Water Quality

The headwaters of Mill Creek flow primarily through rural, sparsely populated, agricultural lands. The lower reach, however, is located within the heavily developed metropolitan area of Nashville. This has resulted in large amounts of impervious cover in the northern portion of the watershed and substantially less impervious cover in the southern portion (Figure 13). As the city has grown, development has spread toward the headwaters of the drainage and agricultural lands have been increasingly converted to residential and commercial developments. Because much of the watershed has been converted from agricultural to residential uses, Mill Creek has been crossed numerous times to service buried utilities necessary for these developments. Such activities potentially pose a threat to the survival of the species in the area, and inappropriate fracturing of bedrock could easily result in the loss of still pools occupied by the species during much of the summer.

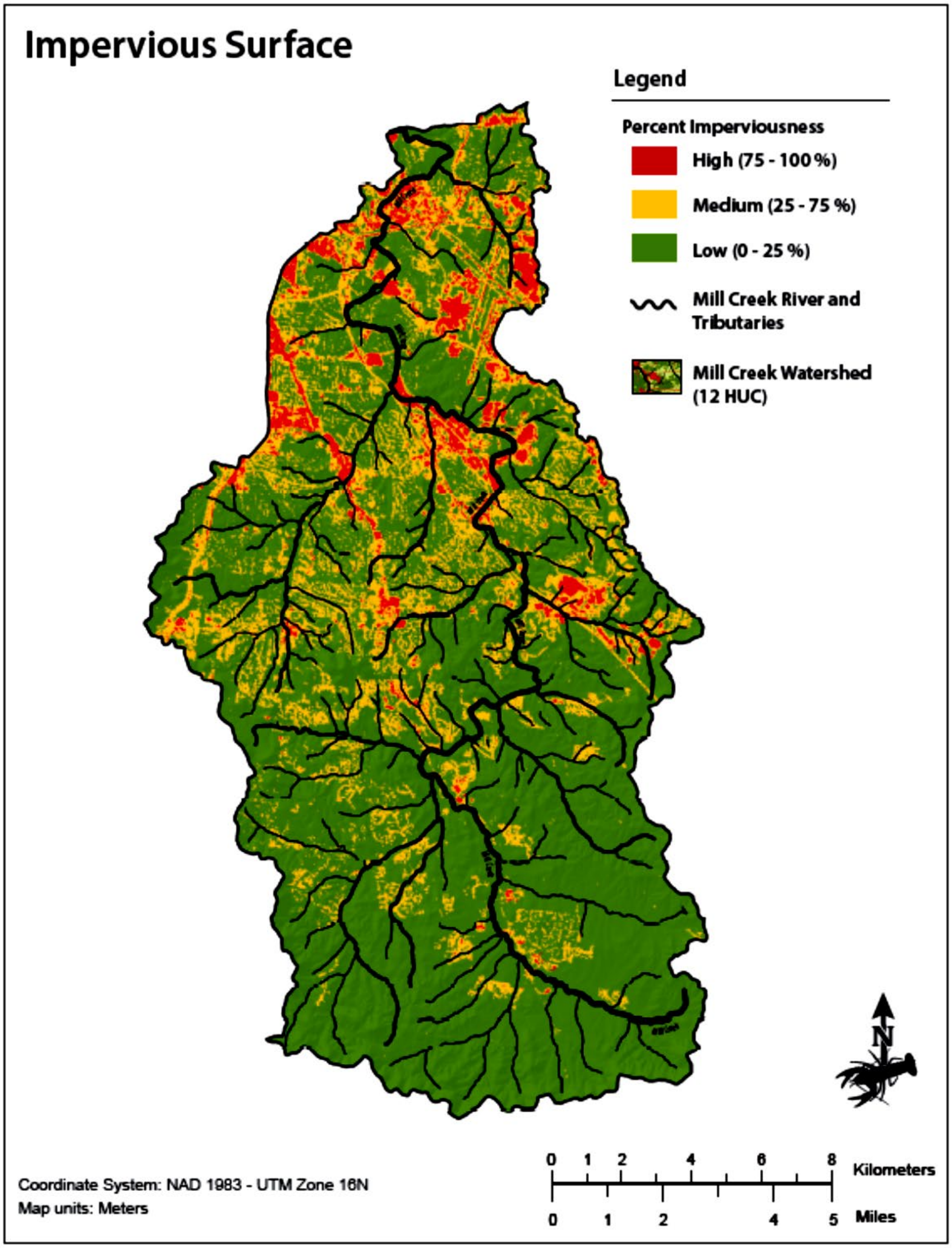


Figure 13--Current impervious cover in the Mill Creek Watershed and surrounding areas.

Stream reaches in the lower portion of the watershed (Davidson County, Tennessee) have been heavily impacted by urban development. Commercial, residential, and industrial construction has affected the stream and encroached on the floodplain. Potable water, gravity sewer, natural gas, electricity, cable television and telephone utility lines have been constructed along and across Mill Creek and its tributaries to provide those utilities to homes, businesses and industrial facilities. These development activities have had significant effects on streams (e.g. siltation and degradation of water quality) in the drainage and their aquatic communities.

Development continues to expand within the drainage (Figure 14), including within the upper reaches of Mill Creek and its tributaries, which are undergoing increasing amounts of residential development. These activities are likely resulting in continued degradation of water quality. Development activities in the Mill Creek drainage have had significant impacts on the streams and affected their aquatic communities. New construction often results in the removal of riparian vegetation and disturbance to streambeds. For example, the headwater reach of Sims Branch, a Mill Creek tributary, was filled during construction activities at the Nashville International Airport.

Areas in the upper reaches of the Mill Creek drainage that were once rural agricultural areas are now being developed for residential purposes. Runoff from denuded areas can result in heavy input of sediment into the stream and lack of canopy cover which may result in bank collapse, excessive in-stream sediment deposition, and increased water turbidity and temperatures. Sediment has been shown to abrade and or suffocate bottom-dwelling algae and other organisms by clogging gills and reducing aquatic insect diversity and abundance (Waters 1995).

Highway and road construction, as well as utility line construction and rights-of-way maintenance, within and adjacent to streams may alter or destroy habitat. Short-term dewatering to excavate trenches for utility lines may result in temporary loss of habitat. Sediment settling and filling in crevices and interstitial spaces under slab rocks may result in increased biological oxygen demand and longer term or permanent loss of habitat for crayfish (Cook and Walton 2008).

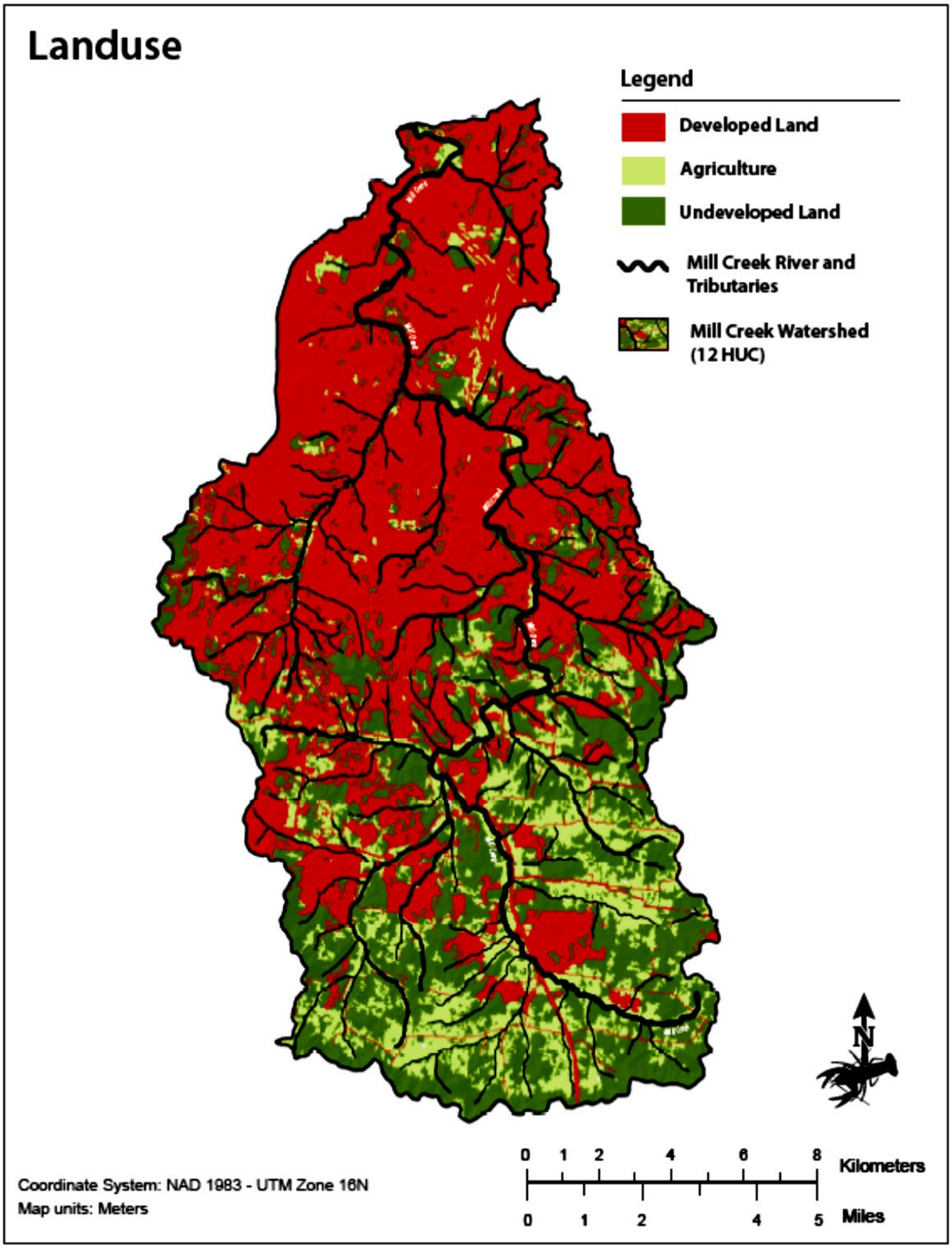


Figure 14--Current land use in Mill Creek Watershed. Developed land includes lands classified as low, medium and high development; Agriculture includes lands classified as hay or pasture; Undeveloped includes lands classified as some type that is not developed, agriculture, or open water

Another significant threat to the species' continued existence is the improper use or overuse of lawn pesticides and fertilizers. Intentional or inadvertent application of chemicals to the stream or runoff from yards after application has resulted in significant mortality of aquatic organisms, including Nashville crayfish. Periodic reports of mortality of stream fauna that likely resulted from input of pesticide into streams in the Mill Creek drainage are received. This threat is likely to increase in the future as residential development increases.

The upper reaches of the Mill Creek drainage (Williamson County, Tennessee) are located in an area that was historically rural, and its tributaries have been impacted by runoff from the agricultural lands through which they flow. Streams were affected by runoff of pesticides and fertilizers from crop fields and organic matter (manure) from livestock pastures. Water quality was reportedly degraded by organic enrichment and considered poor (U.S. Army Corps of Engineers 1984). Livestock using the streams as sources of drinking water likely contributed to streambank erosion and subsequent sedimentation. Although this portion of the Mill Creek drainage is still largely rural, the area is undergoing an increasing amount of development, primarily residential, as Nashville continues to expand southward. These new developments typically result in removal of riparian vegetation and runoff of sediment and pollutants from construction sites. The streams also continue to receive runoff of pesticides and fertilizers from home sites and the remaining agricultural lands.

As of 2014, 17 stream reaches in Mill Creek and its tributaries were listed as impaired on the State of Tennessee's 303(d) list (TDEC 2014). Impairment of stream reaches in the drainage is the result of low dissolved oxygen, siltation, removal of riparian vegetation, nutrient enrichment, high bacteria levels from stormwater discharges, sewage collection system failures, land development, and unrestricted cattle access (TDEC 2014).

Table 6--Water impairments in the Mill Creek Watershed from the 2014 303(d) list

Waterbody	Miles Impaired	Cause	Pollutant Source
Sims Branch	1.5	Phosphorus; DO; E Coli	Discharges from MS4 area Industrial Permitted Stormwater
Sims Branch	1.4	Propylene Glycol; DO	Discharges from MS4 area Industrial Permitted Stormwater
Finley Branch	1.2	E Coli; Phosphorus	Discharges from MS4 area

Collins Creek	6.7	Siltation; alteration of vegetation	Discharges from MS4 area Land development
Indian Creek	5.7	Phosphorus; E Coli	Discharges from MS4 area Pasture Grazing
Owl Creek	15.96	Phosphorus; Siltation; alteration of vegetation	Discharges from MS4 area
Mill Creek	3.5	Phosphorus; Siltation; alteration of vegetation; DO	Discharges from MS4 area Collection system failure
Holt Creek	6.2	Phosphorus; E Coli; Nitrate+Nitrite	Discharges from MS4 area
Whittemore Branch	2.9	E Coli	Discharges from MS4 area
Sorghum Branch	3.1	Siltation; E Coli	Discharges from MS4 area
Sevenmile Creek	2.4	DO; E Coli; Nitrate+Nitrite; Phosphorus	Discharges from MS4 area
Cathy Jo Branch	1.1	Phosphorus; Siltation; alteration of vegetation; Nitrate+Nitrite	Discharges from MS4 area Collection system failure
Pavillion Branch	1.3	E Coli	Discharges from MS4 area
Mill Creek	4.0	Phosphorus; Siltation; DO	Discharges from MS4 area Collection system failure
Mill Creek	5.9	Phosphorus; Siltation; DO	Discharges from MS4 area Collection system failure
Mill Creek	8.1	Phosphorus; Siltation; DO; E Coli	Unrestricted cattle access Pasture Grazing

Catastrophic Spills

The Nashville crayfish's limited geographic range and apparent small population size leaves the species somewhat vulnerable to localized extinctions from accidental toxic chemical spills or other stochastic disturbances. Potential sources of such spills include accidents involving vehicles transporting chemicals over road crossings of streams inhabited by Nashville crayfish and accidental or intentional release into streams of chemicals used in industrial, agricultural, or residential applications. Dead crayfish, including Nashville crayfish, have been collected by various agency personnel downstream from construction sites and sewage releases on numerous occasions in the past. In 2010 and 2011, discharges of propylene glycol de-icing fluids from the runways and tarmac at the Metropolitan Nashville International Airport adversely affected Sims Branch. An attempt to translocate these individuals to the Cumberland River Aquatic Center failed as the specimens died during transport. The TDEC and the U.S. Fish and Wildlife Service's Tennessee Field Office developed specific recommendations for stormwater treatment, monitoring, and compliance to the Metropolitan Nashville Airport Authority (MNAA). Civil Clean Water Act (CWA) penalties were also assessed by TDEC. In cooperation with the Service and our partners, MNAA made substantial improvements to the stormwater collection and treatment system at their facility. The TFO also provided specific recommendations to TDEC in the revision of MNAA's National Pollutant Discharge Elimination System permit after the incidents.

To avoid direct adverse impacts to the crayfish and its habitat, developers increasingly utilize directional boring under the stream as a means of accomplishing crossings for utility and communication lines; however, if not done properly, boring can cause fracturing of the stream bottom. This can result in release of bentonite and other slurries, as well as toxic materials from the bore hole into the stream. Dewatering of short or long reaches of the stream channel downstream from the fracture may also occur. Dewatering can be permanent if the fracture causes the entire surface flow to go underground. Materials released into the stream from bore holes range from inert slurries to potentially toxic chemicals and lubricants; however, inert slurry, if released in large amounts, could result in mortality to crayfish and other benthic fauna by smothering adults and juveniles. During installation of fiber optic cables in 2000 in the Mill Creek drainage, several incidents of fracturing occurred resulting in the release of large amounts of bentonite slurry into the streams. In 2013, a Piedmont Natural Gas Pipeline boring under Sevenmile Creek in a tributary fractured the underlying bedrock, releasing a bentonite slurry which resulted in mortality of six individuals. Due to these incidents, areas where known bedrock fracturing potential exist are now being trenched (surface cut) for projects involving utility line crossings.

The TDEC and Metropolitan Nashville Water Services (MNWS) routinely issue Clean Water Act Notice of Violations for incidents in the Mill Creek watershed. Service Law Enforcement personnel have assisted in numerous investigations; however, formal prosecutions are rarely pursued. In 2011, a contractor constructing a replacement sewage force main (i.e. a device that moves wastewater under pressure by using pumps or compressors in lift stations) bypassed a section of an existing sewage force main by pumping past the section of force main to be replaced. Over the extended holiday weekend, the pump failed releasing a significant amount of sewage to Mill Creek. Crayfish mortality was observed; however, Service Law Enforcement did not pursue an ESA enforcement action since this was an accidental release.

Current and future spill risk can be associated with road crossings and road density (Figure 15), because more vehicles with potential contaminants would be in close proximity of streams. Also, a variety of other potential contaminant sources can be found throughout the watershed. These sources include landfills, wastewater treatment facilities, and hazardous waste sites reported via National Pollutant Discharge Elimination System (NPDES), Resource Conservation and Recovery Act (RCRA), and Storage and Retrieval data warehouse (STORETS). Because more developed areas are associated with greater road density and more potential contaminant sources, we can predict that the risk of a catastrophic spill increases as areas become more developed.

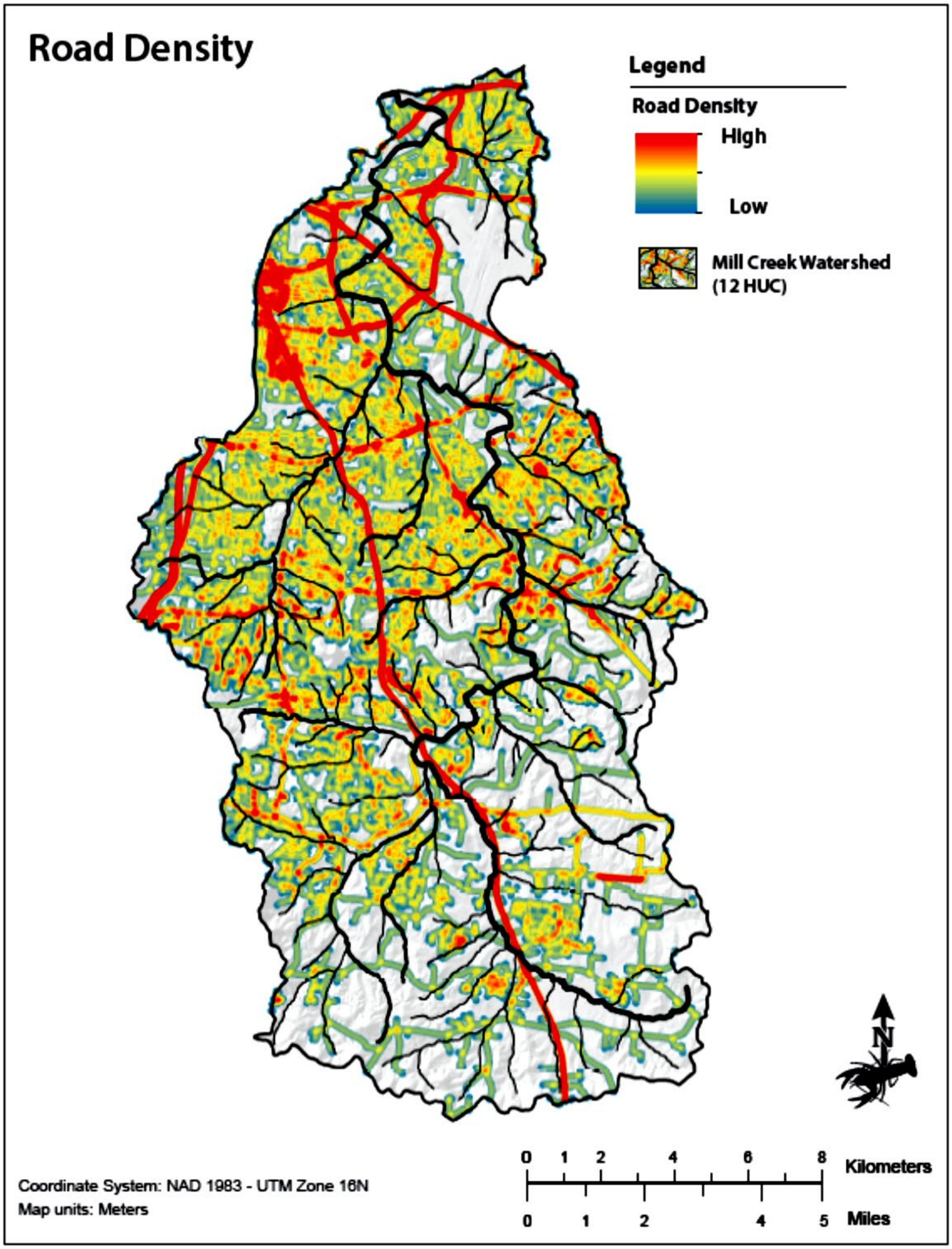


Figure 15--current road density throughout the Mill Creek Watershed.

Competition with Invasive Crayfish

Many crayfish experts now believe the introduction of invasive crayfish species such as the rusty crayfish (*Orconectes rusticus*) to be the greatest threat to native species, especially species with small distributions. In east Tennessee, there have been several introductions; the most serious is the Kentucky River crayfish (*O. juvenilis*) which has replaced the surgeon crayfish (*O. forceps*) in most of the Holston River system above Cherokee Reservoir. It is conceivable that one of these extremely aggressive species could be introduced into the Mill Creek system and, once established, there is no known method to remove them. A simple aquarium release of a single ovigerous female or other live specimens would be detrimental to the Nashville crayfish. Nashville crayfish are not currently threatened by other invasive crayfish species, but it is a potential future threat.

Assessment of Current Threats

We used the most recent U.S. Geological Survey National Land Cover Database (NLCD) spatial data to quantify land use-land cover and impervious cover within 100 meters of the stream for each of the 10 delineated population segments by using zonal statistics in ArcMap. These data allow us to qualitatively assess potential water quality risk for each of the population segments.

We used ArcMap to summarize road density and potential contaminant sources within each of the 10 delineated population segments, which allow us to qualitatively assess potential catastrophic spill risk. Table 9 summarizes the current potential spill risks (contaminant source < .5 miles from stream; road density) by population segment.

There does not seem to be any strong correlations between increased levels of impervious cover or development and resilience levels of Nashville crayfish. However, in both low resilience populations, there are high amounts of impervious cover and development, plus a high density of roads and potential contaminant sources. Given the history of catastrophic spills in the lower mill creek population segment, particularly at the airport, it is likely that these spills are the main factor impacting population resilience in this area.

Table 7--summary statistics for impervious cover in each of the 10 population segments. Values were derived from zonal statistics and represent impervious cover within 100 meters of the stream.
*--Population Segment includes current resilience rank as H (high), M (moderate), or L (low)
1—IMP_LOW is the percentage of the landscape within 100 m of the stream that is between 0-25% impervious.
2—IMP_MED is the percentage of the landscape within 100 m of the stream that is between 26-75% impervious.
3—IMP_HIGH is the percentage of the landscape within 100 m of the stream that is between >75% impervious.
4—MEAN IMP is the mean impervious cover of the landscape within 100 m of the stream

Population Segment*	IMP_LOW[1]	IMP_MID[2]	IMP_HIGH[3]	Mean_IMP[4]
Holt Creek (H)	76	23	1	12.76
Mainstem Mill Creek (H)	79	15	6	14.89
Owl Creek (M)	94	6	0	4.32
Sevenmile Creek (H)	75	21	4	16.81
Upper Mill Creek System (H)	96	4	0	2.64
Collins Creek (H)	72	22	6	18.32
Indian Creek (H)	97	3	0	1.92
Lower Mill Creek Streams (L)	60	31	9	26.23
Middle Mill Creek Streams (L)	76	21	3	15.61
Upper Mill Creek Streams (M)	98	2	0	0.88

Table 8--summary statistics for land use in each of the 10 population segments. Values were derived from zonal statistics and represent land use within 100 meters of the stream.
*--Population Segment includes current resilience rank as H (high), M (moderate), or L (low)
1—% Developed is the percentage of the landscape within 100 m of the stream that is classified developed.
2—% Undeveloped is the percentage of the landscape within 100 m of the stream that is classified as some type that is not developed, agriculture, or open water.
3—% Agriculture is the percentage of the landscape within 100 m of the stream that is classified as hay or pasture

Population Segment	% Developed[1]	% Undeveloped[2]	% Agriculture[3]
Holt Creek (H)	49.19	33.32	17.49
Mainstem Mill Creek (H)	48.27	35.73	16.00
Owl Creek (M)	29.94	41.25	28.81
Sevenmile Creek (H)	68.03	25.61	6.37
Upper Mill Creek System (H)	13.52	38.98	47.50
Collins Creek (H)	53.71	36.43	9.86
Indian Creek (H)	8.10	49.63	42.26
Lower Mill Creek Streams (L)	78.33	17.50	4.17
Middle Mill Creek Streams (L)	62.35	32.28	5.37
Upper Mill Creek Streams (M)	5.09	45.68	49.24

Table 9--summary statistics for contaminant sources, road-stream crossings, and road density for each of the 10 population segments.
*--Population Segment includes current resilience rank as H (high), M (moderate), or L (low)
1—contaminant sources include all landfills, wastewater treatment facilities, and hazardous waste sites reported via NPDES, RCRA, and STORETS within 0.5 miles of streams.
2—road density was done by intersecting the roads within a 100 m stream buffer and dividing the total length of the roads (miles) by the total area of the buffer ($miles^2$).

Population Segment*	Contaminant sources[1]	Road Density[2]
Holt Creek (H)	1 (0.1/mile)	10.88
Mainstem Mill Creek (H)	35 (1.5/mile)	8.72
Owl Creek (M)	1 (0.05/mile)	5.72
Sevenmile Creek (H)	13 (0.3/mile)	13.23
Upper Mill Creek System (H)	1 (0.02/mile)	4.55
Collins Creek (H)	6 (0.4/mile)	9.12
Indian Creek (H)	0 (n/a)	3.83
Lower Mill Creek Streams (L)	49 (4.01/mile)	11.09
Middle Mill Creek Streams (L)	8 (0.86/mile)	10.71
Upper Mill Creek Streams (M)	0 (n/a)	4.31

Conservation Measures in the Mill Creek Watershed

The Service issued a programmatic biological opinion in 2010, and the Army Corp of Engineers was issued reasonable and prudent measures that are necessary to minimize impacts of incidental take to Nashville crayfish from development activities. These reasonable and prudent measures include evaluating potential effects to the species through site-specific consultation, fill permit applications subject to review with protection of Nashville crayfish in mind, implementating measures to minimize or eliminate effects from construction activities (e.g. removal and relocation of Nashville crayfish in the area), and ensuring the level of take of Nashville crayfish is adequately monitored and reported to the Service.

The Mill Creek Watershed Association (MCWA) was formed in 2009 by a collaboration of organizations with a common goal. The MCWA was rejuvenated in 2013 by the Cumberland River Compact with the support of the Tennessee Department of Agriculture Division of Forestry. Their common goal is to provide education and support for improving and protecting the Mill Creek Watershed. The Mill Creek Watershed Association endeavors to clean the water in Mill Creek, work to eliminate water pollution in local neighborhoods, and make the water safe for wildlife and human use. Focal activities for the MCWA include adopt a stream, riparian buffers, pollution prevention, rain gardens and barrels, and protecting the Nashville crayfish.

The Cumberland River Compact sponsors meetings every other month to bring all interested stakeholders together to reach a realistic approach to ensure a brighter future for the Mill Creek Watershed. These meetings provide stakeholders an opportunity to learn and provide perspective on current conditions, recommendations for improvements, and plan activities to address the current concerns and needs in the Watershed. Current participants include Cumberland River Compact, Tennessee Department of Agriculture, Division of Forestry , Metro Water Services, Nashville Zoo at Grassmere, Tennessee Department of Environment & Conservation, Tennessee Scenic Rivers Association, Tennessee Wildlife Resources Agency, US Army Corps of Engineers, and the Service.

The Tennessee Stream Mitigation Program (TSMP) was established under the Tennessee Wildlife Resources Foundation in 2002 as a state wide in-lieu fee program. The TSMP provides mitigation by improving in-stream and riparian habitat and overall water quality. It funds projects on significantly degraded streams to arrest bank erosion, improve water quality, and restore aquatic and riparian habitat. The TSMP has implemented 28 projects, restoring over 45 miles of degraded stream and over 800 acres of riparian habitat.

The TSMP initiated a restoration project in the Mill Creek Watershed in 2009. The project encompasses 2,385 feet of Mill Creek near Nolensville in Williamson County, Tennessee. The existing channel was highly degraded due to channelization, vegetation removal, and infrastructure including roadway fills, and has been listed on the 303(d) list due to impacts from unrestricted livestock access. The degradation of this reach was particularly concerning as it provides habitat for the Nashville crayfish. The primary goals of the project were to improve water quality, restore channel stability, enhance aquatic habitat, and restore riparian buffer function by eliminating non-point source pollutants such as sedimentation and nutrients by excluding livestock from the channel and riparian corridor; elimination of accelerated bank erosion problems; reestablishment of in-stream habitat by restoring bed form diversity in the form of riffles and pools; and enhancement of the riparian zone by planting native plants. The restored riparian buffer will decrease stream temperatures. The floodplain basins will help improve water quality, decrease peak flows, and provide valuable flood plain habitat.

The Nashville Zoo at Grassmere has been heavily involved in Nashville crayfish recovery efforts. In March 2017, the Nashville Zoo, in collaboration with the Cumberland River Compact, Tennessee Wildlife Resource Agency, and KCI Technologies Inc., removed two dams on Cathy Jo Branch. Dam removal allows for the migration of aquatic species which were previously blocked by dams within a watershed and improves aquatic biodiversity, including the Nashville crayfish. The dams located on zoo property created a barrier to crayfish, small fish and other small aquatic life which prevented the migration of aquatic species upstream and reduced the biodiversity of the aquatic systems. These dam removals opened up three miles of habitat and transformed the stream into a free-flowing system again. The Nashville Crayfish now has access to ten miles of creek and improved habitat.

The Nashville Zoo has also implemented a zoo stormwater management project that benefits Nashville crayfish and other aquatic organisms. The Nashville Zoo had a stormwater detention pond on the edge of Zoo property that served to capture stormwater runoff from a large office park next door to the Zoo, but several times a year, excess water is discharged from the pond's outlet pipe, where it carries sediment and other pollutants into Cathy Jo Branch. There are also issues with runoff from the office park damaging the perimeter fence and carrying trash and debris into the pond. The project retrofitted the detention pond to modify the two inlets structures and expand the water holding capacity of the pond. In addition, the brushy area below the outfall pipe became an infiltration zone to slow, spread, and soak in the excess water discharges after rain events. Ultimately, this project has directly improved water quality in known occupied Nashville crayfish habitat. Also, educational programs are now provided about this project and other stormwater practices for development professionals, homeowners, and other interested parties.

FUTURE CONDITIONS

Our analysis of threats and risk factors, as well as the past, current, and future influences on what the Nashville crayfish needs for long term viability revealed that there are two influences that pose the largest risk to future viability of the species. These risks are primarily related to habitat changes: the risk of a catastrophic spill and impairment of water quality. We did not assess overutilization for scientific and commercial purposes, disease, or competition with invasive crayfish because these risks do not appear to be occurring at a level that affects Nashville crayfish populations. The risk of a catastrophic spill and impairment of water quality, as well as management efforts, are carried forward in our assessment of the future conditions of Nashville crayfish populations and the viability of the species overall. Qualitative assessments of urban development for each population segment are based on SLEUTH model predictions.

We assess viability out to the year 2040 under three scenarios: status quo, worst case, and conservation. We chose 2040 for several reasons. First, the metrics representing the main threats influencing viability for Nashville crayfish (human population growth, impervious cover, and urban development) are all available at this timeframe. Also, the EO scores that underlie the resilience of the population segments were determined based on a 20-30 year future time horizon. We think a 20-25 year foreseeable future is appropriate for this species.

The future scenario assessment has sought to understand how viability of the Nashville crayfish may change over the course of 20-30 years in the terms of resilience, representation, and redundancy. To account for considerable uncertainty associated with future projections, we defined three scenarios that would capture the breadth of changes likely to be observed in the Mill Creek Watershed to which the Nashville crayfish will be exposed. These scenarios considered three elements of change: water quality, catastrophic spill risk, and conservation effort. While we consider these scenarios plausible, we acknowledge that each scenario has a different probability of materializing at different time steps. To account for this difference in probability, a discretized range of probabilities was used to describe the likelihood a scenario will occur (Table 10). We assume rates of human population increase and increases in impervious cover to be similar across all three scenarios, thus the differences in the likelihood of the three scenarios (Table 11) represent our best assessment of (1) the degree to which projected increases in human population and impervious cover will manifest in water quality degradation and increased spill risk (2) how the Nashville crayfish will actually respond to these changes based on past observations, and (3) how likely conservation measures will be implemented within population segments in the Mill Creek Watershed.

Confidence Terminology	Explanation
Very likely	Greater than 90% certain
Likely	70-90% certain
As likely as not	40-70% certain
Unlikely	10-40% certain
Very unlikely	Less than 10% certain

Table 10**.** Explanation of confidence terminologies used to estimate the likelihood of a scenario (after IPCC guidance, Mastrandrea et al. 2011)

	Status Quo	Worst Case	Conservation
20-30 years	Likely	Unlikely	As likely as not

Table 11. Likelihood of a scenario occurring in 20-30 years.

Status Quo Scenario

Under the status quo scenario, the factors that are having an influence on populations of Nashville crayfish (e.g. human population growth, urban development, impervious cover, and catastrophic spills) continue at current rates. Human population increases at currently predicted rates, which leads to substantial increases in urban development and impervious cover in a few high intensity areas throughout the watershed (e.g. Nolensville, Brentwood and areas immediately east of Franklin). In this scenario, the risk of a contaminant spill increases in and around the high urban growth areas. Also, the increase in human population and impervious cover results in some decreases in water quality.

Worst Case Scenario

Under the worst case scenario, the factors that are having an influence on populations of Nashville crayfish continue at current rates like the status quo scenario. Human population increases at currently predicted rates, which leads to substantial increases in urban development and impervious cover in the same high intensity areas throughout the watershed as the status quo. In this scenario, effects associated with increasing human populations and impervious cover (water quality degradation and catastrophic spill risk) are much greater in magnitude compared to the status quo scenario. The risk of a contaminant spill increases significantly in the urban and suburban high-growth areas. Also, increases in human population and impervious cover result in substantial decreases in water quality in several population segments. We include this scenario because there is a lot of uncertainty as to the magnitude of effects on water quality and spill risk of a growing human population and the subsequent increases in impervious cover.

Conservation Scenario

Under the conservation scenario, the factors that are having an influence on populations of Nashville crayfish continue at current rates, but targeted conservation ameliorates some of the associated impacts of water quality degradation. Human population increases continue at currently predicted rates, leading to increases in urban development and impervious cover in a few high-intensity areas throughout the watershed. In this scenario, the risk of a contaminant spill increases in and around some of the urban growth areas, and increases in population and impervious cover result in some decreases in water quality. However, if targeted conservation actions are implemented, including riparian protection and restoration, water quality degradation in some streams could be reduced.

Mainstem Mill Creek

	Population Size	Water Quality	Presence of Slabrock	Overall Resilience
Current	Very High	Moderate	High	High
Status Quo	Very High	Moderate	High	High
Worst Case	High	Low	High	Moderate
Conservation	Very High	Moderate	High	High

Table 12—Assessment of mainstem mill creek population and habitat factors and their impact on overall resilience for current condition, and under 3 future scenarios (out to year 2040).

Status Quo Scenario-- Under the status quo scenario, the mainstem population segment experiences moderate human population growth, particularly in the northern portion of the stream. This population is currently in an urbanized area, so the increases in population are not expected to result in further drastic water quality reductions or increased contaminant spill risk. We expect slabrock to remain abundant in the mainstem, providing plenty of potential habitat for Nashville crayfish to occupy. Resilience of this population segment is expected to remain high.

Worst Case Scenario-- Under the worst case scenario, human population growth is moderate, and plenty of potential habitat is expected to be available for occupancy as in the status quo scenario. In this scenario, increases in population are expected to result in further water quality reductions. Increases in road density and other associated infrastructure will result in an increased contaminant spill risk. Resilience of this population segment is expected to drop from high to moderate.

Conservation Scenario-- Under the conservation scenario, human population growth is moderate, and potential habitat availability is expected to be high. Human population growth is not expected to result in drastic water quality reductions or increased contaminant spill risk for several reasons. First, a 2009 poll conducted by the Human Dimensions Research Lab at University of Tennessee showed that 90% of Tennessee residents view protecting water quality in rivers and streams as extremely important. Also, the City of Nashville has plans to expand green spaces and vegetated buffers along streams in areas around the northern portion of the Mill Creek watershed that would remove pollutants, reduce soil erosion, and slow down storm water runoff (The Conservation Fund 2011). Resilience of this population segment is expected to remain high.

Sevenmile Creek

	Population Size	Water Quality	Presence of Slabrock	Overall Resilience
Current	Very High	Moderate	High	High
Status Quo	Very High	Moderate	High	High
Worst Case	High	Low	High	Moderate
Conservation	Very High	Moderate	High	High

Table 13—Assessment of sevenmile creek population and habitat factors and their impact on overall resilience for current condition, and under 3 future scenarios (out to year 2040).

Status Quo Scenario-- Under the status quo scenario, the Sevenmile population segment experiences moderate human population growth, particularly in the western portion of the streams near the city of Oak Hill. This population is currently in a suburban area, so the increases in population are not expected to result in drastic water quality reductions or increased contaminant spill risk. Runoff from fertilizer use is a primary concern in this suburban area. Slabrock is expected to remain abundant in Sevenmile, providing plenty of potential habitat for Nashville crayfish to occupy. Resilience of this population segment is expected to remain high.

Worst Case Scenario-- Under the worst case scenario, human population growth is moderate, and potential habitat availability is expected to be high. Potentially drastic water quality reductions are expected from fertilizer use, and increases in road density and other associated infrastructure will result in an increased contaminant spill risk. Resilience of this population segment is expected to drop from high to moderate.

Conservation Scenario-- Under the conservation scenario, as with the previous two scenarios, the Sevenmile population segment experiences moderate human population growth, and potential habitat availability is expected to remain high. Increases in human population are not expected to result in drastic water quality reductions or increased contaminant spill risk. Although runoff from fertilizer use is a concern, riparian conservation and restoration could minimize nutrient input to a certain extent. Resilience of this population segment is expected to remain high.

Indian Creek

	Population Size	Water Quality	Presence of Slabrock	Overall Resilience
Current	Moderate	Low	High	High
Status Quo	Moderate	Low	High	High
Worst Case	Moderate	Low	High	Moderate
Conservation	Moderate	Moderate	High	High

Table 14—Assessment of Indian creek population and habitat factors and their impact on overall resilience for current condition, and under 3 future scenarios (out to year 2040).

Status Quo Scenario-- Under the status quo scenario, the Indian Creek population segment experiences light-moderate human population growth. Based on 40-year projections for future land use in the Nashville Metro Area, this population is expected to be predominantly residential agriculture, multi-family residential, and open space. Because increases in development and impervious cover are anticipated to be relatively low, impacts to water quality and risk of spills is anticipated to be low. Slabrock is expected to remain abundant in Indian creek, providing plenty of potential habitat for Nashville crayfish to occupy. Resilience of this population segment is expected to remain high.

Worst Case Scenario-- Under the worst case scenario, human population growth is light-moderate and potential habitat availability is expected to be high. As with the status quo scenario, this population is expected to be predominantly residential agriculture, multi-family residential, and open space. Population growth is expected to have some negative impacts to water quality and spill risk, but these effects are anticipated to be minimal. Resilience of this population segment is expected to remain high.

Conservation Scenario-- Under the conservation scenario, as with the previous two scenarios, the Indian Creek population segment experiences light-moderate human population growth and potential habitat availability is expected to be high. Negative impacts to water quality are expected to be minimal, and alleviated by targeted conservation in riparian buffers or general agricultural best management practices for water quality (i.e. soil testing, selective grazing, etc). Spill risk is assumed to be low due to low population growth projections. Resilience of this population segment is expected to remain high.

Holt Creek

	Population Size	Water Quality	Presence of Slabrock	Overall Resilience
Current	High	Low	High	High
Status Quo	High	Low	High	High
Worst Case	High	Low	High	High
Conservation	High	Moderate	High	High

Table 15—Assessment of Holt creek population and habitat factors and their impact on overall resilience for current condition, and under 3 future scenarios (out to year 2040).

Status Quo Scenario-- Under the status quo scenario, the Holt Creek population segment experiences low-moderate degrees of human population growth. This population is currently just outside of the boundaries of the town of Brentwood, and 40-year projections show the western portion of this population segment will see higher rates of population growth and land use conversion. Land use conversion and increases in road density will likely result in slight reductions in water quality, and slight increases in catastrophic spill risk, but the majority of this population segment would be unchanged. Slabrock is expected to remain abundant in Holt Creek, providing plenty of potential habitat for Nashville crayfish to occupy. Resilience of this population segment is expected to remain high.

Worst Case Scenario-- Under the worst case scenario, as with the status quo scenario, the Holt Creek population segment human population growth and land conversion will be highest just outside of the boundaries of the town of Brentwood. This land conversion is anticipated to negatively impact water quality in the western portion of this population segment, but Holt Creek in general will see low levels of growth and development. Increases in road density will likely result in slight increases in catastrophic spill risk, but only in the western portion of the population segment. Potential habitat availability is expected to remain high in Holt Creek. Although negative impacts are predicted, the impacts are predicted to be localized, and the majority of the streams will remain in good condition. Resilience of this population segment is expected to remain high.

Conservation Scenario-- Under the conservation scenario, as with the previous two scenarios, human population growth and land conversion will be highest in the western portion of the population segment, and potential habitat availability throughout Holt Creek is expected to remain abundant. Negative impacts to water quality are expected to be minimal, and spill risk is assumed to be similar to the status quo scenario. Negative impacts to water quality in the western portion of this segment can be ameliorated through targeted conservation, including riparian conservation and general water quality best management practices. Resilience of this population segment is expected to remain high.

Owl Creek

	Population Size	Water Quality	Presence of Slabrock	Overall Resilience
Current	Moderate	Low	Moderate	Moderate
Status Quo	Moderate	Low	Moderate	Low
Worst Case	Low	Low	Moderate	Low
Conservation	High	Low	Moderate	Moderate

Table 16—Assessment of Owl creek population and habitat factors and their impact on overall resilience for current condition, and under 3 future scenarios (out to year 2040).

Status Quo Scenario-- Under the status quo scenario, the Owl Creek population segment experiences high population growth and high levels of land conversion from urban development. Urban sprawl is anticipated from the nearby cities of Brentwood and Franklin, affecting the western and southern portions of this segment. Because 40-year land use projections show a dramatic increase in industrial and commercial uses adjacent to streams within this segment, there will likely be drastic water quality reductions and increased contaminant spill risk. We expect slabrock to remain abundant, providing plenty of potential habitat for Nashville crayfish to occupy, but water quality conditions may not be conducive to their occupation. Resilience of this population segment is expected to drop from moderate to low under a status quo scenario.

Worst Case Scenario-- Under the worst case scenario, as with the status quo scenario, human population growth and land conversion are anticipated to be high, particularly in the western and southern portions of this segment near the cities of Brentwood and Franklin. Drastic water quality reductions and increased contaminant spill risk are anticipated. Potential habitat availability is expected to remain high, but water quality is not expected to be conducive to their occupation at moderate-high densities. Resilience of this population segment is expected to drop from moderate to low.

Conservation Scenario-- Under the conservation scenario, as with the previous two scenarios, human population growth and land conversion will be highest in the southern and western portion of the population segment, and this has the potential to negatively impact water quality and spill risk. Conservation measures, such as riparian maintenance and restoration, will be important to avoid drastic water quality reductions and increased contaminant spill risk. Potential habitat is expected to be available throughout the population segment, so maintaining or improving water quality conditions is important to ensure occupation. Resilience of this population segment is expected to remain moderate under a conservation scenario.

Collins Creek

	Population Size	Water Quality	Presence of Slabrock	Overall Resilience
Current	Moderate	Low	High	High
Status Quo	Moderate	Low	High	High
Worst Case	Moderate	Low	High	Moderate
Conservation	Moderate	Low	High	High

Table 17—Assessment of Collins creek population and habitat factors and their impact on overall resilience for current condition, and under 3 future scenarios (out to year 2040).

Status Quo Scenario-- Under the status quo scenario, the Collins Creek population segment experiences moderate human population growth. This population is currently in a suburban area, and 40-year projections show the area to be dominated by single family residential homes. The increases in population are not expected to result in drastic water quality reductions or increased contaminant spill risk. Runoff from fertilizer use is a primary concern in this suburban area. Slabrock is expected to remain abundant in Collins Creek, providing plenty of potential habitat for Nashville crayfish to occupy. Resilience of this population segment is expected to remain high.

Worst Case Scenario-- Under the worst case scenario, as with the status quo scenario, human population growth and land conversion are anticipated to be moderate, and potential habitat is expected to be available throughout the population segment. Water quality reductions are anticipated from significant increases in nutrient inputs from fertilizer use. Increases in road density and other associated infrastructure will result in an increased contaminant spill risk. Resilience of this population segment is expected to drop from high to moderate.

Conservation Scenario-- Under the conservation scenario, as with the previous two scenarios, human population growth and land conversion are anticipated to be moderate, and potential habitat is expected to be available throughout the population segment. Runoff from fertilizer use is a primary concern in this suburbanized area, but maintaining riparian vegetation would ameliorate some of these inputs. There is an expected increase in spill risk associated with an increase in road density, but given that most of this area is anticipated to be residential with minimal commercial development, the increased spill risk is expected to be minimal. Resilience of this population segment is expected to remain high.

Upper Mill Creek System

	Population Size	Water Quality	Presence of Slabrock	Overall Resilience
Current	Moderate	High	High	High
Status Quo	Moderate	Low	High	Moderate
Worst Case	Moderate	Low	High	Moderate
Conservation	Moderate	High	High	High

Table 18—Assessment of Upper Mill Creek System population and habitat factors and their impact on overall resilience for current condition, and under 3 future scenarios (out to year 2040).

Status Quo Scenario-- Under the status quo scenario, the Upper Mill Creek System population segment experiences high degrees of human population growth. This population is currently in an area with low levels of urbanization, but the town of Nolensville has been growing at a rate of 153% (2000-2010), and the rate of increase is projected to remain constant or increase. These increases in population are expected to result in water quality reductions and increased contaminant spill risk due to increases in impervious cover and road density, particularly a dramatic increase in projected commercial development. Slabrock is expected to remain abundant, providing plenty of potential habitat for Nashville crayfish to occupy. Resilience of this population segment is expected to drop from high to moderate.

Worst Case Scenario-- Under the worst case scenario, as with the status quo scenario, human population growth and land conversion are anticipated to be low in most of the segment, but high in and around the town of Nolensville. Water quality reductions and increased contaminant spill risk are anticipated due to high levels of commercial development and road density in Nolensville and immediately surrounding areas. Potential habitat is expected to be available throughout the population segment, with lower densities expected near Nolensville. Resilience of this population segment is expected to drop from high to moderate.

Conservation Scenario-- Under the conservation scenario, as with the previous two scenarios, human population growth and land conversion are anticipated to be low in most of the segment, but high in and around the town of Nolensville. Although some water quality reductions and increased contaminant spill risk are expected, focused conservation in and around Nolensville would reduce much of the water quality concerns, and there are many miles of streams that will not see these high rates of urban encroachment. Potential habitat is expected to be available throughout the population segment. Resilience of this population segment is expected to remain high.

Lower Mill Creek Streams

	Population Size	Water Quality	Presence of Slabrock	Overall Resilience
Current	Low	Low	High	Low
Status Quo	Low	Low	High	Low
Worst Case	Low*	Low	High	Low
Conservation	Moderate	Moderate	High	Moderate

Table 19—Assessment of Lower Mill Creek Streams population and habitat factors and their impact on overall resilience for current condition, and under 3 future scenarios (out to year 2040). *-Sims Branch could be extirpated under this scenario.

Status Quo Scenario-- Under the status quo scenario, the Lower Mill Creek Streams population segment experiences moderate-high population growth in an already heavily populated area. This population is currently in an urbanized area with lots of commercial infrastructure, including Nashville International Airport, resulting in poor water quality and high risk of contaminant spills. There have already been several catastrophic spills in this population segment, and more spills are likely. We expect slabrock to remain abundant, providing plenty of potential habitat for Nashville crayfish to occupy, but poor water quality will lead low crayfish occupancy and density. Resilience of this population segment is expected to remain low.

Worst Case Scenario-- Under the worst case scenario, as with the status quo scenario, human population growth and land conversion are anticipated to remain moderate-high, and commercial infrastructure such as the Nashville International Airport will remain significant stressors on water quality. Catastrophic spills are likely in this scenario. Potential habitat is expected to be available throughout the population segment for Nashville crayfish to occupy, but poor water quality will negatively impact occupancy and density. Resilience of this population segment is expected to remain low, with potential local extirpation at Sims Branch, a stream in near proximity to the airport.

Conservation Scenario-- Under the conservation scenario, as with the previous two scenarios, human population growth and land conversion are anticipated to remain moderate-high. There have already been several catastrophic spills in this population segment, particularly Sims Branch, but conservation measures will ensure spills are less likely. The TDEC and the TFO made recommendations for stormwater treatment, monitoring, and compliance to the Metropolitan Nashville Airport Authority (MNAA). In cooperation with the Service and other partners, MNAA made substantial improvements to the stormwater collection and treatment system at their facility. The TFO also provided specific recommendations to TDEC in the revision of MNAA's National Pollutant Discharge Elimination System permit after the incidents. If Sims Branch was to be restored, and future airport spills avoided, this population segment has plenty of good habitat to be occupied. In fact, crayfish are routinely found in Sims Branch, but at low densities. We expect plenty of potential habitat to be available for Nashville crayfish to occupy. Resilience of this population segment is expected to improve to moderate under a conservation scenario.

Upper Mill Creek Streams

	Population Size	Water Quality	Presence of Slabrock	Overall Resilience
Current	Low	High	High	Moderate
Status Quo	Low	High	High	Moderate
Worst Case	Low	Moderate	High	Moderate
Conservation	Moderate	Moderate	High	High

Table 20—Assessment of Upper Mill Creek Streams population and habitat factors and their impact on overall resilience for current condition, and under 3 future scenarios (out to year 2040).

Status Quo Scenario-- Under the status quo scenario, the Upper Mill Creek Streams population segment experiences low-moderate degrees of human population growth. This population is currently outside of the boundaries of the town of Nolensville, which is one of the fastest growing areas in Williamson County. Because increases in population are expected to be low-moderate, water quality reductions and contaminant spill risk are not expected to significantly increase. Slabrock is expected to remain abundant, providing plenty of potential habitat for Nashville crayfish to occupy, although crayfish are found at somewhat low densities in this segment. Resilience of this population segment is expected to remain moderate.

Worst Case Scenario-- Under the worst case scenario, as with the status quo scenario, human population growth and land conversion are anticipated to be low in most of the segment, but moderate near to the town of Nolensville. Water quality reductions and contaminant spill risk are expected to increase, but these risks are localized. Potential habitat is expected to be available throughout the population segment. Resilience of this population segment is expected to remain moderate.

Conservation Scenario-- Under the conservation scenario, as with the previous two scenarios, human population growth and land conversion are anticipated to be low in most of the segment, but moderate near to the town of Nolensville. There is already good conservation work happening in this segment. In an area near the mainstem where banks are severely eroded and the riparian vegetation is highly degraded, the Tennessee Stream Mitigation Program in partnership with the owner (Turnberry Homes) is doing restoration work that is anticipated to benefit the Nashville crayfish. Because water quality reductions and spill risk are expected to be minimal, and restoration work is already in progress, the resilience of this population segment is expected to increase to high.

Middle Mill Creek Streams

	Population Size	Water Quality	Presence of Slabrock	Overall Resilience
Current	Low	Low	High	Low
Status Quo	Low	Low	High	Low
Worst Case	Low	Low	High	Low
Conservation	Low	Low	High	Low

Table 21—Assessment of Middle Mill Creek Streams population and habitat factors and their impact on overall resilience for current condition, and under 3 future scenarios (out to year 2040).

Status Quo Scenario-- Under the status quo scenario, the Middle Mill Creek Streams population segment experiences moderate-high population growth. This population segment is already heavily developed and SLEUTH models predict high levels of urban development to occur in the eastern and northern portions of this segment. Turkey creek is the only stream that currently has low urbanization and impervious cover, and SLEUTH models predict it will remain at those low levels by 2050. Because of these patterns of development, water quality degradation and spill risk is expected to remain high in all streams except Turkey creek. Slabrock is expected to remain abundant, providing plenty of potential habitat for Nashville crayfish to occupy, although reduced water quality may result in low density. Resilience of this population segment is expected to remain low.

Worst Case Scenario-- Under the worst case scenario, as with the status quo scenario, human population growth and land conversion are anticipated to remain high in all streams except for Turkey Creek, resulting in an overall reduction in water quality and increase in catastrophic spill risk. Potential habitat is expected to be available throughout the population segment for Nashville crayfish to occupy, but poor water quality will negatively impact occupancy and density in all streams except for Turkey Creek. Resilience of this population segment is expected to remain low.

Conservation Scenario-- Under the conservation scenario, as with the previous two scenarios, human population growth and land conversion are anticipated to remain high in all streams except for Turkey Creek. Conservation measures implemented at the Nashville airport (as described above in the Lower Mill Creek Streams population segment) will ensure spills are less likely in the northern most unnamed tributary. Riparian conservation and restoration would help reduce the impact of runoff, and ultimately alleviate further water quality reductions. We expect plenty of potential habitat to be available for Nashville crayfish to occupy, but several of the streams would still likely have crayfish at low densities. Resilience of this population segment is expected to improve slightly, but remain low under a conservation scenario.

Viability Summary

We used the best available information to forecast the likely future condition of the Nashville crayfish. Our goal was to describe the viability of the species in a manner that will address the needs of the species in terms of resiliency, representation, and redundancy. We considered the possible future condition of the species. We considered three potential scenarios that we think are important influences on the status of the species. Our results describe a range of possible conditions in terms of how many and where Nashville crayfish populations are likely to persist into the future (Table 10).

Table 22—Resilience summary for population segments, currently, and under 3 scenarios out to 2040.

Population Segment	Current	Status Quo	Conservation	Worst Case
Mainstem	High	High	High	Moderate
Sevenmile	High	High	High	Moderate
Indian Creek	High	High	High	High
Holt Creek	High	High	High	High
Owl Creek	Moderate	Low	Moderate	Low
Collins Creek	High	High	High	Moderate
Upper System	High	Moderate	High	Moderate
Lower Streams	Low	Low	Moderate	Low
Upper Streams	Moderate	Moderate	High	Moderate
Middle Streams	Low	Low	Low	Low

The Nashville crayfish faces risks from degraded water quality and catastrophic spills associated with increasing human populations and urbanization. However, the species has been in found in large numbers at several locations that are already heavily developed, and the species has been found in several additional tributaries to Mill Creek since its original listing under the ESA. Although the Metropolitan Nashville area is experiencing significant growth, with numerous residential, commercial, utility, and other infrastructure developments occurring in the watershed, Nashville crayfish populations have been documented to be stable or increasing in size. Additionally, there have been consistent stormwater and sediment inputs to the Mill Creek watershed, as well as frequent spills/releases of raw sewage and hazardous substances, yet the Nashville crayfish persists in high numbers. The species exhibits a high degree of resistance to disturbance, indicating the species has a low susceptibility to threats and a high degree of stability.

Because the species has a naturally limited range, and there is increasing development pressures projected in the future, the species will continue to experience unquantifiable threats. Targeted conservation can ameliorate threats associated with reductions in water quality, but even under a status quo and worst case scenario, all population segments are predicted to persist within a 40 year time frame.

Under a status quo scenario—we would expect the Nashville crayfish's viability to be characterized by a small loss in population resiliency (Owl Creek drops from moderate to low; Upper Mill Creek System drops from high to moderate), with no loss in redundancy. Representation is impacted in that the two populations predicted to lose resiliency, are both in the same representative unit, but all representative units are predicted to retain the same number of populations.

Under a worst case scenario—we would expect the Nashville crayfish's viability to be characterized by a moderate losses in population resiliency (Mainstem, Sevenmile, Collins Creek, and Upper Mill Creek System drop from high to moderate; Owl Creek drops from moderate to low; possible extirpation of Sims Branch in the Lower Mill Creek Streams population segment), with no loss in redundancy. All representative units are predicted to retain the same number of populations, although many at a lower resilience level.

Under a conservation scenario—we would expect the Nashville crayfish's viability to be characterized by no losses in resiliency, redundancy, or representation. In fact, the Lower Mill Creek Streams are predicted to increase their resiliency due to targeted conservation implemented by the City of Nashville, and minimization of spills by the nearby Nashville International airport. Upper Mill Creek Streams are predicted to increase their resiliency due, in part, to targeted conservation implemented by the Tennessee Stream Mitigation Program.

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