Determining Mitigation Needs for NiSource Natural Gas Transmission Facilities - Implementation of the Multi-Species Habitat Conservation Plan (MSHCP)

Mitigation Site Report

Nashville Crayfish

Section 6 Cooperative Endangered Species Conservation Fund Grant
(IDFW Subtask 2.2)
Prepared by The Conservation Fund
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Mitigation Site Report Summary

The key task of the NiSource Multi-Species Habitat Conservation Plan (MSHCP) Section 6 grant is to identify potential mitigation opportunities for take species outlined in the MSHCP. The Conservation Fund (the Fund), in consultation with the US Fish and Wildlife Service (USFWS), NiSource, and state natural resource agencies, has prepared customized mitigation site reports, organized by species that provide selection criteria and an initial list of potential mitigation project opportunities that are likely to meet the requirements outlined in the MSHCP.

Additional information on individual projects will be required at the time of mitigation need as outlined in the Mitigation Proposal Requirements section of the MSHCP. Whether a mitigation proposal can be funded will depend on a number of factors, including but not limited to the species affected, the location of the mitigation activities compared to the location of the species impacts, the cost of the mitigation proposal, whether the proposal satisfies the mitigation proposal criteria, and the scientific justification for the mitigation proposal. This species report is a helpful resource in preparing the future applications for mitigation funding and should be used in conjunction with the Decision Support Framework for Evaluating and Ranking Mitigation Sites report.

<u>Mitigation Project Criteria</u>

Each take species has a set of project selection criteria that will be used to help evaluate and rank potential mitigation projects. The MSHCP currently includes nine take species where potential mitigation projects meeting specific requirements will need to be identified over the 50-year timeframe of the MSHCP (see table).

<u>NiSource MSHCP Take Species Requiring Mitigation</u>
Bog Turtle
Clubshell
Fanshell
Indiana Bat
James Spinymussel
Madison Cave Isopod
Nashville Crayfish
Northern Riffleshell
Sheepnose

The Fund generated an initial set of mitigation project selection criteria for each species based upon an analysis of the draft MSHCP. These criteria were reviewed and refined in detail during a series of webinars held by the Fund, NiSource, and USFWS in spring 2010. These criteria were then presented to the states during focus group meetings in summer 2010 where additional enhancements were made. The Fund synthesized the comments from the states in September 2010 and organized the criteria for each species into a hierarchical structure known as a 'decision tree'.

Each decision tree evaluates to what extent a potential mitigation project meets the particular take species mitigation needs and desires (including habitat quality, location, likely protection in perpetuity, and protection of other listed species) as well as how it supports the green infrastructure network design, advances state and regional planning goals, and leverages other financial and partnership resources. The Fund has included a copy of the decision tree as a reference in this report.

Each criterion spans a range of characteristics from most to least suitable in terms of meeting species mitigation requirements. Where each project falls within this range is represented numerically on a standard scale from 0-100 that describes how well it satisfies that particular criteria (100 being the highest). In addition to the score for each criterion, weights are assigned relative to other criteria within its 'branch of the tree' since some factors are more important than others in evaluating a potential project. In addition, criteria have a 'logic structure' that designates them as mandatory, sufficient, or desired based on their contribution to species protection. The Fund has included descriptions of the criteria and their values as reference in this report. The project selection criteria provide an applicant with insight into project characteristics that make them more attractive for mitigation funding and hopefully will lead to well prepared applications that are responsive to the articulated goals of the mitigation effort.

The design of the decision trees is based on a state-of-the-art method known as 'logic scoring of preference' (LSP) to ensure that all criteria and weightings are designed to reflect fundamental properties of human reasoning and ensure that the benefits calculated accurately reflect the desired intent of decision makers (Dujmović, 2007). Dr. Jozo Dujmović, one of the world's pioneers in the use of LSP for decision making, has designed a customized desktop software package (ISEE) and a web-based application (LSPWeb) to support the ongoing refinement of the species decision trees as the MSHCP begins to be implemented in 2011. Instructions on the use of LSP software are found within the ISEE Users Manual-Integrated System Evaluation Environment V1.1. For web applications, refer to the LSP Methods for Evaluation over the Internet V1.

Although the details of the application review process are not firm at this time, it is likely that the application reviewer(s) would enter the criteria values into the LSP software for each potential mitigation project. Next, the LSP software generates a numerical score on a 100-point scale that represents the percent satisfaction that the project meets the decision tree criteria. The *ISEE* desktop application is the tool that ensures the criterion scores, weights, and logic structure are structured properly and follow the scientifically rigorous techniques of the LSP method. A project's percent satisfaction, when combined with the costs of implementing the project, can be used to help evaluate and rank potential mitigation projects. When trying to select a single project to meet mitigation requirements, the *LSPWeb* application streamlines the selection process and helps clarify the tradeoffs involving benefits and costs for potential projects.

In situations where a large number of projects need to be selected concurrently within a relatively fixed budget constraint, tools using the concept of optimization are most suitable for helping to select multiple projects at a time. The Fund has collaborated with Dr. Kent Messer from the University of Delaware to develop the Optimization Decision Support Tool (*ODST*). The ODST is an Excel™ based application that allows users to evaluate mitigation opportunities based on a variety of evaluation techniques: (1) identifying an optimal set of mitigation projects within a fixed budget constraint, (2) exploring the relative cost effectiveness of mitigation projects and selecting the portfolio with the highest benefit: cost ratio, and/or (3) identifying the minimum cost required to achieve a defined benefit level. The details of the use of the software application are covered in the user manual "Optimization Decision Support Tool Reference Guide–Lite Version.

<u>All mitigation project selection will be governed by the decision making process outlined in the MSHCP. A final MSHCP will not be available before the end of the Section 6 grant project. The weights and logic structure outlined in the enclosed decision trees are likely to be adjusted in the future by USFWS and NiSource, in consultation with the states</u>.

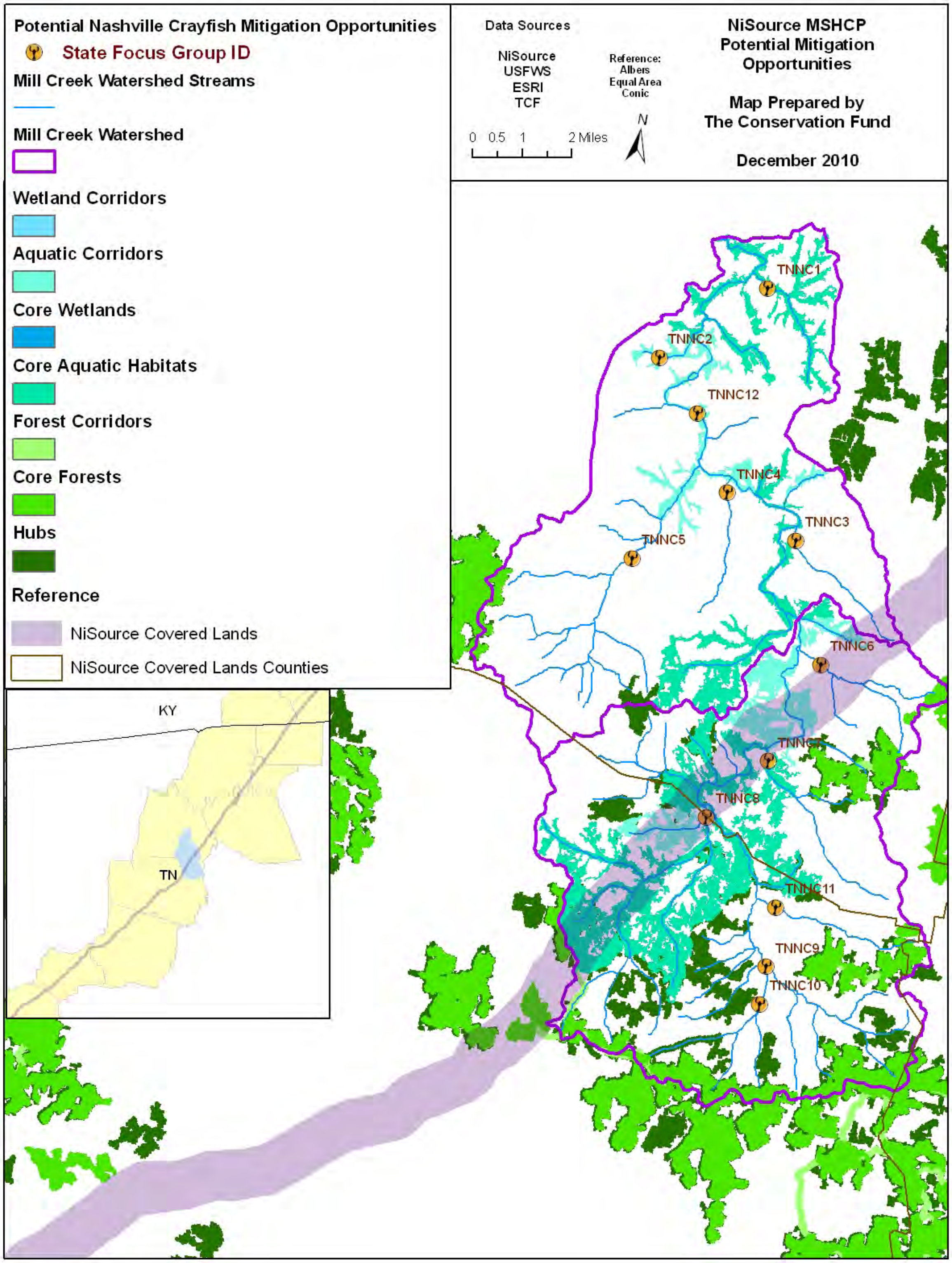
With the above caveats in mind, this species mitigation site report summarizes each state's Wildlife Action Plan recommendations, Maxent models and mitigation opportunities; and provides a true landscape scale snap shot of the alternatives. This document hopefully will serve as a desk reference for mitigation needs and opportunities for the Nashville crayfish within Tennessee.

Potential Nashville Crayfish Mitigation Opportunity Summary Table

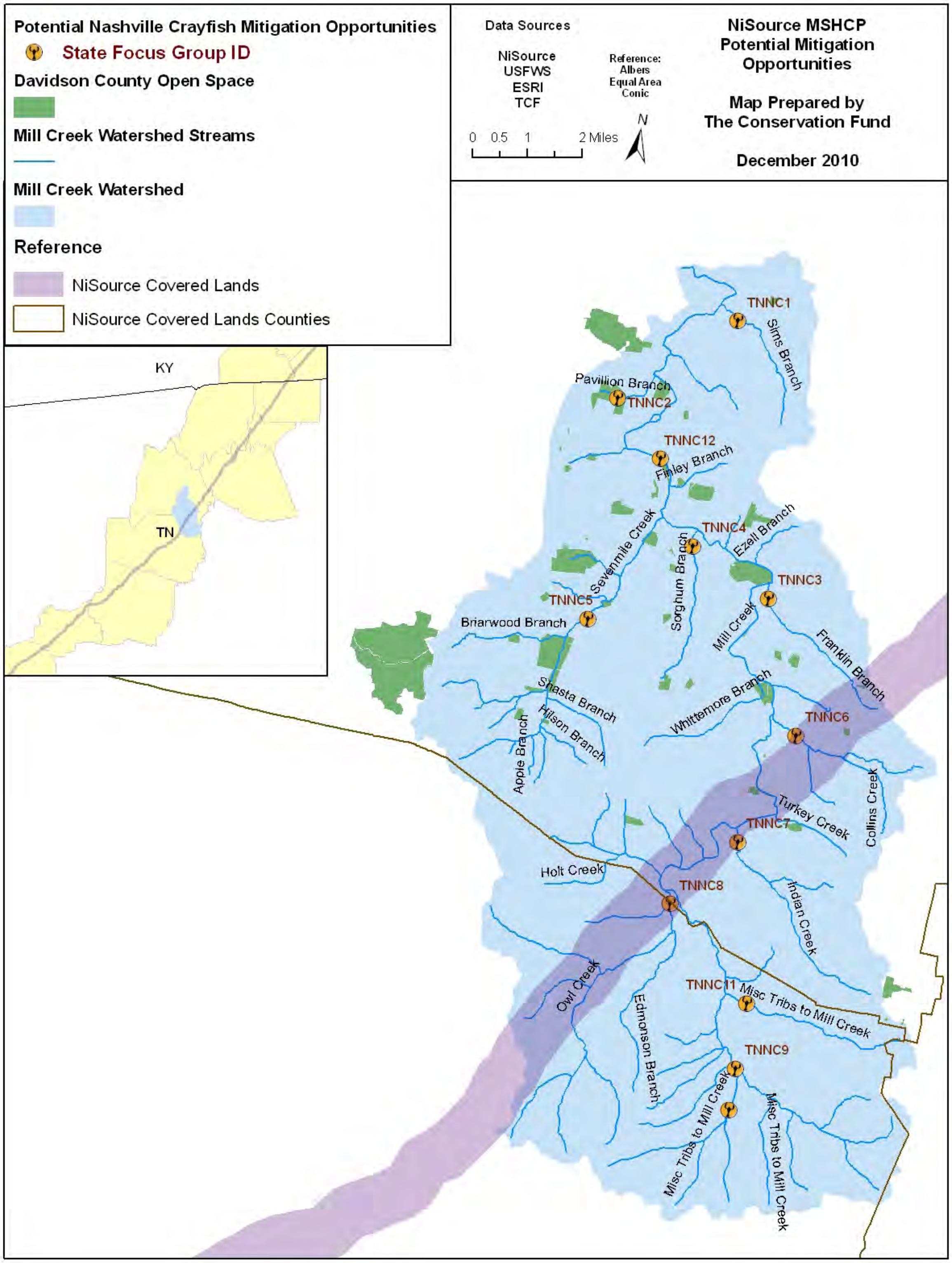
The following table summarizes potential mitigation site opportunities for the Nashville crayfish. The bulk of sites were contributed by state agency staff at two outreach meetings held in 2008 and 2010. Each site represents a general location for a potential mitigation opportunity, but the features in the associated GIS layer are not accurate to the parcel scale.

ID	Opportunity	Location	NOTES
TNNC1	Restoration	Sims Branch	Coordination required with BNA airport and nearby urban and commercial interests
TNNC2	Translocation	Pavilion Branch	Upstream restored segment isolated by industrial zone
TNNC3	Protection, Enhancement	Franklin Branch	Known occurrences upstream of quarry and downstream of Franklin Limestone Rd
TNNC4	Restoration	Sorghum Branch	Occurs in mouth but poor water quality upstream
TNNC5	Enhancement	Sevenmile Creek	Blackman Rd to OHB
TNNC6	Protection, Enhancement	Collins Creek	Commercial landowner agreements to protect creek, crosses covered lands
TNNC7	Protection	Indian Creek	Protect entire system, crosses covered lands
TNNC8	Protection	Owl Creek	Take advantage of all opportunities, crosses covered lands
TNNC9	Protection, Enhancement	Mill Creek, Nolensville	Williamson County
TNNC10	Protection, Enhancement	Bittick Creek, Nolensville	Williamson County, need to confirm tributary location
TNNC11	Protection, Enhancement	Snake Creek, Kidd Road, Nolensville	Williamson County
TNNC12	Protection, Enhancement	Mill Creek Mainstem	Protect and enhance along entire mainstem

Map 1 – Nashville Crayfish Opportunities and the Green Infrastructure Network



Map 2 – Nashville Crayfish Opportunities in Mill Creek Watershed



Nashville Crayfish Decision Tree

1 Nashville Crayfish Mitigation Projects
- 11 *Habitat Mitigation Needs*
  - 111 *Mandatory Requirements*
    - **1111 Mitigation Units**
    - 1112 *Site Assessment*
      - **11121 Buffer Size & Shape**
      - **11122 Intact Buffer Sites**
      - *11123 Canopy Cover & Shade*
        - **111231 Conservation Projects**
        - **111232 Restoration Projects**
    - 1113 *Physical Conditions*
      - **11131 Substratum**
      - **11132 Water Quality**
    - 1114 *Species Occurrence*
      - **11141 Index of Biological Integrity**
      - **11142 Recruitment**
    - **1115 Project Location**
  - 112 *Desired Characteristics*
    - *1121 Protection in Perpetuity*
      - **11211 Point & Nonpoint Pollution Risk**
      - **11212 Sedimentation Risk**
      - **11213 Stream Buffer Clearing Potential**
      - **11214 Project Monitoring**
    - *1122 Listed Species Protection*
      - **11221 NiSource MSHCP Take Species**
      - **11222 Federal & State Listed Species**
- 12 *Strategic Conservation Goals*
  - **121 Green Infrastructure Network**
  - 122 *Adopted Plans & Leverage*
    - **1221 State Wildlife Action Plans**
    - **1222 Conservation Planning**
    - **1223 Collaboration**

KEY

Bold - Criteria where values are directly input into Decision Tree Software

Italic - Categories with logic structure (i.e. mandatory/desired, simultaneity, replaceability)

Nashville Crayfish Tree Logic & Criteria Weights

1 **Nashville Crayfish Mitigation Projects** [CPA -20+15]
- 11 MANDATORY Take Species Habitat Mitigation Requirements
- 12 DESIRED Other Conservation Goals

The DESIRED input cannot compensate the absence of MANDATORY input, but the MANDATORY input can significantly compensate the absence or low value of the DESIRED input. There is a 20% penalty for a low DESIRED value and a 15% reward for a high DESIRED value. This is known as conjunctive partial absorption (CPA).

11 **Habitat Mitigation Needs** [CPA -25+20]
- 111 MANDATORY Requirements
- 112 DESIRED Characteristics

The DESIRED input cannot compensate the absence of MANDATORY input, but the MANDATORY input can significantly compensate the absence or low value of the DESIRED input. There is a 25% penalty for a low DESIRED value and a 20% reward for a high DESIRED value. This is known as conjunctive partial absorption (CPA).

111 **Mandatory Requirements** [C+- Medium-strong simultaneity]
- 1111 Mitigation Units – 30%
- 1112 Site Assessment – 15%
- 1113 Physical Conditions – 15%
- 1114 Species Occurrence – 25%
- 1115 Project Location – 15%

In medium-strong simultaneity, all inputs must be to some extent simultaneously satisfied. Any zero input yields a zero output. This is known as hard partial conjunction (HPC), which is used to model mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

1112 **Site Assessment** [C-+ Medium-weak simultaneity]
- 11121 Buffer Size & Shape – 40%
- 11122 Intact Buffer Sites – 30%
- 11123 Canopy Cover & Shade – 30%

In medium-weak simultaneity, all inputs should be to some extent simultaneously satisfied. Any zero input yields a zero output. This is known as hard partial conjunction (HPC), which is used to model mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

11123 **Canopy Cover & Shade** [D Strongest replaceability]

111231 Conservation Projects – 50%
111232 Restoration Projects – 50%

In strongest replaceability, each input can be used to completely compensate the lack of remaining inputs. This is known as hard partial disjunction (HPD), and the strongest form of this is to evaluate mutually exclusive items. In this case, a project can either be conservation or restoration but not both. The percentages here are representing equal importance.

1113 **Physical Conditions** [C-+ Medium-weak simultaneity]

11131 Substratum – 40%
11132 Water Quality – 60%

In medium-weak simultaneity, all inputs should be to some extent simultaneously satisfied. Any zero input yields a zero output. This is known as hard partial conjunction (HPC), which is used to model mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

1114 **Species Occurrence** [C-+ Medium-weak simultaneity]

11141 Index of Biological Integrity – 30%
11142 Recruitment – 70%

In medium-weak simultaneity, all inputs should be to some extent simultaneously satisfied. Any zero input yields a zero output. This is known as hard partial conjunction (HPC), which is used to model mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

112 **Desired Characteristics** [C-- Very-weak simultaneity]

1121 Protection in Perpetuity – 60%
1122 Listed Species Protection – 40%

In very weak simultaneity, all inputs should be to some extent simultaneously satisfied. A zero input does not necessarily yield a zero output. This is known as soft partial conjunction (SPC), which is used to model non-mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

1121 **Likely Protection in Perpetuity** [C-+ Medium-weak simultaneity]

11211 Point & Nonpoint Pollution Risk – 35%
11212 Sedimentation Risk – 35%
11213 Stream Buffer Clearing Potential – 15%
11214 Project Monitoring – 15%

In medium-weak simultaneity, all inputs should be to some extent simultaneously satisfied. Any zero input yields a zero output. This is known as hard partial conjunction (HPC), which is used to model mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

1122 **Protection of Other Listed Species** [DA Strong replaceability]

- 11221 NiSource MSHCP Take Species – 75%
- 11222 Other Federal and State Listed Species – 25%

In strong replaceability, each input can be used to completely compensate the lack of remaining inputs. This is known as hard partial disjunction (HPD), which is used to model sufficient conditions. Percentages correspond to the relative weights of each criterion within this branch of the tree.

12 **Other Conservation Goals** [C- Weak simultaneity 65/35]

- 121 Support for Green Infrastructure Goals – 65%
- 122 Planning Goals and Leverage Opportunities -35%

In weak simultaneity, all inputs should be to some extent simultaneously satisfied. A zero input does not necessarily yield a zero output. This is known as soft partial conjunction (SPC), which is used to model non-mandatory requirements. Percentages correspond to the relative weights of each criterion within this branch of the tree.

122 **Planning Goals and Leverage Opportunities** [DA Strong replaceability 30/20/50]

- 1221 State Wildlife Action Plans – 30%
- 1222 Other State and Regional Plans – 20%
- 1223 In-Kind Support – 50%

In strong replaceability, each input can be used to completely compensate the lack of remaining inputs. This is known as hard partial disjunction (HPD), which is used to model sufficient conditions. Percentages correspond to the relative weights of each criterion within this branch of the tree.

Nashville Crayfish Criteria Descriptions & Values

1 Nashville Crayfish Mitigation Projects
  11 Habitat Mitigation Needs
    111 Mandatory Requirements
      1111 **Mitigation Units** – (30%)

1111		**Mitigation Units [0,100]**
Value	*%*	Evaluated as the following normalized indicator:
0	0	U = 100 * M / Mmax [%]
100	100	where
		M = Mitigation area protected by proposed project
		Mmax = Mitigation required by MSHCP
		(M and Mmax are measured in same units)
		The value of Mmax can be either expressed as:
		(a) the total mitigation required in the MSHCP, or
		(b) an annual or project-specific mitigation requirement
		Aggregate take = 0.6 acres, OCM take = 3.4 acres
		This criterion represents a mandatory requirement.

1 Nashville Crayfish Mitigation Projects
  11 Habitat Mitigation Needs
    111 Mandatory Requirements
        1112 Site Assessment (15%)
        11121 **Buffer Size & Shape** – 40%
        11122 **Intact Buffer Sites** – 30%
        11123 Canopy Cover & Shade – 30%
          111231 **Conservation Projects**
          111232 **Restoration Projects**

11121		**Buffer Size & Shape [0,150]**
Value	*%*	USFWS, NiSource, and the States have determined that the average buffer size with an optimal ratio of length to width is an important factor for evaluating potential mitigation projects. This criterion represents a mandatory requirement.
49	0	
50	25	
75	50	
125	75	
150	100	

		The buffer size is measured in feet. USFWS and NiSource will determine how to define optimal for the Nashville crayfish. Values within this criteria are currently tied only to the width, but a revised table incorporating the length-width ratio may be developed in the future.

11122		**Intact Buffer Sites [0,3]**
Value	*%*	USFWS, NiSource, and the States have determined suitability based upon four potential buffer configurations that may result from a mitigation project. 3 = Includes ONE site that is internally intact (i.e. there can be no unprotected or unrestored gaps > 100 feet on each bank at the conclusion of the project) fulfilling the required ratio of protection to restoration outlined in the MSHCP (50/50 for aggregrate take and > 25% restoration for other projects). This is highly suitable. 2 = 2 sites internally intact, but sites less than one mile upstream (as measured from the bottom of the first site to the bottom of the second) 1 = 3 sites internally intact, but sites more than one mile upstream 0 = > 3 sites. This is considered unsuitable. This criterion represents a mandatory requirement.
0	0	
1	20	
2	80	
3	100	

111231		**Conservation Projects [0,100]**
Value	*%*	USFWS, NiSource, and the States have determined suitability based upon percent canopy cover and shade for potential mitigation projects that involve conservation. Greater than 80% is ideal and less than 60% is not
59	0	
60	30	
80	100	

		suitable This criterion represents a mandatory requirement.

1 Nashville Crayfish Mitigation Projects
  11 Habitat Mitigation Needs
    111 Mandatory Requirements
      1113 Physical Conditions (15%)
        11131 **Substratum** – 40%
        11132 **Water Quality** – 60%

11131		**Substratum [0,3]**
Value	*%*	USFWS, NiSource, and the States have determined suitability based upon four potential substratum conditions that may occur within a proposed mitigation project. 3 = Stream reach has slabrock on bedrock with minimal sediment 2 = Stream has slabrock on bedrock with sediment deposits below 3.9 inches with visible crevices and institial spaces still available 1 = Stream has slabrock on bedrock with sediment deposits above 3.9 inches with few crevices and institial spaces still available 0 = Does not contain suitable characteristics This criterion represents a mandatory requirement.
0 3	0 100	

11132		**Water Quality [0,4]**
Value	*%*	USFWS, NiSource, and the States have determined suitability based upon a characterization of water quality indicators that may occur within a mitigation project location.
0 4	0 100	

		Project should be in a stream reach with favorable water quality indicators. Exact threshold values will be determined for each species and watershed. Indicators may include, but are not limited to: Nitrogen, Phosphorus, Sedimentation, Turbidity, Bacteria (e.g. eColi), and Manmade Chemicals (e.g. herbicide). Evaluation based on the five-level scale: 4 = Excellent water quality indicators (ideal) 3 = Very Good 2 = Good 1 = Fair 0 = Poor (not suitable) This criterion represents a mandatory requirement.

1 Nashville Crayfish Mitigation Projects
  11 Habitat Mitigation Needs
    111 Mandatory Requirements
      1114 Species Occurrence (25%)
        11141 **Index of Biological Integrity** – 30%
        11142 **Recruitment** – 70%

11141		**Index of Biological Integrity [0,4]**
Value	*%*	USFWS, NiSource, and the States have determined suitability based upon IBI score for a potential mitigation project. 4 = Excellent IBI score (ideal) 3 = Very Good 2 = Good 1 = Fair 0 = Poor (not suitable) This criterion represents a mandatory requirement.
0 4	0 100	

11142	**Recruitment [0,4]**

Value	*%*	USFWS, NiSource, and the States have determined suitability based upon the distribution of age classes (adults and juveniles) among the local population of Nashville crayfish at the potential mitigation project location. 4 = Excellent (ideal) 3 = Very Good 2 = Good 1 = Fair 0 = Poor (not suitable) The weights and logic structure may be adjusted by USFWS and NiSource in the future. This criterion represents a mandatory requirement.
0 4	0 100	

1 Nashville Crayfish Mitigation Projects
  11 Habitat Mitigation Needs
    111 Mandatory Requirements
      1115 **Project Location** – 15%

1115		**Project Location [0,2]**
Value	*%*	Location of the project based on priority locations for species viability. Mix of high density populations and important fringe populations in upper tributaries. Priority areas identified by David Withers in Withers, 2009 report. 2 = One of 6 conservation needs outlined in Withers 2009. 1 = Other tributaries wirth existing viable populations. 0 = Tributaries without existing viable populations. This criterion represents a mandatory requirement.
0 1 2	0 75 100	

1 Nashville Crayfish Mitigation Projects
11 Habitat Mitigation Needs
112 Desired Characteristics
1121 Protection in Perpetuity (60%)
11211 **Point & Nonpoint Pollution Risk** – 35%
11212 **Sedimentation Risk** – 35%
11213 **Stream Buffer Clearing Potential** – 15%
11214 **Project Monitoring** – 15%

11211		**Point & Nonpoint Pollution Risk [0,4]**
Value	*%*	USFWS, NiSource, and the States have determined suitability based upon the risk of upstream point and nonpoint source runoff from activities near a mitigation project location. Potential magnitude of nearby, upstream point and nonpoint source runoff, which may include, but is not limited to sewage treatment, agricultural operations, lawn insecticides, toxic chemical spills (from airport or other industrial facilities) and contamination or other pollution sources. 4 = None 3 = Low 2 = Medium 1 = High 0 = Very High This criterion is not a mandatory requirement.
0 4	0 100	

11212		**Sedimentation Risk [0,4]**
Value	*%*	USFWS, NiSource, and the States have determined suitability based upon the risk of sedimentation near a mitigation project location. Potential magnitude of activities that result in sedimentation include but are not limited to bridge/road/pipeline construction and urban development in riparian zones. 4 = None
0 4	0 100	

		3 = Low 2 = Medium 1 = High 0 = Very High This criterion is not a mandatory requirement.

11213		**Stream Buffer Clearing Potential [0,4]**
Value	*%*	USFWS, NiSource, and the States have determined suitability based upon the risk of stream buffer clearing near a mitigation project location. Is the project located on or near a stream that has been designated a legal drain (OH, IN), wet weather conveyance (TN), or comparable designation that entitles clearing of vegetation without a permit? Evaluated using the likelihood of clearing: 4 = None 3 = Low 2 = Medium 1 = High 0 = Very High This criterion is not a mandatory requirement.
0 4	0 100	

11214		**Project Monitoring [0,4]**
Value	*%*	USFWS, NiSource, and the States have determined suitability based upon the quality and efficacy of the monitoring program for a mitigation project. An excellent monitoring program would be multi-year, require dual phase qualitative and quantitative sampling, and have an experienced monitoring team. 4 = Excellent 3 = Very Good 2 = Good
0 4	0 100	

		1 = Fair 0 = Poor This criterion is not a mandatory requirement.

1 Nashville Crayfish Mitigation Projects
11 Habitat Mitigation Needs
112 Desired Characteristics
1122 Listed Species Protection (40%)
11221 **NiSource MSHCP Take Species** – 75%
11222 **Federal & State Listed Species** – 25%

11221		**NiSource MSHCP Take Species [0,3]**
Value	*%*	USFWS, NiSource, and the States have determined suitability based upon where the potential mitigation project supports protection of other NiSource MSHCP take species. Evaluated as the number of supported species. This criterion is not a mandatory requirement.
0 1 3	0 80 100	

11222		**Federal & State Listed Species [0,3]**
Value	*%*	USFWS, NiSource, and the States have determined suitability based upon where the potential mitigation project supports protection of federally listed threatened or endangered species, G1-G3 species, GCN species, or state listed rare habitats or communities not included as take species within the MSHCP: Evaluated as the number of species (0-3). This criterion is not a mandatory requirement.
0 1 3	0 80 100	

1 Nashville Crayfish Mitigation Projects
12 Strategic Conservation Goals
121 **Green Infrastructure Network** (65%)

121		**Green Infrastructure Network [0,5]**
Value	*%*	Characterized green infrastructure network.
0	0	
1	50	The value is generated by combining the following
2	70	GIS layers: GI hubs (2 points), GI core forest (1),
3	80	GI aquatic areas (1), GI wetlands (1) and GI corridors (1).
4	90	The maximum number of points is 6, and 5 points is
5	100	sufficient for complete satisfaction of this criterion.
		The value is a proxy for the contribution of the mitigation project to the protection of an interconnected network of natural resource lands.
		This criterion is not a mandatory requirement.

1 Nashville Crayfish Mitigation Projects
12 Strategic Conservation Goals
122 Adopted Plans & Leverage (35%)
1221 **State Wildlife Action Plans** – 30%
1222 **Conservation Planning** – 20%
1223 **Collaboration** – 50%

1221		**State Wildlife Action Plans [0,4]**
Value	*%*	How well does the potential mitigation project support
0	0	the adopted State Wildlife Action Plan?
1	50	
3	90	Evaluated as the number of supported actions/plans.
4	100	
		This criterion is not a mandatory requirement.

1222		**Conservation Planning [0,4]**
Value	*%*	Does the potential mitigation project support other state
0	0	and regional planning efforts?
1	50	
3	90	Plans may include, but are not limited to:
4	100	

		Coastal and Estuarine Land Conservation Plan State Wetlands Plan State Greenways and Trails Plan State Forestry Plan Climate Action Plans Statewide Comprehensive Recreation Plan State GAP Analysis Forest Legacy Needs Assessment Natural Areas Statewide Plan Nature Conservancy Eco-regional Plans/Assessments Eastern Brook Trout Joint Venture Report Ohio River Valley Ecosystem Mollusk Conservation Plan Ohio River Islands National Wildlife Refuge CCR Partners in Flight North American Conservation Plan Chesapeake Bay Health and Restoration Assessment Evaluated as the number of supported actions/plans. This criterion is not a mandatory requirement.

1223		**Collaboration [0,100]**
Value	*%*	How well does the potential mitigation project leverage in-kind resources for restoration, monitoring, stewardship, management, and education/interpretation? Projects that bring additional resources will receive additional consideration when compared with projects that rely solely on funding from the project application. Value range is 0-100% based on the level of collaboration included in the mitigation project proposal. This criterion is not a mandatory requirement.
0 100	0 100	

Riparian Buffers and the Nashville Crayfish

by Ole Amundsen, The Conservation Fund

The Conservation Fund (the Fund) involvement in the mitigation planning for the NiSource Multispecies Habitat Conservation Plan (MSHCP) and Nashville: *Naturally* – Creating, Enhancing, and Preserving Places that Matter (a conservation planning effort for Metro Parks and the Land Trust for Tennessee) have overlapping interests in conservation activities in the Mill Creek watershed associated with the Nashville crayfish. Riparian buffers contribute to the protection of Nashville crayfish habitat and offer a host of other public benefits such as water quality improvements, pollutant removal and corridors for wildlife movement. A literature review was conducted on riparian buffers and land use planning ordinances to bring the latest research to bear upon the issue.

Few of the studies examined were within Mill Creek watershed or focused specifically on the Nashville crayfish. Care must be taken in extrapolating findings from one geographic location and applying them to a different location. Even studies on crayfish should be examined carefully as there is great diversity between species in terms of habitat needs, food sources, adaptability and other important factors. Certainly over time there is much to be learned about the specific needs and degree of adaptability of the Nashville crayfish, and with further study additional recommendations would be expected. With these caveats in mind, the literature review draws on research from ecology, forestry, planning, cartography and other disciplines that contribute to the understanding of riparian buffers' important role and application for the benefit of the Nashville crayfish.

A common theme within the literature is the importance of considering the type and degree of ecosystem service expected and then matching the buffer to achieve that goal. With the Nashville crayfish the goals for buffer use would be maintaining and/or improving overall water quality – in particular controlling sediment, protecting and/or expanding tree canopy to provide sufficient shade for temperature control and support food web dependences, and providing in-stream stable wood for shelter.

Buffers for Water Quality

Further deterioration of water quality in Mill Creek will have a negative impact on the Nashville crayfish. Increases in sedimentation have been linked to declines in fish and invertebrates, thus measures to trap sediment and prevent erosion are critical to the viability of the Nashville crayfish (Nerbonne and Vondracek 2001). Extensive research has been conducted on the ability of native vegetative riparian buffers to protect water quality by trapping sediment, reducing erosion and removing nonpoint source pollution such as nitrogen and phosphorus (Bentrup 2008, Correl 2005, Mayer et al. 2004, Wenger and Fowler 2000, Castelle et al. 1994).

Different types of vegetation within a riparian buffer have been found to have varying levels of effectiveness on protecting water quality. For example, native grasses are widely believed to be more effective at trapping sediment than trees, whereas trees are believed to outperform grasses in terms of overall erosion control (Hawes and Smith 2004). Vegetation types also differ in their able to capture pollutants that are either bound to sediment or pollutants that are soluble (Fischer and Fischenich 2000). For the best overall performance in controlling sediment and removing the widest range of pollutants, a mixed vegetated buffer of native species of trees, scrubs and grasses is believed to be the most effective (Hawes and Smith 2004).

In addition to buffer vegetation diversity, age diversity of the vegetation is also important. Early to mid-successional plant communities can have greater nutrient retention capacities than older or climatic plant communities. However, older trees contribute heavily to the amount of woody debris in the riparian zone and in stream beds, providing a range of benefits, including food, shelter and pool formation. A matrix of different aged woodland communities is recommended to capture a broad spectrum of benefits (Broadmeadow and Nisbet 2004). The performance of different width buffers has been examined in relationship to several categories of ecosystem services. A mixed native vegetation buffer starts providing basic filtration services, erosion control and moderating stream temperature through shading around 30 ft to 45 ft (Castelle et al. 1994, Mayer et al. 2004, Broadmeadow and Nisbet 2004). As the width of the mixed vegetated buffer increases, a greater degree and number of ecosystem services are provided. In 1977, a pioneering study in California examined the ability of stream buffers to protect aquatic species and benthic invertebrates from the impacts of nearby logging, concluding that a 30-meter buffer provided sufficient protection (Erman et al. 1977). Over time, the 100-foot buffer with mixed vegetation of native trees, scrubs and grasses has become a standard recommendation for securing water quality benefits such as filtering pollutants, trapping sediment and preventing erosion (Mayer et al. 2004, Wenger and Fowler 2000, Semlitsch and Bodie 2003).

Summary of Buffer Widths Thresholds and Benefits

Benefit Provided:	**Buffer Width:**					
	30 ft	**50 ft**	**100 ft**	**300 ft**	**1,000 ft**	**1,500 ft**
Sediment Removal - Minimum	💧	💧	💧	💧	💧	💧
Maintain Stream Temperature	🐟	🐟	🐟	🐟	🐟	🐟
Nitrogen Removal - Minimum		💧	💧	💧	💧	💧
Contaminant Removal		💧	💧	💧	💧	💧
Large Woody Debris for Stream Habitat		🐟	🐟	🐟	🐟	🐟
Effective Sediment Removal			💧	💧	💧	💧
Short-Term Phosphorus Control			💧	💧	💧	💧
Effective Nitrogen Removal			💧	💧	💧	💧
Maintain Diverse Stream Invertebrates			🐟	🐟	🐟	🐟
Bird Corridors				🐦	🐦	🐦
Reptile and Amphibian Habitat					🐦	🐦
Habitat for Interior Forest Species					🐦	🐦
Flatwoods Salamander Habitat – Protected Species						🦎

From US Fish and Wildlife Service, Panama City Field Office. Buffers: An Efficient Tool for Watershed Protection. See website www.fws.gov/PanamaCity/resources/Buffers.doc

Buffers for Stream Temperature Control

Maintaining a tree canopy that provides shade and regulates the stream temperature is important for the Nashville crayfish. According to the USFWS Recovery Plan for the Nashville crayfish from 1988, “the species is highly photosensitive and is usually found undercover during the day. Occupied sites typically have tree canopy cover of 60 to 90 percent.” Many variables are involved in temperature regulation including differences in leaf cover of tree and scrub species, degree of seasonal leaf loss, variability in sun exposure due to meandering stream channels, width of stream, surrounding slopes, and the overall heat budget of stream reach (Chagrin River Watershed Partners 2006). Current research indicates that the longer distance a stream is shaded, the smaller the buffer required to maintain constant temperature (Broadmeadow and Nisbet 2004, Barton at al. 1985, and Correll 2005). While the NiSource pipeline crosses Mill Creek at a specific location, the degree of shade offered upstream is a critical factor to maintaining a constant temperature for the crayfish. In addition, minimizing gaps in a vegetative riparian buffer from the headwaters is critical to keeping water temperature constant.

Another benefit of shading is the protection of shallow pools from evaporation in the summer and fall months. As stream flow decreases, or in some cases stops altogether, shallow pools provide a crucial refuge for the Nashville crayfish. Increases in direct sun exposure may lead to a more rapid evaporation of these pools, placing increased stress upon the crayfish (David Withers 2010). An extensive tree canopy can help extend the life of these pools for crayfish habitat.

There can be “too much of a good thing”, and this saying can applied to the amount of shading and type of vegetation providing shading. Broadmeadow and Nisbet (2004) point out the European experience of replanting areas with conifers, which has led to increasing the amount of year-round shading ,and over time, has resulted in bare stream banks and increased erosion. The authors’ central recommendation acknowledges the challenge that “the optimum level of shade is difficult to quantify but limited work suggests a good balance is achieved where around 50 percent of the stream surface is open to sunlight and the remainder covered by dappled shade”. In their literature review, several studies on the impact of shading on benthic invertebrates and macro invertebrates suggest benefits of balanced shading. However, these studies did not examine the needs of the Nashville crayfish, which may have a higher need for shade than other species. In the American context, Phillips (1989) examined pollution control effectiveness in 19 riparian forests in North Carolina. One of the key findings was that buffers with substantial tree canopies and little undergrowth need to be 28 percent wider than buffers with dense undergrowth in order to be as effective in controlling sediment loss. As with any natural resource management question, there are trade-offs, and decision makers need to be aware of potential impacts of any management approach.

Based on regulations from the City of Everett and the City of Renton in Washington, the recommended buffer for shading and temperature control ranges from 35 feet to 250 feet (Chagrin River Watershed Partners 2006, Hawes and Smith 2005).

Stable Wood

An important factor in stream health is the presence of stable wood, debris and leaf litter. Stable wood in stream channels traps alluvial sediments, creates hydraulic variability, provides in-stream habitat and shelter for fish, adds to the supply of organic material supporting invertebrates, bacteria and insects (Chagrin River Watershed Partners 2006, Broadmeadow and Nisbet 2004, Correll 2005). The Conservation Framework for the NiSource project does not discuss the role of stable wood in supporting the Nashville crayfish. However, presumably, stable wood provides similar shelter opportunities as do large stones, which are recommended for in-stream habitat. Stable wood may provide nutrients and shelter for other species that are part of the food web of the Nashville crayfish. The combination of shelter and secondary benefits offered by stable wood make its presence in creeks and streams a desired quality for the Nashville crayfish (Withers, 2010).

In urban and suburban regions, stable wood may be seen as a potential hazard, creating flooding and posing aesthetic problems. Hawes and Smith (2005) offer the greatest recommended range for buffer width for debris input to be between 10 and 328 feet. The City of Everett, Washington recommends a 250-foot buffer to provide woody debris (Chagrin River Watershed Partners 2006).

Importance of Forested Headwaters

Protecting forested buffers in the headwaters has a disproportionate impact on downstream water quality and heat budgets (Correll 2005, Fischer and Fischenich 2000). While the role of forested headwater streams has long been known in terms of water quality and temperature control, exciting research has focused on the link between healthy forests and aquatic system food webs. Researchers from the University of Georgia examined the diets of crayfish and insectivorous fish in headwater streams in the Upper Chattahoochee Basin for dependence on terrestrial (tree leaves) energy sources versus aquatic energy sources. The local canopy cover was between 77 percent and 89 percent, while the continuity of the canopy throughout the stream network was more variable (63 percent to 100 percent). The crayfish examined were true omnivores feeding on leaf litter (between 74 percent and 44 percent of gut contents) and animal material (32 percent to 15 percent). England and Rosemond's (2004) main finding was that "moderate levels of riparian deforestation (reductions in canopy cover and riparian buffer width and continuity) can lead to reduced dependence of headwater food webs on terrestrial subsidies". Researchers believe that forest cover for both riparian buffers as well as forest cover across the entire catchment is important to these food webs in headwater streams. Even subtle changes in the forest canopy have an impact on the crayfish diet. A topic for future study is the degree to which deforestation in headwaters regions is linked to changes in food webs downstream. While the Nashville crayfish is rarely found in small streams, the forest canopy most likely plays a role in the food web for this species.

Habitat Buffers

Buffers required for habitat protection, in particular for terrestrial species, tend to be wider than standard buffers for water quality (Marczak 2010). Semlitsch and Bodie (2003) undertook a literature review of studies of amphibians and reptiles to craft recommendations for core area habitat and buffer protection. Core area recommendations from the literature review were for 466 feet to 948 feet from the stream, and a terrestrial buffer of an additional 164 feet. Amphibians and reptiles demand the large buffers as they move between aquatic habitat of streams and wetlands to upland habitat for different stages in their life cycle. The 328-foot buffer level is the minimum level for use of the buffer as a corridor for bird species, with wider buffers being necessary for forest interior bird corridors. As the Nashville crayfish life cycle occurs completely within an aquatic environment, the maximum widest buffer for its habitat needs (for shade and support of stable wood) is 328 feet.

Impervious Surfaces

Because the Mill Creek watershed has urbanized sections, impact assessment of impervious surface on water quality is warranted. At a watershed scale, the linkage between the overall percentage of a watershed or catchment that is covered by impervious surfaces, such as roads or parking lots, and the percent as forest cover within a watershed is a meaningful indicator of water quality. Researchers with Woods Hole Research Center and the University of Maryland used remote sensing techniques in Maryland, with a fine grain analysis in Montgomery County to study the impact of impervious surface at a landscape scale. Based on the research, researchers recommended that in order for a stream to maintain excellent stream health, impervious surfaces would be restricted to no more that 6 percent of the total area, and that at least 65 percent of a 100-foot riparian buffer be vegetated with trees. An overall rating of good stream health could be achieved by an impervious surface level of 10 percent and 60 percent of a 100-foot buffer zone vegetation cover (Goetz et al. 2003). In 2007 The Fund completed a Green Infrastructure Plan for Cecil County, Maryland. The analysis found that water quality was highest in watersheds with less than 7 percent impervious cover and greater than 50 percent forest and wetland cover (Allen and Weber 2007). In analyzing Cecil County, the Fund focused on recommendations to target restoration activities in areas with forest and wetland cover between 30 and 40 percent, and with impervious surface of less than 7 percent. In prioritizing mitigation opportunities for the Nashville crayfish, examining the ability of projects to reduce impervious cover and increase forest cover appears advisable.

Slopes

Because streams seldom have uniform bank topography, researchers, ecologists and planners have been exploring variable width buffers, adjusting the buffer for a range of factors. As practitioners have wrestled with implementing buffers within zoning ordinances, complex model formulas have been simplified to crudely take into account changes in slope and presences of impervious surfaces and wetlands. A standard rule of thumb is the buffer width is expanded by two feet for every one percent of slope (Wenger and Fowler 2000, Hawes and Smith 2005). In addition, impervious surfaces, wetlands and extreme slopes above 25 percent do not count against the buffer width.

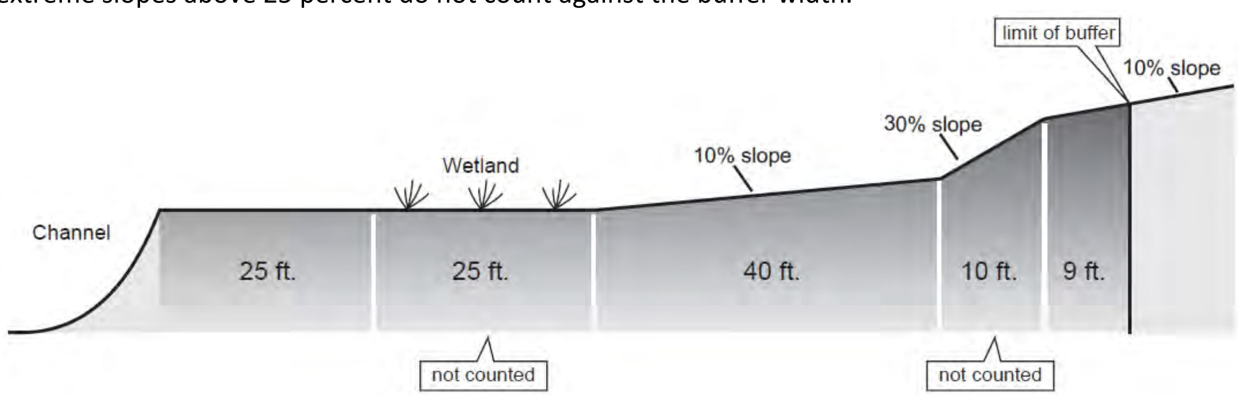


Illustration from Wenger and Fowler 2000

Nashville/Davidson County Land Use Planning Policies

In August 2009, the Metropolitan Water Service Department (MWS) released a new regulation requiring buffers for water quality. The water quality buffers apply to community waters defined as intermittent and perennial streams, lakes and ponds with hydrologic connectivity and wetlands identified by the Army Corps of Engineers, Tennessee Department of Environmental Conservation (TDEC), or MWS staff.

Currently MWS uses a three-tier approach to buffers, with a 30-foot buffer, a 50-foot buffer and a 75-foot buffer. Each buffer relies on a stream drainage acreage threshold. The first buffer of 30 feet applies to streams draining more than 100 acres, and a second buffer is for stream drainages equal to or above 100 acres. The most rigorous buffers are applied to streams that have been subject to FEMA studies or local flood studies and to those that drain an area greater than 1 square mile. The last buffer included the entire floodway within an unmanaged forest zone, therefore, the total buffer width potentially may be wider than 75 feet.

An unintended consequence of the acreage thresholds for the buffers is that headwater streams and creeks are often subject to the minimum 30-foot buffer. The protection of headwater streams with wider buffers produces disproportionate benefits in terms of temperature stability, food web protection and sediment reduction.

The issue of stream classification has been a heated statewide regulatory debate for many years. On June 23, 2009, Tennessee Governor Phil Bredesen approved Public Chapter No. 464, Acts of 2009, which provided more guidance on making determination of “wet weather conveyances” and streams. The new standards by TDEC define “Wet Weather Conveyances are man-made or natural watercourses, including natural watercourses that have been modified by channelization: that flow only in direct response to precipitation runoff in their immediate locality; whose channels are at all times above the groundwater table; that are not suitable for drinking water supplies; and in which hydrological and biological analyses indicate that, under normal weather conditions, due to naturally occurring ephemeral or low flow there is not sufficient water to support fish, or multiple populations of obligate lotic aquatic organisms whose life cycle includes an aquatic phase of at least two months. [Section 1 of P. Ch. 464 of the Acts of 2009]”. A weakens in the buffer system is that buffers are not required along wet weather conveyances.

The new definition of the wet weather conveyance includes more detail making a determination based on levels of aquatic life. For further clarification, “Obligate lotic aquatic organisms means organisms that require flowing water for all or almost all of the aquatic phase of their life cycles”). Additional “Multiple populations means two or more individuals, from each of two or more distinct taxa, in the context of obligate lotic aquatic organisms” (Public Chapter No. 464).

In December 2009, the Metro Nashville Stormwater National Pollutant Discharge Elimination System (NPDES) Office filed comments with the TDEC on the proposed rule changes and the guidance for making wet weather conveyance determinations. Within these comments, staff focused the determination of water flow during dry periods as outlined from February to April. The absence of flow during this period is considered primary evidence that the water body is a wet weather conveyance. MWS advocated for changing this period from three months to one month (March 15 to April 15), citing the significant danger that natural water courses would be reclassified as wet weather conveyances. Although not articulated in the MWS letter, headwater streams are particularly vulnerable to absence of flow during dry periods. In addition, the MWS letter recommended that the presence of one taxa of lotic benthic organisms be sufficient to prove the water course is a stream. MWS staff points out that the population of lotic benthic organisms varies seasonally, that limitations in locating these organisms exists, and that the impact of poor water quality makes a compelling case for a more ecological conservative (Hunt 2009).

While the definition of aquatic life would not appear to directly apply to the Nashville crayfish, certainly, indirect impacts may affect the crayfish. Water flowing through wet weather conveyances may empty into natural stream channels, compromising the progress made by buffers and other techniques that improve water quality. The revised definition of wet weather conveyances could result in reduced habitat, deterioration of water quality, and reduced flexibility in addressing new drainage patterns as a result of climate change and development.

NiSource Draft MSHCP

The February 2010 draft of the NiSource MSHCP mandates a 50- to 150-foot wide vegetative buffer on both sides of the mitigation stream reach. Within the NiSource MSHCP, a series of conservation frameworks was prepared for each federally listed species covered by the USFWS permit. The conservation frameworks contain information on habitat thresholds, steps to manage impacts due to maintenance activities and other species specific insights.

Summary of Conservation Frameworks Guidelines – with Spatial Components

- Occupied sites have tree canopy cover of 60 to 90 percent
- Avoid impact within 300 feet of occupied stream

Conservation Framework Guidelines Restoration Opportunity and Stewardship Guidelines

- Minimize tree cleaning within 25 feet of creek or stream
- Erosion controls on slopes greater than 30 percent
- Avoid use of fertilizer or herbicide within 100 feet

Comparable Cities

The riparian protection efforts of the cities of Austin, Texas; Indianapolis, Indiana; Raleigh, North Carolina; Charlotte, North Carolina; Atlanta, Georgia; Louisville, Kentucky; and Memphis, Tennessee were examined. Based on the analysis of buffer ordinances in these peer cities, Nashville is in the middle of the pack in term of progressive buffers.

Indianapolis has no required riparian buffers as part of its planning ordinances. Instead, as part of its NPDES permit requirements, an educational brochure on the benefits of riparian buffers is made available. In addition, the county survey's office may declare creeks to be regulated drains, and once declared; the survey's office can clear a 75-foot buffer on both sides of the creek, remove any fallen trees from the creek channel, and send a bill to the landowner for the services provided.

Memphis relies on the Tennessee Department of Environmental Conservation requirements with add additional requirement that any development along a blue line stream stay off the stream bank for a distance 2 ½ times the width of the stream per side. Also, no building development is allowed within 25 feet of a stream. Memphis is in the process of adopting a unified development code with Shelby County, and currently a 60-foot stream buffer is proposed. It is unclear if the proposed 60-foot buffer is a tiered approach with no-build zones and management zones. The unified development code was reviewed by the Shelby County Board of Commissioners and the Memphis City Council in the summer of 2010.

Both Raleigh and Charlotte are covered by buffer requirements along the Neuse River Basin and Catawba River Basin from the North Carolina Department of Environment and Natural Resources (NCDENR). The state requirements necessitate buffers of 50 feet with no disturbances in the first 30 feet along blue line streams from the U.S. Geological Survey (USGS) or streams from county soil survey maps. The outer 20 feet can be cleared and replanted (Bowden 2010).

The City of Charlotte has additional requirements, and like Nashville, applies a three-tier structure with acreage thresholds. The acreage thresholds for a drainage area greater or equal to 100 acres are for a 35-foot buffer with 20 feet in a stream zone and 15 feet in an upland zone. Next, drainages greater than 300 acres trigger a 50-foot buffer, with 20 feet in the stream zone, 20 feet in a managed use zone and 10 feet in an upland zone. Finally, drainages over 640 acres trigger a buffer of 30 feet in the stream zone, 45 feet in the managed use zone and 25 feet plus 50 percent of the area of the FEMA fringe beyond 100 feet in the upland zone. Within Charlotte/Mecklenburg County there are eight communities with separate ordinances. The smaller communities have a 35-foot buffer triggered at the 50 acre drainage level and have similar requirements for the other drainage thresholds.

The City of Austin has a highly complex series of buffer requirements. In 1986, Austin adopted the Comprehensive Watersheds Ordinance (CWO) that organized watersheds into groups based on their relationship to the water supply, the aquifer, and the degree of urbanization. The five groups are Urban, Suburban, Water Supply Suburban, Water Supply Rural, and the Barton Springs Zone. The CWO also established a two-tier buffer system for creeks, consisting of the Critical Water Quality Zone and the Water Quality Transition Zone. See the following buffer width chart for reference: http://www.ci.austin.tx.us/watershed/ordinance_table.htm

The Critical Water Quality Zone is directly adjacent to the creek and is the most restrictive. The width is based on the watershed group, the contributing drainage area, and the location of the 100-year floodplain. The creeks are divided into minor, intermediate, and major waterways based on contributing drainage area. The narrowest buffers are 50 feet, triggered by a drainage area of 64 acres for a minor waterway/critical water quality zone. The maximum buffer ranges between 200 feet to 400 feet for major waterways having a drainage area of over 640 acres for water supply protection zones and over 1,280 acres for suburban areas.

The Water Quality Transition Zone is an additional buffer that allows limited development between the uplands and the Critical Water Quality Zone. The width is based on the waterway classification (minor, intermediate, or major). The amount of development allowed in the Transition Zone is based on the watershed group. No buffers are required for the zone areas classified for urban development. The basic 100-foot buffer is the entry level for all other development zones, with the maximum buffer of 300 feet.

The City of Austin has significant needs to protect areas for the city's drinking water supply. This factor makes using Austin as a model for buffers for Nashville not as useful. However, the commitment to water resource protection over the long term is an element that leaders in Nashville can aspire to surpass.

Georgia and the City of Atlanta have made steady progress on protecting stream buffers. The State requires a 25-foot stream buffer. Currently the Metropolitan North Georgia Water Planning District requires a minimum 50-foot undisturbed buffer with an additional 25-foot setback from the buffer where impervious surfaces are not allowed but disturbances such as grading are allowed. In winter of 2010, the City of Atlanta adopted a 75-foot no-disturbed buffer and revised the process for reviewing variance requests.

Atlanta's progress is the result of years of experimentation, blending regulatory approaches with scientific research on stream buffers and reflects a concerted effort by state and local leaders, academics, business community and citizens. The policy discussion on stream buffers is a long-term conversation, educational outreach campaign and regulatory exercise. Periodic review and revisions to stream buffers are normal to the development process. Engaging both state and local leaders on the importance of stream buffers is crucial, in particular in Tennessee at this time.

Policy Recommendations
Based on the literature review and analysis of comparable policies in peer cities, the following policy recommendations are offered:

1. Creation of an overlay zone for Mill Creek watershed for the enhanced protection of Nashville crayfish based on a variable 100-ft buffer. Impervious surfaces, floodplains, wetlands and extreme slopes of above 25 percent do not count against the buffer width.
2. If a variable 100-ft buffer proves not feasible, expanding the buffer in the headwaters beyond 30 ft is a fall back position that would provide significant benefits.
3. For the NiSource MSHCP, minimizing tree cutting within 300 feet of streams and creeks beyond the current 25 feet recommendation would be beneficial for the Nashville crayfish.
4. Provide outreach material to the public and landowners in Mill Creek communicating the benefits of riparian buffers including information about the benefits of stable wood in streams and creeks to be used for voluntary management consideration.
5. Restoration of public lands within the Mill Creek watershed, with expanded native tree planting, and planting mixed native vegetation with the 100-ft buffer. Include management provisions on public land to not remove downed trees and branches from creeks and streams on public land unless the risk of flooding is significant. On public lands, focus on minimizing and removing impervious surfaces.
6. For the Tennessee Land Trust, influencing state policy on wet weather conveyances to ensure that natural creeks are not being reclassified as conveyances. Monitoring the implementation of the revised definition of wet weather conveyances will be crucial to protecting Mill Creek and other streams from further deteriorations in water quality. As a statewide organization, the Land Trust for Tennessee is well positioned to critique this statewide policy.

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Mill Creek Nashville Crayfish Modeling Report

Coarse-scale modeling of *Orconectes shoupi* (Nashville crayfish) habitat in the Mill Creek watershed, Tennessee

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Introduction

The Conservation Fund (the Fund) assisted the US Fish and Wildlife Service (USFWS), NiSource, and 13 affected states (DE, IN, KY, LA, MD, MS, NJ, NY, OH, PA, TN, VA, and WV) to create a multi-species, multi-state habitat conservation plan covering future construction, operation, and maintenance of NiSource natural gas pipelines and ancillary facilities. The Nashville crayfish (*Orconectes shoupi*), a federally endangered crayfish restricted to the Mill Creek watershed in Tennessee (USFWS, 1988), is one of the covered species.

<u>Habitat requirements</u>
Similar to other crayfish, *O. shoupi* (Fig. 1) is an opportunistic feeder. A 1986 study cited in NatureServe (2009) found 41% of stomach contents were plant fragments, and 26% were parts of arthropods. Adult Nashville crayfish tend to be solitary, and seek cover under large rocks (e.g., Fig. 3), logs, debris, or rubble, with the largest individuals selecting the largest cover available (USFWS 1988). Cover is aggressively defended (see Fig. 5), and cover availability may be a limiting factor in some areas (USFWS 1988). Predators include raccoons (Fig. 4), and a number of other mammals, fish, and birds are known to prey on crayfish. Humans also harvest crayfish, although "the harvest, use, and possession of crayfish is prohibited in Mill Creek in Davidson and Williamson counties including tributaries and adjacent stream banks" (Tennessee Wildlife Resources Agency, 2010).

The Nashville crayfish may be fairly tolerant of habitat conditions. USFWS (1988) reported that *O. shoupi* "has been found in a wide range of environments including gravel and cobble runs, pools with up to 10 centimeters of settled sediment, and under slabrocks and other cover… The species has also been found in small pools where the flow was intermittent. Gravel-cobble substrate provides good cover for juveniles. Females seek out large slabrocks when they are carrying eggs and young; these secluded places are also needed for molting. The species is highly photosensitive and is usually found under cover during the day, although they sometimes forage in the open, at least in the main stem of Mill Creek during parts of the summer. Occupied sites typically have tree canopy cover of 60 to 90 percent."

NatureServe (2009) states that *O. shoupi* "inhabits moderately flowing streams with firm, usually rocky bottoms." Barrociere (1986) reported that *O. shoupi* is rare in small streams, but is able to maintain populations in areas of the main channel of Mill Creek (Fig. 2) that are not heavily polluted and contain rocky cover. Removal of riparian vegetation greatly decreased an *O. shoupi* population (Barrociere, 1986). Barrociere (1986) recommended preserving areas with adequate vegetation, medium to large limestone rocks, and moderate flow conditions. Withers (2005) wrote that "preferred habitat includes slabrock over bedrock or cobble substrates in free flowing streams, although at least two exceptions involving impoundments have been reported." Siltation from poor land use practices are the primary threat (Withers, 2005).

Withers (2005) identified three drainages in particular as having a high conservation priority based on the relative abundance of *O. shoupi* and apparent system integrity: Indian Creek; Mill Creek upstream of downtown Nolensville; and the unnamed Nolensville tributary to Mill Creek that originates near Burke Hollow Road. Each of these streams was in relatively good condition compared to much of the remainder of the Mill Creek watershed (Withers, 2005).

<u>Habitat modeling</u>

Hopkins (2009) compared the distribution of *Quadrula cylindrica*, a freshwater mussel, to environmental variables at multiple scales in the upper Green River system in Kentucky. Variables included land use/land cover pattern and composition, soil composition, and geology, at the subcatchment scale, subcatchment riparian buffer (100 m from the stream), and riparian buffer for a 100m upstream reach. Boosted regression trees found the most influential variables to be patch density at the reach scale and soil composition at the riparian scale.

We sought to identify habitat with the highest conservation importance, separating robust populations (in particular, with Excellent or Good viability) from incidental or less viable occurrences. Our analyses, described below, were limited to coarse-scale variables. Microhabitat features like stream substrate or submerged vegetation might be inferred by larger scale conditions, but are best measured by field surveys.

Methods

<u>Study area</u>

Orconectes shoupi is restricted to the Mill Creek watershed in Williamson and Davidson Counties, Tennessee. Mill Creek flows north into the Cumberland River about 2 miles upstream from downtown Nashville. The watershed covers 280 km^2. Mean annual discharge at the Woodbine gauge varied between 65.8 and 222.0 cubic feet per second (cfs) between 1997 and 2008 (USGS, 2010). Peak streamflow during the same period varied between 2,670 and 14,400 cfs.

The Mill Creek watershed is underlain by limestone, with three types dominating the watershed, especially in stream valleys (Table 1). Mill Creek's substrate is primarily bedrock, which is covered in some areas with gravel and scattered limestone slabs (Biggins, 1988). The pools, backwater areas, and stream margins are covered with silt and sand (Biggins, 1988).

Table 1. Geology types along streams in the Mill Creek watershed (using Hardeman, 1966).

Code	Geologic classification	Description	% of riparian zone
Oca	Carters Limestone	Brownish-gray phosphatic calcarenite and light-gray to brownish-gray, cryptograined to medium-grained, even-bedded limestone. Thickness 50 to 125 feet.	55%
Olb	Lebanon Limestone	Fine-grained, yellowish-brown limestone; thin-bedded in upper part; thicker bedded and very slightly cherty with scattered mottlings of magnesian limestone in lower part. Contains thin bentonite beds. Thickness 50 to 100 feet.	24%
Obh	Bigby-Cannon Limestone	Thin-bedded, gray limestone with calcareous shale partings. Thickness 80 to 100 feet.	20%

Much of the upper Mill Creek watershed is still rural, with a mixture of pasture and forest. The lower half of the watershed, however, is heavily urbanized, with a mixture of commercial and residential development. Nashville International Airport covers a large part of the lower watershed. Urbanization has been increasing rapidly, and very little land (<5%) is protected from development. Many landowners clear streamside vegetation, which can lead to drying, eutrophication, and other impairments (Figs. 9-13).

Mill Creek is prone to flooding. The May 2010 flood surpassed all previous records (26.1 feet (8.0 m) at the Antioch gauge and 21.4 feet (6.6 m) at the Woodbine gauge on May 1), killed at least five people and caused millions of dollars in property damage (see Figs. 2 and 6). Conversely, many of the tributaries, especially the upper reaches, dry completely during periods of low rainfall (see Figs. 7 and 12). Some individual crayfish may bury themselves until water returns (Fig. 8).

Locational data

We received *O. shoupi* occurrence polygons (n=111) from the Tennessee Natural Heritage Inventory Program, spanning the years 1985-2010. Some of these polygons were buffered stream segments; the species was found throughout that section of stream. The others were buffered points. We used the entire data set, because none of these occurrences had been extirpated. 88% of the observations dated from 1999 or later, and 62% dated from 2005-2010. We converted multipart features to singlepart, calculated the centroids of these polygons, and moved them, if necessary, to align with the stream. We considered sections bounded by stream confluences separately.

We then added absence data from 2005-8 surveys, disregarding unsampled sites. To correct spatial errors, we moved some of the locations slightly to align with the corresponding stream location. We split the combined data into two groups: (1) persisting populations of *O. shoupi* (estimated population viability of "Fair" or better; n = 159), and (2) populations not persisting on their own without recolonization (estimated population viability of "Possibly fair", "Fair or poor", or "Poor"), or individuals absent entirely (n = 74).

Land cover

We contracted WorldView Solutions, Inc. (Richmond, VA) to classify land use/land cover (LU/LC) from 2008 National Agriculture Imagery Program (NAIP) aerial imagery, with a 1 m spatial resolution (Table 2). We selected 10 random points within each class and compared them to aerial photographs and local knowledge for accuracy. WorldView revised the imagery twice to improve its accuracy. Table 3 summarizes the second round of accuracy assessment. The final classification eliminated the open wetland class, as none could be found. Table 2 lists the area of each LU/LC class in the Mill Creek watershed.

Table 2. Land use/land cover classes and areas in the Mill Creek watershed (final version).

Class	**Description**	**Area (ha)**	**Area (%)**
Forest	Areas with generally >75% tree cover	7239.4	26.0%
Emerging forest / shrub	Young forest or shrub-scrub	980.4	3.5%
Urban canopy	Trees in urban areas (e.g., backyards)	3408.6	12.2%
Developed land	Generally clear of forest, not used for an agricultural purpose, and may include some areas of sparse tree cover.	5623.9	20.2%
Developing land	Bare due to construction or some other similar type of development.	419.5	1.5%
Golf course	Areas of golf courses that are clear of trees and contain, but are not limited to, fairways, greens, and sand traps.	62.4	0.2%
Rural land	Generally clear of forest, rural in nature, and may include some areas of sparse tree cover. This includes unmaintained fields, grazed pasture, row crops, orchards, vineyards, and nurseries.	4138.0	14.8%
Disturbed land	Bare earth, unreplanted clearcuts, and debris-filled land, but not man-made hard surfaces.	66.6	0.2%
Exposed mining	Surface mined land	44.8	0.2%
Open water	Covered with open water	70.7	0.3%
Forested wetland	Areas defined as wetlands by the National Wetlands Inventory, and generally forested (>25% tree cover).	19.5	0.1%
Herbaceous wetland	Areas defined as wetlands by the National Wetlands Inventory, and generally clear of trees (<25% tree cover).	0.0	0.0%
Impervious surfaces	Buildings, paved surfaces, and other man-made hard surfaces.	5794.2	20.8%

Table 3. Classification accuracy of Mill Creek land use/land cover.

		Visual interpretation of aerial imagery												
Land cover classification	Number of samples	Forest	Emerging Forest/Shrub	Developed Land	Developing Land	Urban Canopy	Golf Course	Rural Land	Disturbed Land	Exposed Mining	Open water	Forested Wetland	Open Wetland	Impervious
Forest	10	8	2											
Emerging Forest/Shrub	10	1	9											
Developed Land	10			8										2
Developing Land	10				10									
Urban Canopy	10					10								
Golf Course	0													
Rural Land	10							10						
Disturbed Land	10								10					
Exposed Mining	10									10				
Open Water	10										10			
Forested Wetland	10											10		
Open Wetland	10												10	
Impervious	10													10

Catchment variables

We obtained streams, stream catchments, and flow data from NHDPlus (Bondelid et al., 2007). In addition, we calculated land cover within each cumulative catchment (i.e., the entire drainage, not just a subsection) using the NHDPlus Catchment Attribute Allocation and Accumulation Tool (CA3T; Horizon Systems Corporation). We also calculated a Developed Land Cover Buffered Flowpath Metric: the length in meters of forest or wetland cells that a developed land cover cell flows through to reach the nearest stream; and an Agriculture Buffered Flowpath Metric; the length in meters of forest or wetland cells that an agricultural land cover cell flows through to the nearest stream. These metrics, which incorporate land cover, topography and hydrology, can represent potential water pollution loads better than simple land use percentages or fixed buffer width metrics (Baker et al., 2006). We summed the inverse buffer width (1 / (buffer flow length in meters + 1)) for agriculture and developed land within each cumulative catchment, representing non-point pollution loading to the stream reach. A value of 1 represents direct inflow from agricultural or developed land, and values below 1 represent pollution absorption by forest or wetland buffers. Accumulated land cover data had to be resampled to 30 m resolution to compute metrics in CA3T.

Table 4 lists the variables computed within each NHDPlus catchment, and Table 5 shows how land cover classes were aggregated into agriculture, developed, forests and wetlands, or other. None of the NHDPlus reaches were classified as channelized, although some streams had been channelized in the past. We examined correlations between catchment variables, and removed variables from highly correlated (>0.8) pairs from further consideration. We computed the remaining catchment variable values at each *O. shoupi* sample location.

Table 4. Variables computed within each NHDPlus catchment in the Mill Creek watershed.

Variable	Definition
DRAIN_AREA	Cumulative drainage area (km^2)
FORA_SUMSC	Cumulative sum of forest area (m^2)
FORP_MEANVC	Cumulative mean percent of forest cover (%)
IBWA_SUMSC	Cumulative sum of inverse buffer width from agriculture (1 / (buffer flow length in meters + 1)).
IBWD_SUMSC	Cumulative sum of inverse buffer width from developed land (1 / (buffer flow length in meters + 1))
ICA_SUMSC	Cumulative sum of impervious cover area (m^2)
ICP_MEANVC	Cumulative mean percent of impervious cover
LC_AGPCT	Cumulative area-weighted percent of agricultural land
LC_DEVPCT	Cumulative area-weighted percent of developed land
LC_FORPCT	Cumulative area-weighted percent of forests and wetlands
LC_OTHPCT	Cumulative area-weighted percent of other land
MAFLOWU	Mean Annual Flow - Unit Method (cfs)
MAFLOWV	Mean Annual Flow - Vogel Method (cfs)
MAVELU	Mean Annual Velocity - Unit Method (fps)
MAVELV	Mean Annual Velocity - Vogel Method (fps)
SLOPE	Mean channel slope (m/m)

Table 5. Reclassification of land cover to compute buffer metrics.

Class Name	Reclass
Forest	forests and wetlands
Emerging forest/shrub	forests and wetlands
Urban canopy	developed
Developed Land	developed
Developing Land	developed
Golf course	developed
Rural land	agricultural
Disturbed land	developed
Exposed mining	developed
Open water	other
Forested wetland	forests and wetlands
Open wetland	forests and wetlands
Impervious surfaces	developed

<u>Local variables</u>

We calculated four variables at the local scale: geology type, flow accumulation, proportion of forest or wetland cover within 30 m, and proportion of tree cover within 30 m. Geology type came from a map digitized from Hardeman (1966) at a scale of 1:250,000; we selected the most abundant (majority) type within 30 m of each sample point. We used the 30 m flow accumulation grid from NHDPlus (which models the surface flow of water through each grid cell by counting the number of upslope cells). Because all sampling was performed in streams and other water bodies, and to correct for positional errors, we selected the maximum flow accumulation value within 30 m of each sample point. Next, we reclassified the 1 m land cover to separate forests and wetlands from developed or agriculture (Table 6), and calculated the proportion of forest and wetland within 30 m of each sample point. Finally, we used a similar procedure to calculate the proportion of tree and shrub cover within 30 m (also in Table 6). This included urban tree cover. We did not use soil data, available from SSURGO, for any variables because they were inconsistent between the two counties comprising the majority of Mill Creek watershed.

Table 6. Reclassification of land cover to identify forests and wetlands and tree cover.

Class Name	Reclassification to forests and wetlands	Reclassification to tree and shrub cover
Forest	1	1
Emerging forest/shrub	1	1
Urban canopy	0	1
Developed Land	0	0
Developing Land	0	0
Golf course	0	0
Rural land	0	0
Disturbed land	0	0
Exposed mining	0	0

Open water	No Data	No Data
Forested wetland	1	1
Open wetland	These areas were not functioning wetlands	0
Impervious surfaces	0	0

We also calculated a binary variable (DRAINS_BNA) at the stream segment scale. We noted whether or not a stream originated at the Nashville International Airport, and received runoff from airfield pavement. None of these streams (Sims Branch, Elissa Branch, and an unnamed tributary to Mill Creek) contained viable populations of *O. shoupi*. De-icing chemicals from airports can kill aquatic life (Fisher et al., 1995). Sims Branch was contaminated by such chemicals in March 2010, and six *O. shoupi* were found dead there (WSMV, 2010a, 2010b).

<u>Univariate tests</u>
We compared individual variables to presence of viable *O. shoupi* populations in NCSS (Hintze, 2007), using one-way analyses of variance (ANOVAs) for continuous variables and cross-tabulation for categorical variables.

<u>Boosted regression model</u>
We converted the data to CSV format and imported it into R (R Development Core Team, 2010; version 2.12.0). We used generalized boosted regression modeling (package gbm, version 1.6-3.1; Ridgeway, 2007) to fit the variables to the *O. shoupi* persistence data. Gradient boosting constructs additive regression models by fitting parameterized functions to sequentially minimize the difference between model output and training data (Friedman, 2002). Random subsampling improves model accuracy (Friedman, 2002). We used the AdaBoost algorithm (Ridgeway, 2007), an exponential loss function that works with binary data (e.g., persistent/non-persistent) and can incorporate categorical data (e.g., geology type).

The first gbm model utilized all variables <80% correlated (DRAIN_AREA, SLOPE, LC_DEVPCT, IBWA_SUMSC, IBWD_SUMSC, GEOTXTCODE, FLOW_ACCUM, PFOREST30M, P_TREE_30M, and DRAINS_BNA). Following recommendations in Ridgeway (2007) and after some experimentation, we set weights = NULL, monotone vector = (1,0,-1,0,0,0,1,1,1,0), number of trees = 10000, interaction depth = 3, minimum number of observations in terminal nodes = 10, shrinkage = 0.001, bag fraction = 0.5, training fraction = 1.0, and 5-fold cross-validation). We compared this to a model that removed catchment variables >70% correlated with others. To avoid model overfitting, we used the module gbm.perf and 5-fold cross-validation to estimate the optimal number of boosting iterations. Then, we used the module predict.gbm to compare model output to the *O. shoupi* persistence data.

<u>Model prediction throughout the watershed</u>
To compensate for spatial inaccuracies, we buffered NHD high resolution flowlines 30 m, and converted this to a grid with 60 m cell size. We then converted these grid cells to points, and buffered these points (in the center of the cell) 30 m to calculate local-scale variables. We identified which NHDPlus catchment the points fell in, and assigned the catchment data to the point. We expected some spatial error here.

We also calculated the same local scale variables within each 30 m point buffer as was done for the *O. shoupi* sample locations.

We converted this data to CSV format and brought it into R. We used the module predict.gbm to predict *O. shoupi* persistence at each stream point in the Mill Creek watershed, using the model created from the sampling data with the "best" number of trees. We omitted stream points with geology types not found in the sampling data (Leipers and Catheys Formations or Water; 0.4% of stream points).

We then computed the average model prediction within each NHDPlus catchment, and compared these values to the sampling data to estimate a suitability threshold. We sought a threshold that captured the highest proportion of known persistent *O. shoupi* occurrences, while rejecting the highest proportion of absences or non-persistent populations. Finally, we identified ESRI named streams (ESRI, 2006) within these catchments. These contained fewer first order streams than NHD high resolution flowlines, and were more likely to be perennial.

Results

Correlations between catchment variables

Drainage area was highly correlated (>0.8) with all measurements of stream flow and velocity, and cumulative forest area (Table 7). Percent development, agriculture, forest and wetland, forest, and impervious surface were all highly correlated, either negatively or positively. Developed inverse buffer width was highly correlated with impervious surface area. We retained the following variables for further analyses: DRAIN_AREA, LC_DEVPCT, SLOPE, IBWA_SUMSC, and IBWD_SUMSC. The last three variables were somewhat highly correlated (0.7-0.8) with DRAIN_AREA.

Table 7. Correlations between catchment variables (Spearman ranks, n=126 for all pairs).

	DRAIN_AREA	MAFLOWU	MAFLOWV	MAVELU	MAVELV	SLOPE	LC_AGPCT	LC_DEVPCT	LC_FORPCT	LC_OTHPCT	IBWA_SUMSC	IBWD_SUMSC	FORA_SUMSC	FORP_MEANVC	ICA_SUMSC	ICP_MEANVC
DRAIN_AREA	1.000															
MAFLOWU	1.000	1.000														
MAFLOWV	0.982	0.982	1.000													
MAVELU	0.901	0.901	0.881	1.000												
MAVELV	0.926	0.926	0.943	0.963	1.000											
SLOPE	-0.789	-0.789	-0.822	-0.557	-0.683	1.000										
LC_AGPCT	0.287	0.287	0.295	0.253	0.273	-0.220	1.000									
LC_DEVPCT	-0.204	-0.204	-0.202	-0.190	-0.178	0.082	-0.920	1.000								
LC_FORPCT	0.196	0.196	0.190	0.193	0.169	-0.058	0.800	-0.952	1.000							
LC_OTHPCT	0.246	0.246	0.234	0.150	0.182	-0.293	0.204	-0.121	0.031	1.000						
IBWA_SUMSC	0.724	0.724	0.747	0.616	0.661	-0.671	0.715	-0.645	0.585	0.268	1.000					
IBWD_SUMSC	0.721	0.721	0.732	0.622	0.672	-0.714	-0.258	0.391	-0.377	0.172	0.383	1.000				
FORA_SUMSC	0.882	0.882	0.886	0.791	0.819	-0.756	0.503	-0.488	0.490	0.273	0.899	0.561	1.000			
FORP_MEANVC	0.196	0.196	0.190	0.192	0.169	-0.058	0.800	-0.952	1.000	0.031	0.585	-0.377	0.490	1.000		
ICA_SUMSC	0.762	0.762	0.763	0.663	0.704	-0.717	-0.241	0.345	-0.329	0.181	0.401	0.957	0.606	-0.329	1.000	
ICP_MEANVC	-0.183	-0.183	-0.184	-0.169	-0.165	0.099	-0.894	0.921	-0.873	-0.135	-0.588	0.358	-0.426	-0.873	0.397	1.000

Univariate tests

Univariate and correlative analyses indicated that larger streams, more rural areas, sites with riparian buffers, and Lebanon limestone bedrock more likely contained persistent populations of *O. shoupi* (Tables 8 and 9). MAFLOWV and MAVELV contained some values of -9999 (corresponding to no data); thus the negative mean values. Persistent *O. shoupi* populations occurred more often over Lebanon limestone than other geology types, and over Bigby-Cannon limestone less often (χ^2 = 26.2, n=232, p<0.001). Carters limestone appeared no different from the average. No persistent populations occurred in streams draining from Nashville International Airport (χ^2 = 13.4, n=232, p<0.001).

Table 8. Relationships between individual variables and *O. shoupi* persistence. Except where marked "n.s.", ANOVA tests were all significant at p<0.05, although data were not normally distributed.

Variable	**Mean value for persistent population**	**Mean value for non-persistent or absent population**
DRAIN_AREA	67.6	36.5
MAFLOWU	36.6	19.8
MAFLOWV	-595	-3132
MAVELU	0.950	0.865
MAVELV	-627	-3150
SLOPE	0.00506	0.00890
LC_AGPCT	19.4	14.5
LC_DEVPCT	45.8	55.9
LC_FORPCT	34.6	29.4
LC_OTHPCT	n.s.	n.s.
IBWA_SUMSC	519	765
IBWD_SUMSC	21631	12027
FORA_SUMSC	2.374297E+07	1.250057E+07
FORP_MEANVC	34.6	29.4
ICA_SUMSC	10.66237E+06	6.351054 E+06
ICP_MEANVC	0.95	1.40
FLOW_ACCUM	74703	26614
PFOREST30M	0.461	0.305
P_TREE_30M	0.590	0.437

Table 9. Relationship between geology types and *O. shoupi* persistence.

	Geology type			
Persistent?	Obh	Oca	Olb	Total
yes	8	91	60	159
no	19	42	12	73
Total	27	133	72	232

Boosted regression tree model

Mean channel slope, catchment runoff from development and agriculture, and geology type were the most important variables in the boosted regression tree model using all variables <80% correlated (Table 10). Using a threshold of 0.3, this model correctly identified 87% of locations containing persistent *O. shoupi* populations and 77% of locations without persistent populations (χ^2 = 91.0, n=232, p<0.001). Cross-validation estimated that the optimal number of iterations was 5929.

Table 10. Variable contributions to predict persistent *O. shoupi* populations in the Mill Creek watershed, using all variables <80% correlated and the optimal number of iterations.

Variable	**Relative influence (%)**
SLOPE	36.99
IBWD_SUMSC	19.10
IBWA_SUMSC	18.74
GEOLOGY_TYPE	11.05
DRAIN_AREA	6.55
LC_DEVPCT	6.18
PFOREST30M	1.02
P_TREE_30M	0.27
FLOW_ACCUM	0.10
DRAINS_BNA	0.00

Geology type and catchment percent development were the most important variables in the boosted regression tree model without catchment variables >70% correlated (Table 11). Using a threshold of 0.3, this model correctly identified 92% of locations containing persistent *O. shoupi* populations, but only 34% of locations without persistent populations (χ^2 = 26.6, n=232, p<0.001). A threshold of 0.4 correctly identified 65% of locations containing persistent *O. shoupi* populations and 56% of locations without persistent populations (χ^2 = 9.0, n=232, p<0.005). Cross-validation estimated that the optimal number of iterations was 1401. This model tended to capture occurrence and non-occurrence points alike, performing much worse than the model that included SLOPE, IBWD_SUMSC, and IBWA_SUMSC.

Table 11. Variable contributions to predict persistent *O. shoupi* populations in the Mill Creek watershed, using variables <70% correlated and the optimal number of iterations.

Variable	**Relative influence (%)**
GEOTXTCODE	85.71
LC_DEVPCT	12.35
PFOREST30M	1.08
P_TREE_30M	0.43
DRAIN_AREA	0.28
FLOW_ACCUM	0.13

<u>Model prediction throughout the watershed</u>

We applied the first boosted regression model, which predicted more accurately than the second, to all streams in the Mill Creek watershed (Fig. 15). Figure 16 shows the predicted suitable streams in the watershed. These captured 83% of locations containing persistent *O. shoupi* populations and omitted 81% of locations without persistent populations ($\chi^2 = 88.7$, n=233, p<0.001; Table 12).

Table 12. Relationship between predicted suitable streams and *O. shoupi* persistence.

	Observed persistent population		
Predicted suitable stream	no	yes	Total
no	60	27	87
yes	14	132	146
Total	74	159	233

Although the model generally agreed with observational data, we noted several discrepancies. The model predicted Turkey Creek and an upper tributary to Sevenmile Creek to be unsuitable, yet these streams contained *O. shoupi*. The model predicted Holt Creek to be suitable, but we had no sampling data except near the confluence with Mill Creek (where the species was found). Finally, entire stream segments were selected, but the upper portions of some streams may dry during the summer.

Discussion

Based on available survey and environmental data, we predicted the Mill Creek main stem and several of its tributaries, including Sevenmile Creek, Whittemore Branch, lower Collins Creek, lower Indian Creek, Holt Creek, most of Owl Creek, Edmondson Branch, and several unnamed tributaries to provide suitable habitat for *Orconectes shoupi*. In most cases, the model identified the lower portions of these tributaries, and rarely selected headwaters. Because we lacked microhabitat data, the model missed Turkey Creek, which has a deep, shaded, linear pool that provides habitat in dry periods.

The boosted regression model resembled a maximum entropy (Maxent) model we ran that relied on 2001 land cover (Fig. 17; see earlier Nashville crayfish report), with some differences. The Maxent model predicted about a third of the stream reaches in the Mill Creek watershed to be Excellent or Good habitat for *O. shoupi*, and captured 100% of 1994-2007 occurrences with a viability of Excellent or Good; 56% of occurrences rated Possibly Good, Fair, or Possibly Fair; and 29% of locations rated Poor or Absent. Model differences probably rely more on differing algorithms than on land use changes between 2001 and 2008.

Catchment slope, inverse agricultural buffer width, inverse development buffer width, and geology type were the top predictive variables. Considered singly, larger streams, more rural areas, better buffered sites, and Lebanon limestone bedrock more likely contained persistent populations of *O. shoupi*. Persistent populations of *O. shoupi* occurred primarily in larger perennial streams like Mill Creek and Sevenmile Creek, rather than in headwaters. In general, headwater streams are more prone to drying out than larger streams, and this may be a factor. Urban streams tend to be flashier than rural streams, with higher peak storm flows and lower base flows, which impacts many aquatic organisms (Konrad and Booth, 2005). Slope was negatively correlated with *O. shoupi* population viability, but streams with greater slopes were also headwater streams. We lacked data on springs, which can make upper tributaries more suitable.

Within stream reaches, microhabitat features such as substrate, bank stability, and pool depth may be important factors. Unlike many species ranges, Mill Creek has a relatively small drainage area (279 km^2), and can be surveyed in detail. We hope that the coarse-scale modeling described here can help prioritize more detailed surveys, and also emphasize the importance of catchment-scale geomorphic and land use conditions.

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Fig. 1. Male *Orconectes shoupi* captured in Bittick Creek.

Fig. 2. Mill Creek downstream of Thompson Lane Dairy King.
Note plastic bags on tree branch, indicating flood height in May 2010.

Fig. 3. Large rock slab in Mill Creek, which had *O. shoupi* beneath.

Fig. 4. Crayfish shells in raccoon midden.

Fig. 5. Two *O. shoupi* displaying territorial behavior.

Fig. 6. Rock slabs pushed against a bridge by the May 2010 flood.

Fig. 7. Owl Creek dried at Ragsdale Road.

Fig. 8. Female juvenile *O. shoupi* awaits standing water beneath a rock slab in Owl Creek at Ragsdale Road.

Fig. 9. Indian Creek reach with riparian cover.

Fig. 10. Vegetation cleared along Indian Creek at golf practice range.

Fig. 11. Vegetation cleared along Indian Creek on opposite bank of golf practice range.

Fig. 12. Indian Creek along golf practice range, with intermittent flow and heavy algae buildup.

Fig.13. Development along Mill Creek with no riparian buffer.

(All photos by T. Weber or D. Withers, 29 July 2010)

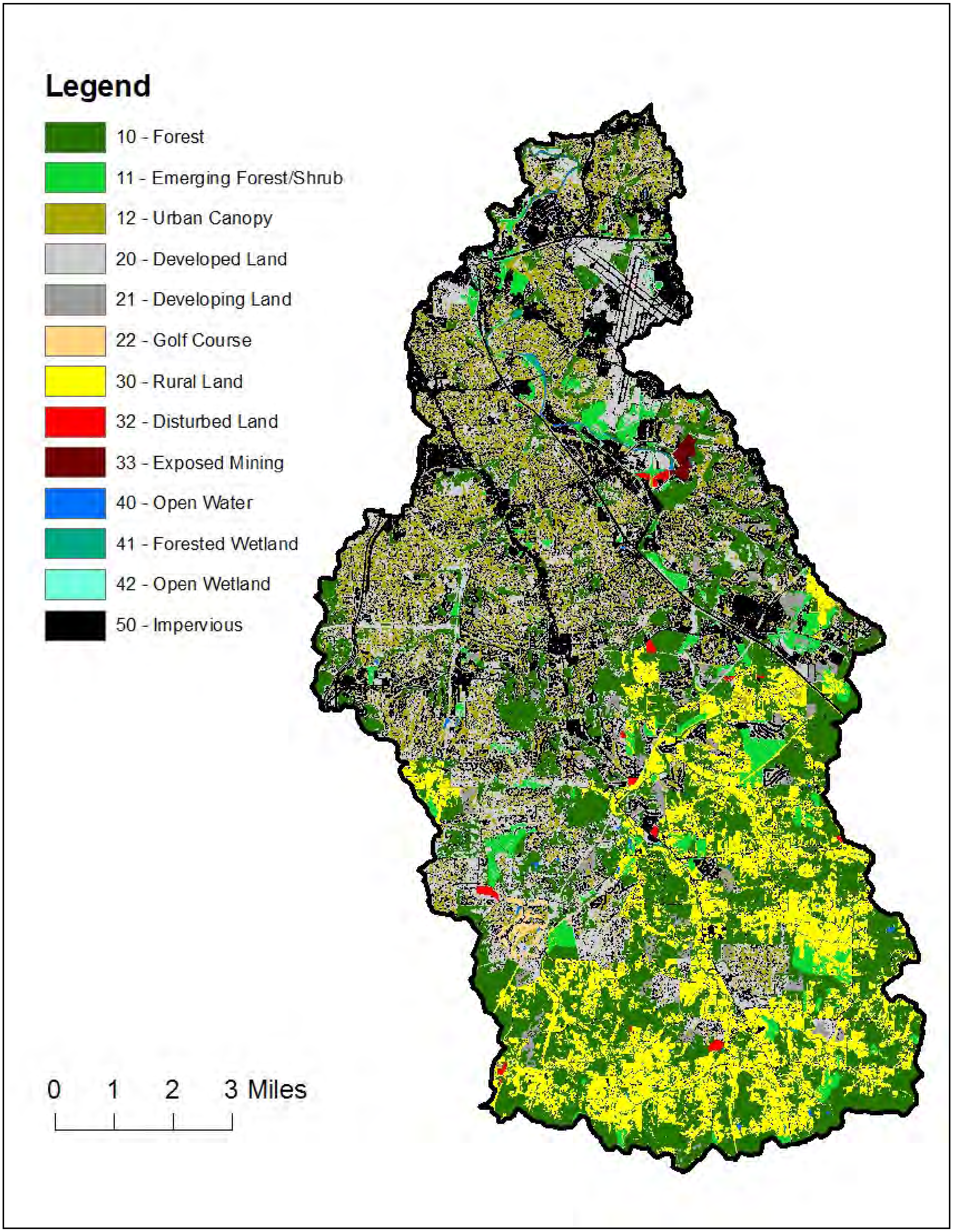

Fig. 14. 2008 land cover in the Mill Creek watershed.

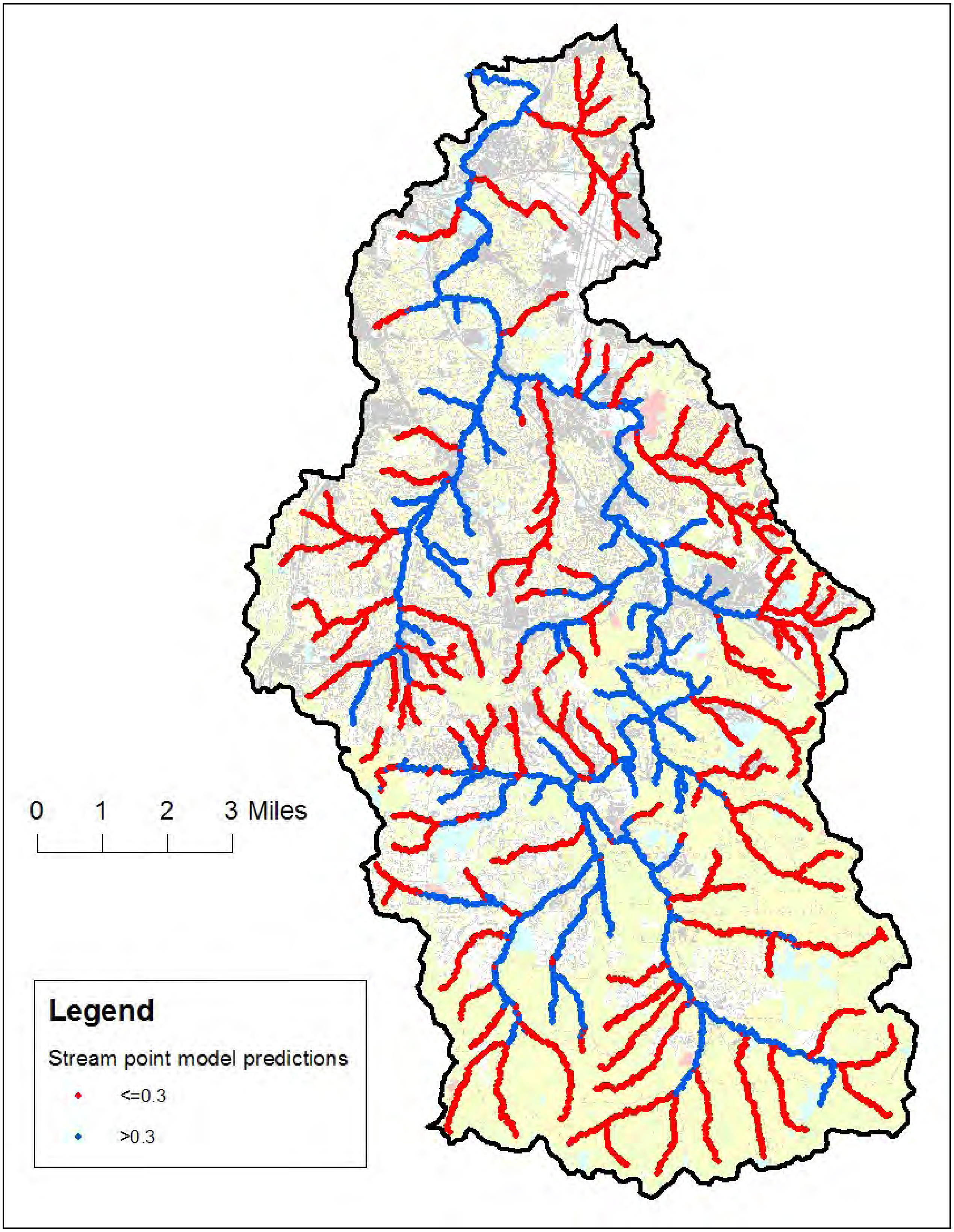

Fig. 15. Boosted regression output predicting suitable habitat for *Orconectes shoupi* in the Mill Creek watershed.

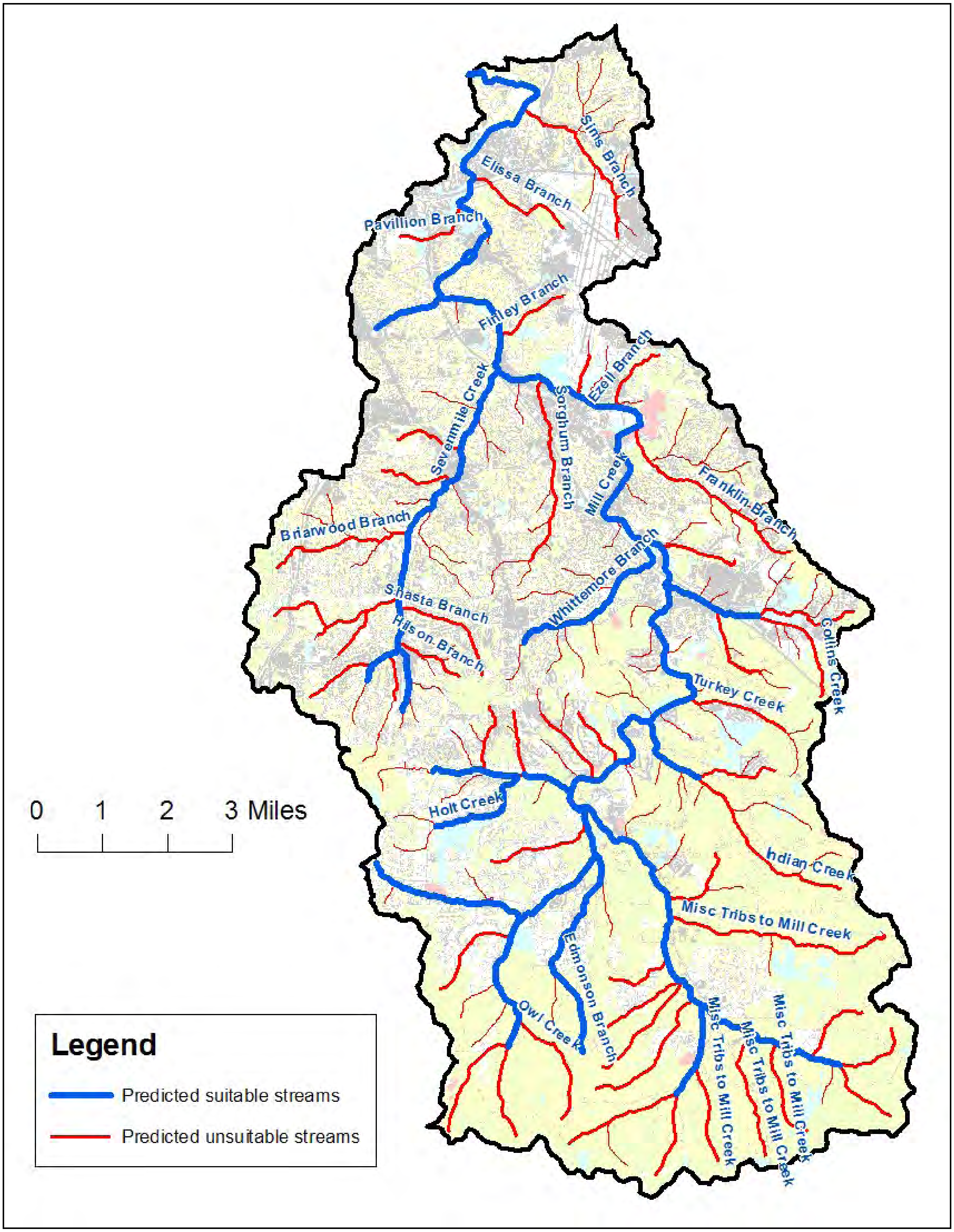

Fig. 16. Predicted suitable streams for *Orconectes shoupi* in the Mill Creek watershed.

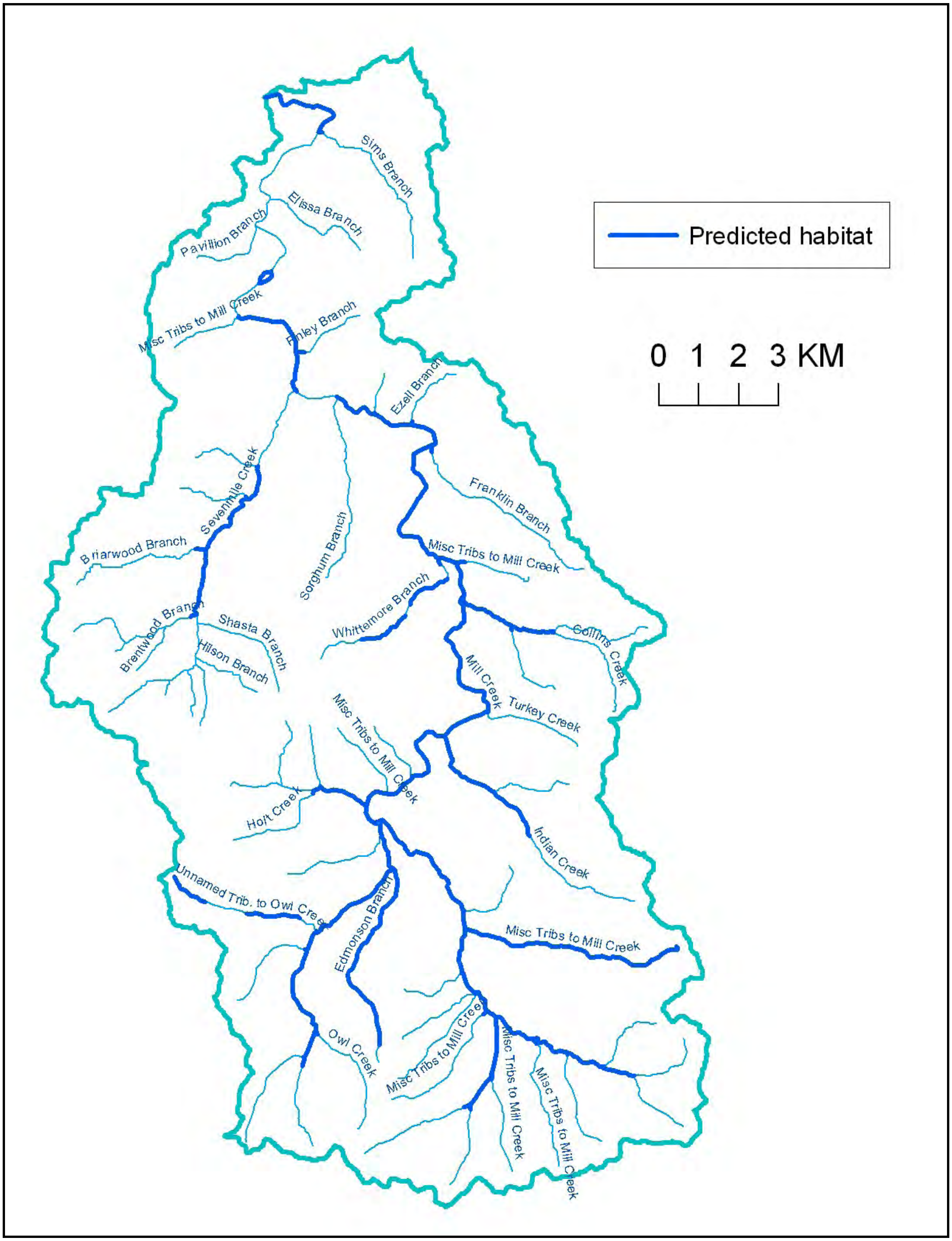

Fig. 17. For comparison, predicted suitable stream segments for *Orconectes shoupi* using a maximum entropy model and 2001 land cover.

Tennessee Wildlife Action Plan Summary

Nashville Crayfish (*Orconectes Shoupi)*

Taxa: Crustacean
Nashville Crayfish Status:
(Appendix A: 9)
Federal Status: Endangered

State Status: Endangered

Aquatic Target Habitat Group
Species of Greatest Conservation Need (SGCN): Tier 3

Critically imperiled in state; 5 or fewer occurrences statewide

Nashville Crayfish Location and Habitat Defined:
(Appendix A: 19)
Cumberland River Drainage
- Lower Cumberland River Drainage

(Appendix A: 34)
Aquatic Habitat Preference Type:
Highland Rim Streams

Conservation Process – Issues and Actions for the Nashville Crayfish:
(Appendix A: 34)
Source of Stress:
- Commercial/Industrial Development
- Incompatible Row Crop Agricultural Practices
- Industrial Discharge
- Municipal Wastewater Treatment/Stormwater Runoff
- Primary Residential Development

(TN CWCS: 172)
Priority Aquatic Conservation Actions by Source of Stress:
Commercial/Industrial Development
- Coordinate planning for land acquisition among agencies and NGOs.
- Coordinate planning for easement acquisition among agencies and NGOs.
- Participate in environmental review procedures for construction projects.
- Participate in the review of county urban growth management plans.

Incompatible Row Crop Agricultural Practices
- Propose legislation to expand government-funded incentive programs.
- Develop strategic alliance with Farm Bureau, NRCS, FSA, and others.
- Utilize government-funded incentive programs for landowners to improve/protect water quality.

- Restore pastures, fields, and other agricultural lands.

Industrial Discharge

- Evaluate standards for conducting environmental review of projects.
- Develop network of trained aquatic biologists to assist TDEC's monitoring.

Municipal Wastewater Treatment/Stormwater Runoff

- Evaluate standards for conducting environmental review of projects.
- Develop network of trained aquatic biologists to assist TDEC's monitoring.
- Participate in environmental review procedures for construction projects.
- Participate in the review of county urban growth management plans.

Primary Residential Development

- Evaluate standards for conducting environmental review of projects.
- Coordinate planning for easement acquisition among agencies and NGOs.
- Participate in the review of county urban growth management plans.
- Develop strategic alliance with TDOT, planners, developers, and others.