Northeast Aquatic Habitat Classification System

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Project Goal: The goal of this project was to develop a standard classification system and GIS dataset to describe and map stream systems across thirteen northeastern states (Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Pennsylvania, New Jersey, Delaware, Maryland, Virginia, West Virginia, and District of Columbia.). We designed the classification and GIS dataset to consistently represent the natural flowing-water aquatic habitat types across this region in a manner deemed appropriate and useful for conservation planning by the participating states. The system is meant to unify state classifications and promote an understanding of aquatic biodiversity patterns across the region. It is not intended to override local stream classifications but rather to put them into a broader context. To ensure the product's utility we formed a workgroup that included more than thirty agency biologists representing every state.

Products: Final products include this report, stream and lake aquatic habitat type GIS datasets, attribute tables, and GIS .lyr files for symbolizing the data in ArcGIS 9.2. The datasets were packaged for the full region, by state, and by the 6 major drainage basins intersecting the region. Please see Appendix I for metadata describing the distributed GIS datasets and attribute tables. We named this project the **Northeast Aquatic Habitat Classification System** or **NAHCS**.

Background: With the creation and implementation of State Wildlife Action Plans (SWAP) by state fisheries and wildlife agencies, the need for consistent, current digital habitat maps has grown dramatically. The implementation of the SWAPs within each state and across the Northeast region will be enhanced by the development of current, consistent terrestrial and aquatic habitat classification systems and their accompanying geographic information systems (GIS) datasets. These habitat datasets are expected to form the foundation of state and regional conservation in the northeast, and to:

- Provide common definitions and mapping of aquatic habitat types across state lines allowing each state to identify aquatic habitats consistently across jurisdictional borders. This will also improve the success of state-level actions by assisting jurisdictions that have not yet developed aquatic habitat classification and mapping tools.
- Facilitate a new understanding of aquatic biota and populations on a regional scale by linking biological datasets to the regional aquatic habitat types for reporting and analysis.
- Create a new opportunity to assess the condition and prioritize habitats at a scale broader than the individual state by linking and reporting information on dams, land use, conservation lands, impaired waters, and other condition metrics by the regional aquatic habitat types

Team and Approach: We formed a workgroup in October 2007 to assist with this project. Aquatic ecologist, fisheries scientist, and freshwater planning State Agency staff from each of the 13 states were invited to participate along with federal, academic, and NGO partners active in freshwater planning in the region. In all, over 30 state, federal, university, and NGO representatives participated in the workgroup during the duration of the project (Appendix II).

Workgroup members were required to participate in monthly team calls, review the proposed methods, facilitate access to state datasets, and review drafts of the developing regional taxonomy and map. Members were also given logins to access and post materials on the project's NBII website, http://my.nbii.gov/portal/. Depending on their time and the availability of relevant state datasets, certain members also provided critical data analysis to help explore questions related to the aquatic classification variables and threshold.

Monthly conference calls were used to facilitate workgroup activity. The calls covered topics related to aquatic classification methods, key variables, methods for modeling each variable in GIS, methods for developing relevant thresholds for each variable, and methods to combine and simplify the variables into unique habitat types. The calls typically had representatives from at least 10 states and the presentations and notes from each call were posted on the project website. Each call began with a presentation by TNC's Regional Director of Conservation Science, Mark Anderson, and TNC's Aquatic Ecologist, Arlene Olivero, and followed with a "round-robin" to allow members from each state to respond and share their feedback. This cross-state sharing allowed all team members to learn about and appreciate the variation in aquatic ecosystem types and classification approaches across the region. Feedback suggests that this opportunity for cross-state discussion and sharing was one of the most valuable parts of the project to team members. It was also critical to the team reaching consensus on a final regional classification which could represent the key aquatic habitat variation in the region and within their state.

Decisions were made after considering the evidence and listening to informed opinions. When an apparent consensus emerged from the group, the project leader stated the decision to the group and asked if there was any remaining disagreement of discussion. Each monthly call began with a review of the consensus points reached on the previous call allowing the team to revisit a previous decision if necessary. For each topic, key issues were laid out and available evidence was presented to the group before the roundtable discussion began. Summaries of the issues and evidence are provided below under the appropriate topic.

Methods

A. Agreeing on a Classification Approach

No standard aquatic habitat or aquatic community classification currently exists for the U.S. To understand the variety of aquatic classifications currently being used in the region, workgroup members were asked to submit a list and description of the aquatic classification types used in their state. This information was entered into a spreadsheet to facilitate comparing and contrasting existing types (report\appendix_tables\original_state_aquatic_types.xls). The initial survey revealed that the eastern states currently recognize over 200 stream types based on many different aquatic classification systems with little standardization of types or approach. The existing classifications ranged from states with one or two aquatic habitat types (e.g. Streams and Rivers vs. Lakes) to states where over 30 unique types had been identified. Some states use habitat types based on defined biotic assemblages of fish or macroinvertebrate species (e.g. Pumpkinseed-Bluntnose Minnow community) or single specific aquatic species (e.g. Brook Trout), while others used classifications focused on abiotic aquatic habitat features (e.g. calcareous streams, high gradient streams, rivers wider than 100ft etc.). Most states separated streams and rivers from lakes and ponds. Within these two major groups, size was the most common habitat distinction. In addition to size, other habitat descriptor variables that were commonly used included water temperature, gradient, elevation, ecoregions, flow permanence, and buffering capacity.

Given the wide variation in state approaches and the lack of the comprehensive biological sample data, the group advocated for a consistent aquatic biophysical classification based on measurable factors. Moreover, the group endorsed the aquatic biophysical classification approach developed by the Nature Conservancy and recommended by the National Fish Habitat Science Panel (Higgins et al. 2005, Beard and Whelan, 2006) as the basis for this project. This approach can be implemented across regional scales using GIS modeled variables and it emphasizes differences in stream size, slope, elevation, climate, and geology which shape aquatic ecosystems at several spatial scales and influence the physical aquatic habitat template (Higgins et al. 2005).

The aquatic habitat classification framework (Higgins et al 2005) is rooted in four key assumptions about the linkages between aquatic habitat structure and biological communities. (Higgins et al. 1998): 1) Aquatic communities exhibit distribution patterns that are predictable from the physical structure of aquatic ecosystems (Schlosser 1982, Tonn 1990, Hudson et al. 1992); 2) Although aquatic habitats are continuous, we can make reasonable generalizations about discrete patterns in habitat use (Vannote et al. 1980, Schlosser 1982, Hudson et al. 1992); and 3) Large-scale physiographic and climatic patterns influence the distribution of aquatic organisms and can be used to predict the expected range of community types within these large zones (Maxwell et al. 1995, Angermeier and Winston 1998); 4) By nesting small classification units within the large climatic and physiographic zones, we can account for aquatic community diversity that is difficult to observe or measure (taxonomic, genetic, ecological, evolutionary context) (Frissell et al. 1986, Angermeier and Schlosser 1995).
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B. The Base Hydrology Map

The 2006 National Hydrography Dataset (NHD-Plus), a widely available 1:100,000 GIS dataset, was used as the base hydrology dataset for this project. This dataset provides greatly improved hydrographic features compared to all previous USGS 1:100,000 hydrology products. The NHD-Plus linework is geometrically corrected, augmented with improved names, and provides line (stream), polygon (lake), and local catchment watersheds for each flowline. This seamless national dataset contains a national system of permanent public ids that are used for linking to EPA 303d and other state and federal databases. The NHD-Plus also comes with a set of important value-added attributes for modeling and navigating upstream/downstream. Many of these pre-calculated attributes were useful in our classification effort. Moreover, USGS has a maintenance infrastructure to improve the NHD-Plus dataset and integrate user updates over time.

Current limitations in the 2006 NHD-Plus include occasional stream segments that lack directionality codes or unevenness in headwater stream densities. These errors were tolerated or adjusted for, but no attempt was made to correct errors in the source data. The team briefly discussed deriving streams from a Digital Elevation Model (DEM) to get a more consistently dense headwater hydrology output, however given that other agencies are linking their freshwater data to the NHD-Plus reach's permanent public ids, the lengthy qc process USGS used in the existing NHD-Plus for the reach spatial shapes and catchments, the reach names, and value added attributes, the team felt the NHD-Plus was still the best choice for a base hydrology map for our NAHCS classification.

C. Defining Aquatic Habitat Types

The aquatic habitat types were structured after the "macrohabitat" level of classification of Higgins et al. 2005 which defines individual stream reach or lake types based on variables that influence aquatic communities at the reach scale and that can be modeled in a GIS. The reach-scale habitat types are designed to be relatively homogeneous with respect to potential energy and nutrient dynamics and overall habitat structure. The variables commonly used to assign habitat types at this scale include stream or lake size, gradient, elevation, water acidity, substrate, stability of flow, water temperature, and local connectivity –and they can vary between regions (Higgins et al. 2005, Beard and Whelan, 2006).

Our process focused on a review of potential variables by the team to reach consensus on the most important variables, and define meaningful ecological breaks to represent aquatic habitat patterns across the eastern region. The resultant primary habitat variables and classes are described below.

Streams and Rivers: Key Variables

1. Size: Stream size is a critical factor determining aquatic biological assemblages (Vannote et al. 1980, Mathews 1998). The well known "river continuum concept" provides a description of how the physical size of the stream relates to major river ecosystem changes from small headwater streams to large river mouth (Vannote et al. 1980). For example, in narrow headwater streams coarse particulate organic matter (e.g. leaves, twigs etc.) from the riparian zone shade the river and provides the energy resource base for a consumer community dominated by shredding insects. As a river broadens at mid-order sites, energy inputs change as sunlight reaches the stream to support significant periphyton production and grazing insects. As the river further increases in size, fine particulate organic matter inputs increases and macrophytes become more abundant as reduced channel gradient and finer sediments form suitable conditions for their establishment. In even larger sites, the main channel becomes unsuitable for macrohphytes or periphyton due to turbidity, fast current, depth and/or lack of stable substrates. Autochthonous production by phytoplankton increases until limited by increasing instream turbidity. Allochthonous organic matter inputs occurring outside the stream channel will again become the primary energy source as processes such as inputs from floodplain scouring increase. These changes in physical habitat and energy source as streams grow in size are correlated with predictable patterns of changes in the aquatic biological communities (Vannote, 1980).

Catchment drainage area, stream order, number of first order streams above a given segment, and bankfull width are all measures of stream size. Catchment drainage area was chosen as the primary measure of stream size for the NAHCS because 1) the majority of states using a quantitative stream size measurement metric were already using drainage area, 2) upstream drainage area was a consistently available variable on the NHD-Plus dataset, 3) upstream drainage area is independent of the scale of the hydrography layer, and 4) the concept of how drainage area is related to stream size is broadly understood.

We determined the number of size classes and the thresholds between classes by studying 1) similarities in size breaks and biological descriptions used in states, 2) the distributions of freshwater species across size classes, and 3) relationships between our regional patterns and the proposed National Fish Habitat Framework. Review of the size classes used in the northeastern states showed that most states described some headwater and small stream class. Many states also described medium vs. large river classes and a very large or great river type. The exact stream size class breaks used by the states varied. We plotted those using drainage areas to review the range and distribution of the size breaks (Table 1).

Various size class breaks were also tested against a regional database of 317 rare and declining fish, mussels, snails, amphibians, and aquatic insect species (6672 point occurrences) to investigate the distribution of these species across stream size classes. We ran a cluster analysis (PCORD, flexible beta and Sorensons linkages, McCune and Grace 1997) in which stream reach samples of various sizes were grouped by their associated rare species (Figure 1). The results highlight large differences in rare species associations between rivers less than 200 sq.mi. and those greater than 200 sq.mi in size and between rivers less than 4000 sq. mi. and those greater than 4000 sq.mi. in drainage size.

Figure 1: The relationship of stream biota to size classes. We used a cluster analysis of Natural Heritage tracked fish, mussels, snails, amphibians, and aquatic insects (317 species, 6672 point occurrences). The set of tested size classes are shown on the left (0_39 sq mi etc.). The "information remaining" scale provides a measure of "similarity" in associated rare species at each step in the hierarchical cluster analysis. As groups are fused, the amount of information decreases until all groups are fused and no species information remains different between the groups to further classify. The magnitude of the information remaining at each steps gives the reader a way to measure how distinctly different the groups are in terms of their rare species composition. In this example the small 0-39 sq mi streams have a very different composition (info remaining about 30%) from the larger classes, but the 400_1000 and 1000_3000 class were virtually identical.

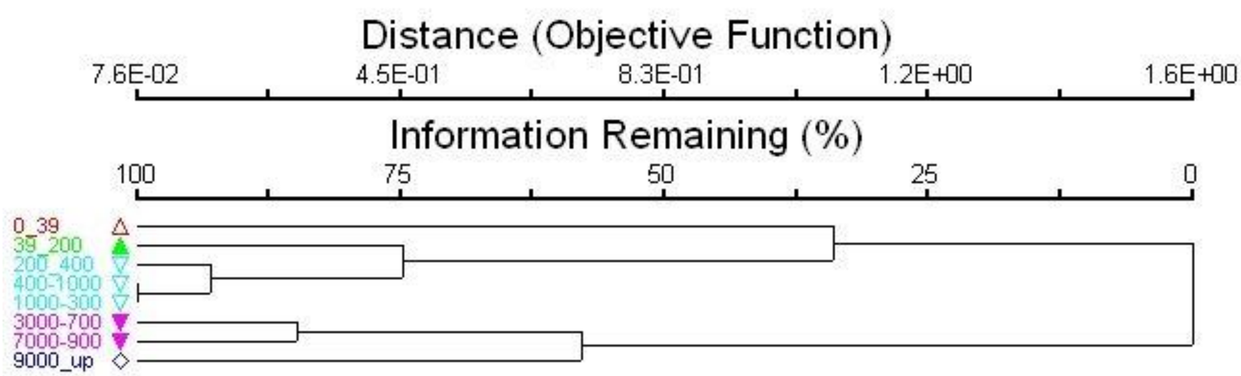
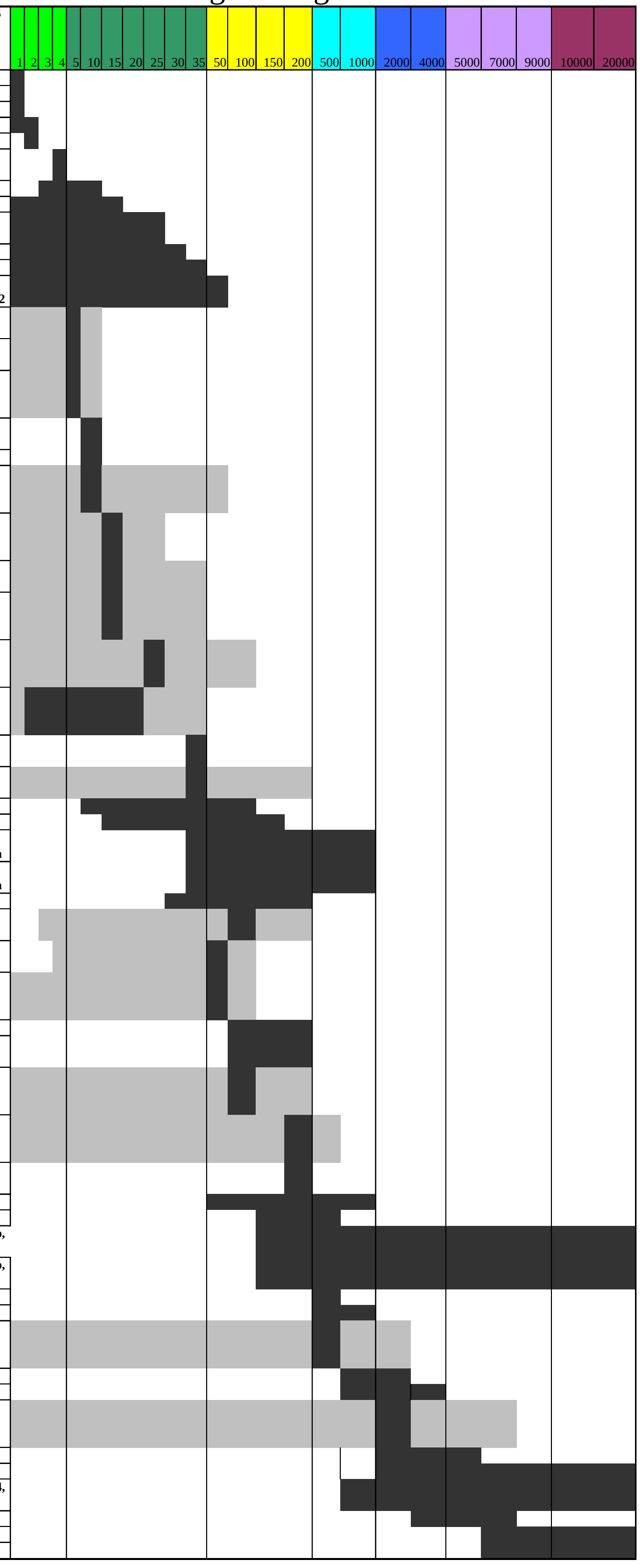


Table 1: Size classes from state and regional classifications using drainage area to measure size

State	Size Classes from classifications that used drainage area to measure size	sq.mi.	NAHCS Stream Size Class
WV	WV: intermittent < 18 acres	0.02813 sqmi	1a
NY	NY Rocky Headwater Stream: 5-10m across	.005-.05 sq.mi.	1a
NY	NY Marshy Headwater Stream: <3m across	< 0.015 sq.mi	1a
PA	PA Macroinvertebrate Physical Stream Type:	0-2 sq.mi.	1a
MA	MA: <2 sq.mi. break for perennial vs. intermittent	2 sqmi.	1a
VT	VT Biomonitoring: Small High Gradient Streams (SHG):10 square kilometers	3.861 sqmi	1a
PA	PA Macroinvertebrate Physical Stream Type:	3-10 sq.mi.	1a, 1b
WV	WV: Small: ≤ 10,000 acres	<15.63 sq.mi.	1a, 1b
MA	MA: <50 ft break for wadeable	<25 sq.mi. (from DA = (w/14.7)^(2.632)	1a, 1b
ME	ME/TNC ERO:	0-29sq.mi.	1a, 1b
NY	NY GAP:	0-39 sq.mi.	1a, 1b
PA	PA Fish Community Type Synthesis Recommendations:	0-50 sq mi	1a, 1b, 2
VT	VT Aquatic Communities: Brook Trout: mean 11 sqkm (3-30)	4.247 (1.158 - 11.58) sqmi	1b
VT	VT Aquatic Communities: Brook Trout - Slimy Sculpin mean 12 sqkm (2-30)	4.633 (0.7722 - 11.58) sqmi	1b
US	USA B3: indicator: creek chub; homogeneous cluster:	eastern mean 4.247 sq.mi (95% conf. int. 0-10 sq.mi.)	1b
CT	CT: <30ft break for wadeable	6.5 sq.mi. (from DA = (w/14.7)^(2.632)	1b
VT	VT Biomonitoring: Slow Winders:average 25 square kilometers	9.653 sqmi	1b
US	USA B2: indicator: fathead minnow; least homogenous:	eastern mean 10.04 sq.mi. (95% conf. int. 0-45 sq.mi.)	1b
US	USA D2: highest elevations, steepest slopes, and coolest air; mountainous areas of the wester USA: indicator rainbow trout:	eastern mean 12.74 sq.mi. (95% conf. int 0-28 sq.mi.	1b
VT	VT Aquatic Communities: Brook Trout - Blacknose Dace: mean 41 sqkm (4-103)	15.83 (1.544 - 39.77) sqmi	1b
US	USA C3: streams of mountainous west, east, and north-central indicator: blacknose dace:	eastern mean 15.44 sqmi (95% conf. int. 0-42 sq.mi.)	1b
US	USA C2: streams of mountainous west, east, and north-central: indicator brook trout, brown trout, mottled sculpin:	eastern mean 23.55 sq.mi. (95% conf. int. 0-101 sq.mi.)	1b
DE	DE: 1-3rd order is break for wadeable	mean 2-23 sq.mi. (10-90% percentile = .91-40)	1b
VT	VT Biomonitoring: Medium High Gradient Streams (MHG):average 88 square kilometers	33.98 sqmi	1b
VT	VT Aquatic Communities: Bluntnose Minnow - Creek Chub: mean 88 sqkm (2-515)	33.98 (0.7722 - 198.8) sqmi	1b, 2
PA	PA Macroinvertebrate Physical Stream Type:	11-100 sq.mi.	1b, 2
WV	WV: Medium: 10,001-100,000 acres	15.63-156.3 sq.mi.	1b, 2
NY	NY Confined River:	>30 sq.mi. < 1000 sq.mi.	1b, 2, 3a
NY	NY Unconfined River:	>30 sq.mi. < 1000 sq.mi.	1b, 2, 3a
ME	ME/TNC ERO:	30-199 sq.mi.	2
VT	VT Aquatic Communities: Pumpkinseed - Bluntnose Minnow: mean 336 sqkm (8-728)	129.7 (3.089 - 281.1) sqmi	2
VT	VT Aquatic Communities: Blacknose Dace -Common Shiner: mean 104 sqkm (10-298)	40.15 (3.861 - 115.1) sqmi	2
US	USA B1: indicator: common shiner and white sucker:	eastern mean 46.72 sqmi (95% conf. int. 0-128 sq.mi)	2
PA	PA Fish Community Type Synthesis :	50-199 sq mi	2
PA	PA Fish Community Type Synthesis :	50-199 sq mi or 50-100 sq.mi.	2
US	USA C1: streams of mountainous west, east, and north-central: indicator longnose dace:	eastern mean 67.57 sq.mi. (95% conf. int 0-193 sq.mi.)	2
US	USA A4: indicator: central stoneroller and striped shiner;:	eastern mean 160.6 sq.mi (95% conf. int. 0-650 sq.mi.	2
VT	VT Biomonitoring: Warm Water Moderate Gradient Streams and Rivers:average 480 square kilometers	185.3 sqmi	2
NY	NY GAP:	39-1158 sq.mi.	2, 3a
PA	PA Fish Community Type Synthesis :	100-499sqmi.	2, 3a
PA	PA Macroinvertebrate Physical Stream Type:	>100 sq.mi.	2, 3a, 3b, 4, 5
WV	WV: Large: > 100,000 acres	>156.3 sq.mi.	2, 3a, 3b, 4, 5
PA	PA Fish Community Type Synthesis :	200-749 sq mi	3a
ME	ME/TNC ERO:	200-999 sq.mi.	3a
US	USA A2:indicator species: bluegill; consists of many different warm water species:	eastern mean 432.4 sqmi (95% conf. int. 0-1773 sq.mi.)	3a
PA	PA Fish Community Type Synthesis :	500-1999 sq.mi.	3a, 3b
PA	PA Fish Community Type Synthesis :	750-2999 sq mi	3a, 3b
US	USA A3: indicator species spotfin shiner, shorthead readhorse, and common carp; all river species:	eastern mean 2319 sqmi (95% conf. int. 0-7083sq.mi.)	3b
ME	ME/TNC ERO:	1000-6999 sq.mi.	3b, 4
NY	NY GAP:	>1158 sq.mi.	3b, 4, 5
NY	NY Deepwater River:	> 965.3 sqmi.	3a, 3b, 4, 5
PA	PA Fish Community Type Synthesis :	3000-6499 sq mi	4
PA	PA Fish Community Type Synthesis :	6500+ sq mi or > 6000	4, 5
ME	ME/TNC ERO:	7000+ sqmi	4,5

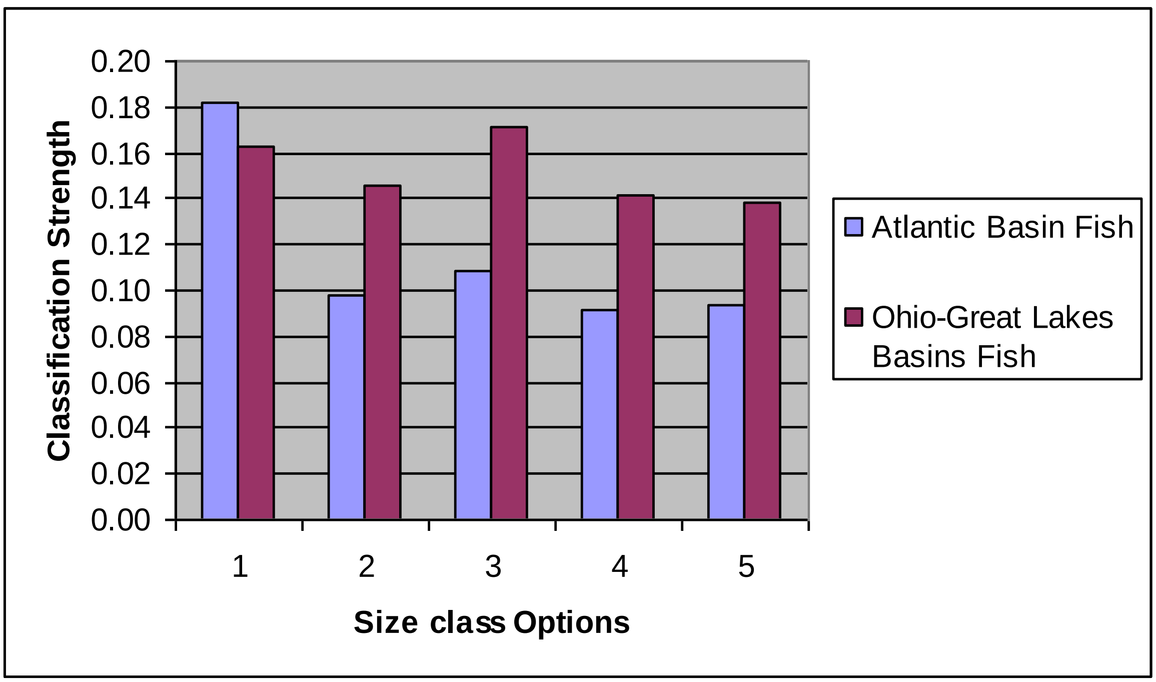


defined class boundaries, or for field studies it is the reported mean =

confidence interval around mean when study used field data =

Another line of evidence was presented by Mary Walsh of the PA Natural Heritage Program who statistically tested potential size breaks in the Atlantic and Ohio basins of Pennsylvania using fish data and measures of classification strenghth (PCORD, Multi-Response Permutation Procedure MRPP and Classification Strength CS). The results suggested that the Option 1 size class breaks: *0-29 sq mi., 30-199 sq mi., 200-999 sq mi., 1000-6999 sq mi., 7000+ sq mi*. had relatively high classification strengths for both fish communities in the Ohio – Great Lakes Basins and the Atlantic Basin.

Figure 2: Pennsylvanian Fisheries Data tested against Stream Size Breaks within the Ohio-Great Lakes Basin and Atlantic Basin. The reported classification strength chart below compares *between* class similarities and *within* class mean similarities as a relative measure of a classification's ability to distinguish patterns (VanSickle 1997). The five stream size classification options tested had classification strengths ranging between 0.09 and 0.18. Option 1 had relatively high classification strengths for fish communities in the Ohio – Great Lakes Basins and the Atlantic Basin. The Ohio – Great Lakes Basins fish communities (1976 sites and 76 species) generally had higher Classification Strenth values than those in the Atlantic Basin (4284 sites and 61 species).



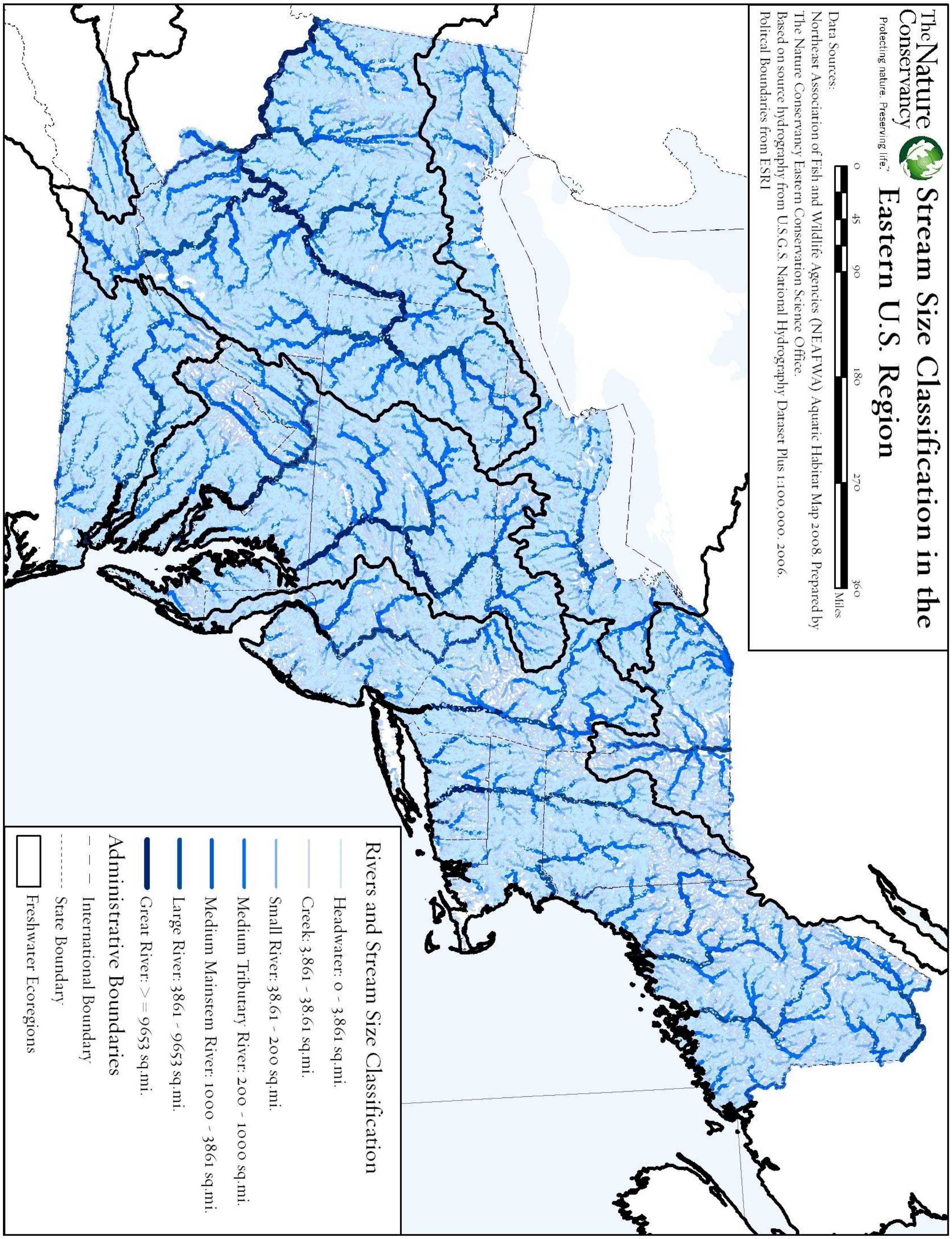
Option 1 (sq.mi): 1=0-29, 2=30-199, 3=200-999, 4=1000-6999, 5=7000+
Option 2 (sq.mi): 1=2-9, 2=10-49, 3=50-99, 4=100-499, 5=500-1999, 6=2000-5999, 7=6000+
Option 3 (sq.mi): 1=0-50, 2=50-199, 3=200-749, 4=750-2999, 5=3000-6499, 6=6500+
Option 4 (sq.mi): 1=0-9, 2=10-24, 3=25-199, 4=200-499, 5=500-1999, 6=2000-3999, 7=4000-6999, 8=7000+
Option 5 (sq.mi): 1=1-9, 2=10-29, 3=30-199, 4=200-999, 5=1000-6999, 6=7000+

Lastly we tried to crosswalk our final size classes to those suggested in the National Fish Habitat (NFH) Science Panel, although the latter are admittedly arbitrary and based solely on order of magnitude, not species patterns (Higgins, personal communication). Where our regionally derived size class thresholds were very close to the NFH breaks, we adopted the NFH breaks for consistency with national classification efforts (e.g. a northeast 30 sq.mi. break became 38 sq.mi to match the NFH). However, where our team recognized important size classes that had no analog in the NFH such as the 39-200 sq mi streams, the 200 – 1000 sq mi rivers and the 1000 – 3900 sq mile rivers our regional classes were given precedence and we crosswalked the classes to the NFH classes (Table 2). Our final NAHCS seven size classes were numbered and named to better reflect biota and descriptions used in the northeast (Table 2, Figure 3).

Table 2: NAHCS Stream Size Classes

NAHCS Size Class	Description	Definition (upstream drainage area in sq.mi.)	Total Length in region (km)	National Fish Habitat Related Class
1a	Headwaters	0<3.861	260949	1
1b	Creeks	>=3.861<38.61	129722	2
2	Small Rivers	>= 38.61<200	34118	3
3a	Medium Tributary Rivers	>=200<1000	16155	4
3b	Medium Mainstem Rivers	>=1000<3861	6067	4
4	Large Rivers	>=3861<9653	2718	5
5	Great Rivers	>=9653	1630	6

Figure 3: Map of Stream Size Classification



2. Gradient: Stream gradient influences stream bed morphology, flow velocity, sediment transport/deposition, substrate and grain size (Rosgen 1994). The presence of riffles is a key factor determining the types of fish and invertebrate assemblages present (Lyons 1996) and gradient generally separates streams with a well developed pool-riffle-run habitat structure from flat streams or step pool streams (Wang et al. 1998). For example, high gradient streams are dominated by step-pools to plane-bed systems. They have substrates of cobble and boulders, colluvial sediment transport, and are usually highly entrenched, valley confined, and have low sinuosity. Moderate gradient streams are generally plane bed systems with some riffle-pool development. They have substrates of gravel, cobble, and boulders, transport sediment regimes, and are moderately entrenched with narrow valleys with low sinuosity. Low gradient systems are dominated by riffle-pool systems. They have substrates of sand, gravel, and cobble, alluvial storage and depositional sediment regimes, high sinuosity, and are only slightly entrenched with adjacent floodplain ecosystems in their broader valleys. Very low gradient streams are dominated by ripple-dune streams with very high sinuosity. These rivers have sand, gravel and finer sediment substrates, alluvial storage and depositional sediment regime, and slight entrenchment with critical adjacent floodplain systems (Rosgen 1996, Allen 1995, Kline 2005).

The final NAHCS quantitative gradient classes were developed by 1) studying breaks used in the existing state classifications and examining the relationship of gradient classes to known places in the region and 2) studying rare species distributions across gradient classes. As to the former, many states used a qualitative description of stream gradient in their aquatic habitat descriptions (e.g. high gradient, moderate gradient, low gradient), but these had different meanings depending on the state. To calibrate this, we circulated maps of regional gradient patterns and asked the team members to tell us whether the proposed regional breaks represented the major patterns of gradient and related stream biotic changes noted on the ground in their states. *Gradient is measured as the slope of the flow line, calculated as rise over run and notated as a percentage.*

We used a cluster analysis to examine the relationship of rare stream biota to gradient classes in the same manner described above under "size." Stream reaches were grouped by gradient classes, allowing us to examine how similar or dissimilar the associated rare species were between classes (Figure 4). Results supported the breaks tested in Figure 4 and suggested that the largest difference in the tested biotic data was between streams with less than 0.5 % slope and those with greater than 0.5% slope. Subsequent breaks show further differences in the stream biota within additional gradient classes. The testing supported the expert knowledge of workgroup members that the potential gradient classes were associated with different ecological settings and freshwater biota. Although the highest gradient class tested (greater that 5% slope) did not show strong differentiation in rare freshwater biota when compared with the next highest class (2-5% slope), the team still felt it was important to have this distinct highest class given the lack of sampling effort in the very high gradient streams and their expert knowledge of the distinct ecological processes and settings in these very highest gradient streams. In the end we recognized six gradient classes (Table 2 and Figure 5).

Figure 4: The relationship of stream biota to gradient classes. A cluster analysis using 6672 points representing 317 Heritage tracked species of fish, mussels, snails, amphibians, and aquatic insects (317 species, 6672 point occurrences) was used to test gradient classes. Tested gradient classes are listed on the left (s 0_0.02 % slope) The "information remaining" scale provides a measure of the "similarity" between the classes based on the information lost at east step in the hierarchical cluster analysis. As groups are fused, the amount of information decreases until all groups are fused and no species information remains different between the groups to further classify. The magnitude of the information remaining at each steps gives the reader a way to measure how distinctly different the groups are in terms of their species composition.

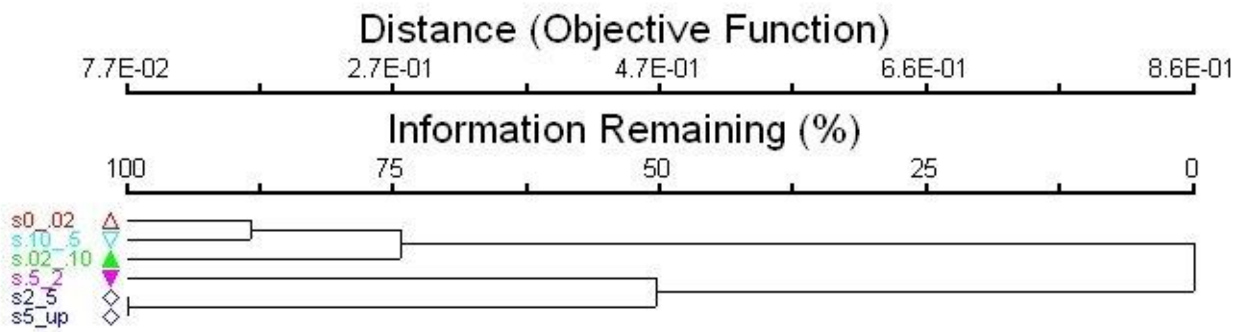
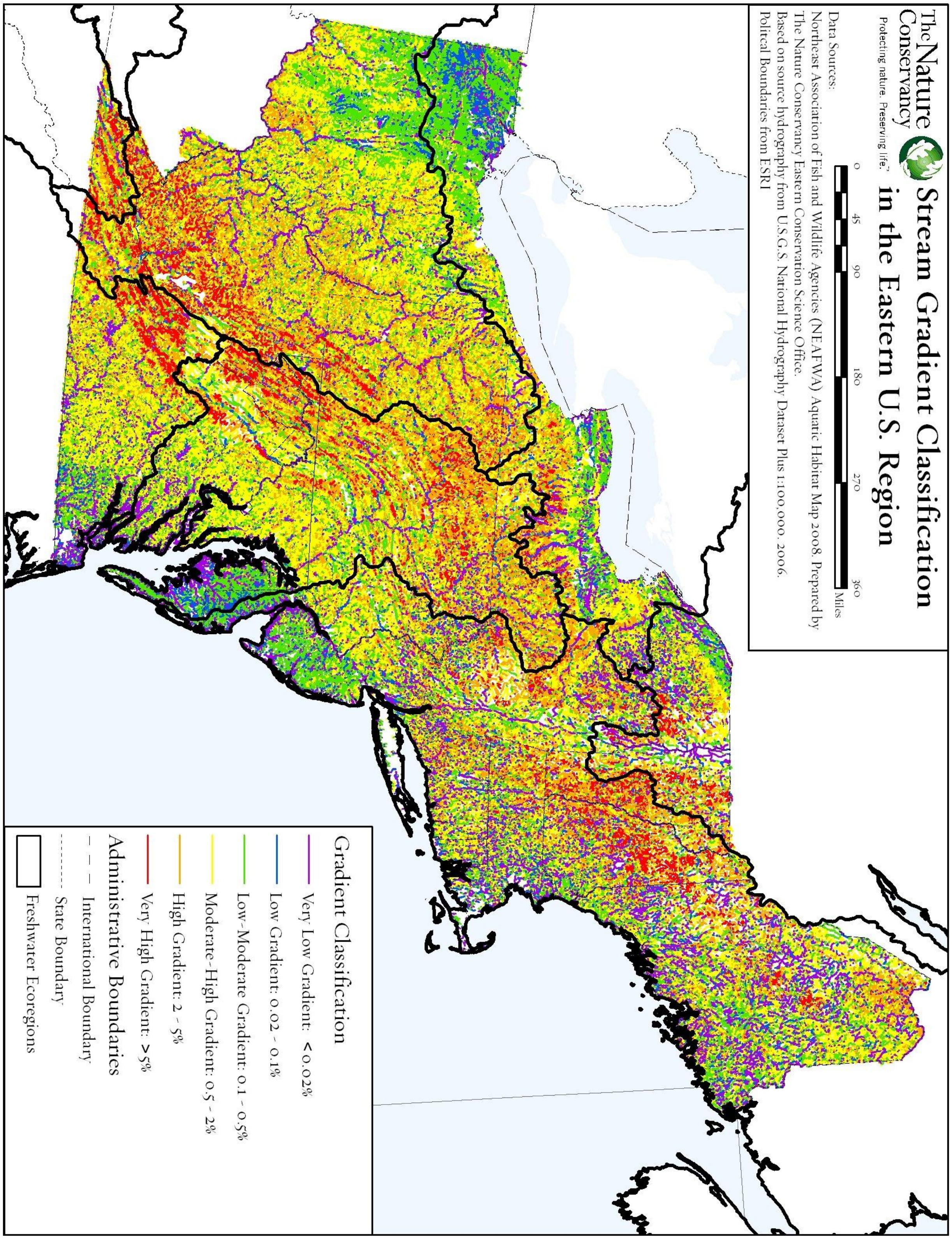


Table 3: NAHCS Stream Gradient Classes

Gradient Class	**Description**	**Definition (slope of the flow line (m/m) * 100**	**Total Length in region (km)**
1	Very Low Gradient	<0.02 %	51477
2	Low Gradient	>= 0.02 < 0.1%	21257
3	Moderate-Low Gradient	>= 0.1 < 0.5 %	80434
4	Moderate-High Gradient	>=0.5 < 2 %	151553
5	High Gradient	>=2 < 5 %	103034
6	Very High Gradient	>5%	43604

Figure 5: Map of Stream Gradient Classification



3. Geologic Setting and Buffering Capacity: Aquatic organisms need water pH to be within a certain range for optimal growth, reproduction, and survival. Most aquatic organisms prefer pH of 6.5-8. Streams and lakes with calcium carbonate concentrations less than 2 mg/L and pH levels below 5, no longer support fish and many other forms of aquatic biota (Allan 1995). Certain types of aquatic biota are also only found in very highly buffered or calcareous streams with pHs continuously near or above a pH of 8. Acid intolerant fish of the northeast include the blacknose dace and creek chub which cannot tolerate pH of less than 6.0-5.5. Acid tolerant fish of the northeast include yellow perch, brown bullhead, and brook trout; however brook trout will not spawn if waters are too acidic (Brown et al. 1990). Examples of acid intolerant macroinvertebrates include, Odonates such as *Gomphus sp.* and *Basiaeschna sp.* while highly acid tolerant invertebrates include *Cordulia sp.* and *Leucorrhinia sp.* (Hunt, 2005).

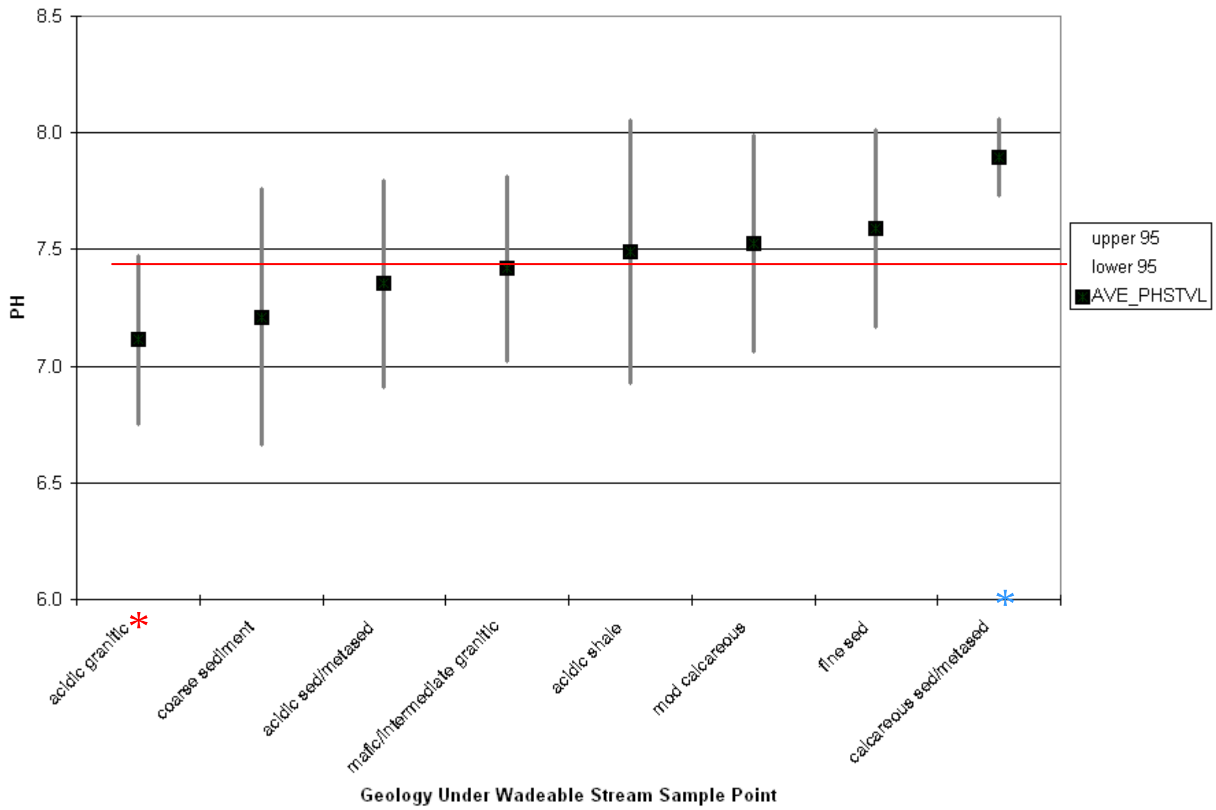
Water chemistry parameters such as pH, acid neutralizing capacity (ANC), and conductivity are strongly influenced by the minerals and ions that leech out of underlying bedrock and surficial material. The report and accompanying state atlas "Geologic Control of Sensitivity of Aquatic Ecosystems in the United States to Acidic Deposition" (Norton 1980), suggested that the sensitivity of aquatic ecosystems to acidic precipitation is based largely on the capacity of the drainage basin bedrock to assimilate acid during chemical weathering. Even small amounts of limestone in a drainage basin can exert an overwhelming influence on terrains that otherwise would be very vulnerable to acidification. Although differences in bedrock and surficial geology are also associated with additional differences in stream systems (in stream substrates, channel morphology, and flashy vs. more stable hydrologic regimes), the team thought that the pronounced geologic influence on waters' buffering capacity was the most critical geologic influence to represent in a basic aquatic habitat type classification across the region.

Current USGS Bedrock geology maps for each of the states in the northeast U.S. were compiled in digital form at a scale of 1:125,000 – 1:250,000. The data was reclassified into nine major bedrock classes according to the rocks' texture, resistance, and chemistry properties (Anderson et al. 1999). In addition, two types of deep surficial geology were also mapped in flat areas where the bedrock was mapped as very deeply buried. For example, deep coarse deltaic or outwash deposits often overlay the bedrock in the flatter pine barrens and sand plains in the northeast, and the consolidated bedrock of valleys of pre-glacial lakes may lie under many meters of fine lacustrine or marine clay sediments. In these settings, it is the nature of the surficial geology that is ecologically relevant; not the nature of the underlying bedrock. Coarse grained (e.g. sand) and fine-grained surficial sediments (e.g. lacustrine or marine clays), were mapped by using the 1:1,000,000 scale USGS Quaternary Geology map in flat landform areas of the region (Ferree, 2005).

The relationship of the mapped bedrock and surficial geology types in the eastern U.S. acid neutralizing capacity of the bedrock were developed by 1) investigating the relationship of underlying geology to known stream pH locations, 2) studying Norton's (1980) descriptions of the formations and visually overlaying of Norton's maps with the compiled eastern regional geology dataset, and 3) examining the relationships between rare aquatic species and geology.

We explored the relationship between our nine geology classes and known stream pH using 171 "non-anthropogenically altered pH" eastern streams from the EPA wadeable stream assessment (EPA, 2006). We sampled the geology underneath stream sample locations and plotted the mean pH and confidence interval of these samples by their underlying geology. (Figure 6). This ordered the nine geology types by their mean stream pH and highlighted that certain geologies such as acidic granitic and calcareous sedimentary were extremely different in stream pH.

Figure 6: Average Stream pH by underlying geology type (points show the mean and two standard deviations)



To develop a cross walk from the nine bedrock geology classes to the four Norton sensitivity classes we used the pH information (Figure 6) in conjunction with Norton's state maps and formations descriptions, to assign each of our nine geology classes to one of Norton's four buffering classes. In Norton Class 1, *bedrock areas of low to no acid neutralizing capacity*, acidic precipitation is expected to have widespread effects on aquatic ecosystems. In Norton Class 2, *medium to low acid neutralizing capacity*, expected effects from acidic precipitation should be restricted to very small first and second order streams and small lakes. In Norton Class 3, *medium to high acid neutralizing capacity*, the effects from acidic precipitation should be improbable except for overland run-off effects in areas of frozen ground. In Norton Class 4, *very high acid neutralizing capacity*, there is no expected effect of acid precipitation on aquatic ecosystems due to the underlying substrate (Norton, 1980). Detail on the regional geology types, their characteristics in terms of lithotypes, texture, nutrients, and associated natural communities and the assigned Norton's class equivalency are provided in Table 4.

Table 4: Characteristics of Eastern Region Major Geology Types

Geology class	*Lithotypes*	*Meta-equivalents*	*Norton Class for Buffering Capacity*	*Texture*	*Nutrients*	*Comments*	*Some characteristic communities*
100: ACIDIC SEDIMENTARY / METASEDIMENTARY: fine- to coarse-grained, acidic sed/metased rock	Mudstone, claystone, siltstone, non-fissile shale, sandstone, conglomerate, breccia, greywacke, arenites	(Low grade:) slates, phyllites, pelites; (Mod grade:) schists, pelitic schists, granofels	2: medium to low acid neutralizing capacity	Fine to Coarse	Low	Low to moderately resistant rocks typical of valleys and lowlands with subdued topography; pure sandstone and meta-sediments are more resistant and may form low to moderate hills or ridges	Many: low- and mid-elevation matrix forests, floodplains, oak-pine forest, deciduous swamps and marshes
200: ACIDIC SHALE: Fine-grained acidic sedimentary rock with fissile texture	Fissile shales		2: medium to low acid neutralizing capacity	Fine	Low	Low resistance; produces unstable slopes of fine talus	Shale cliff and talus, shale barrens
300: CALCAREOUS SEDIMENTARY / META-SEDIMENTARY: basic/alkaline, soft sed/metased rock with high calcium content	Limestone, dolomite, dolostone, other carbonate-rich clastic rocks	Marble	4: very high to infinite acid neutralizing capacity	Fine to Medium	Moderate to High	Lowlands and depressions, stream/river channels, ponds/lakes, groundwater discharge areas; soils are thin alkaline clays, high calcium, low potassium; rock is very susceptible to chemical weathering; often underlies prime agricultural areas	Rich fens and wetlands, rich woodlands, rich cove forests, cedar swamps, alkaline cliffs
400: MODERATELY CALCAREOUS SEDIMENTARY / METASED: Neutral to basic, moderately soft sed/metased rock with some calcium but less so than above	Calc shales, calc pelites and siltstones, calc sandstones	Lightly to mod. metamorphosed calc pelites and quartzites, calc schists and phyllites, calc-silicate granofels	3: medium to high acid neutralizing capacity	Fine to Medium	Moderate	Variable group depending on lithology but generally susceptible to chemical weathering; soft shales often underlie agricultural areas	Rich coves, intermediate fens
500: ACIDIC GRANITIC: Quartz-rich, resistant acidic igneous and high grade meta-sedimentary rock; weathers to thin coarse soils	Granite, granodiorite, rhyolite, felsite, pegmatite	Granitic gneiss, charnockites, migmatites, quartzose gneiss, quartzite, quartz granofels	1: low to no acid neutralizing capacity	Coarse	Low	Resistant, quartz-rich rock, underlies mts and poorly drained depressions; uplands & highlands may have little internal relief and steep slopes along borders; generally sandy nutrient-poor soils	Many: matrix forest, high elevation types, bogs and peatlands
600: MAFIC / INTERMEDIATE GRANITIC: quartz-poor alkaline to slightly acidic rock, weathers to clays	(Ultrabasic:) anorthosite; (Basic:) gabbro, diabase, basalt; (Intermediate, quartz-poor:) diorite/ andesite, syenite/ trachyte	Greenstone, amphibolites, epidiorite, granulite, bostonite, essexite	3: medium to high acid neutralizing capacity	Fine to Coarse	Moderate to High	Mod resistant; thin, rocky, clay soils, sl acidic to sl basic, high in magnesium, low in potassium; mod hills or rolling topography, uplands and lowlands, depending on adjacent lithologies; quartz-poor plutonic rocks weather to thin clay soils with topogr	Traprock ridges, greenstone glades, alpine areas in Adirondacks
700: ULTRAMAFIC: magnesium-rich alkaline rock	Serpentine, soapstone, pyroxenites, dunites, peridotites, talc schists		3: medium to high acid neutralizing capacity	Fine to Medium	Low to High	Thin rocky iron-rich soils may be toxic to many species, high Ma to Ca ratios often support endemic flora favoring high magnesium, low potassium, alkaline soils; upland hills, knobs or ridges	Serpentine barrens
800: DEEP COARSE SURFICIAL			1: low to no acid neutralizing capacity	undiferentiated coarse sediments (e.g. sands)	low	common on coastal plain and in piedmont where deep coarse deltaic or outwash deposits often overlay the bedrock	pine barrens and sand plains
900: DEEP FINE SEDIMENT			3: medium to high acid neutralizing capacity	undiferentiated fine sediments (e.g.fine lacustrine or marine clays)	medium-high	common in alluvial settings and where lacustine and marine clays have overlaid bedrock	floodplains, wetlands

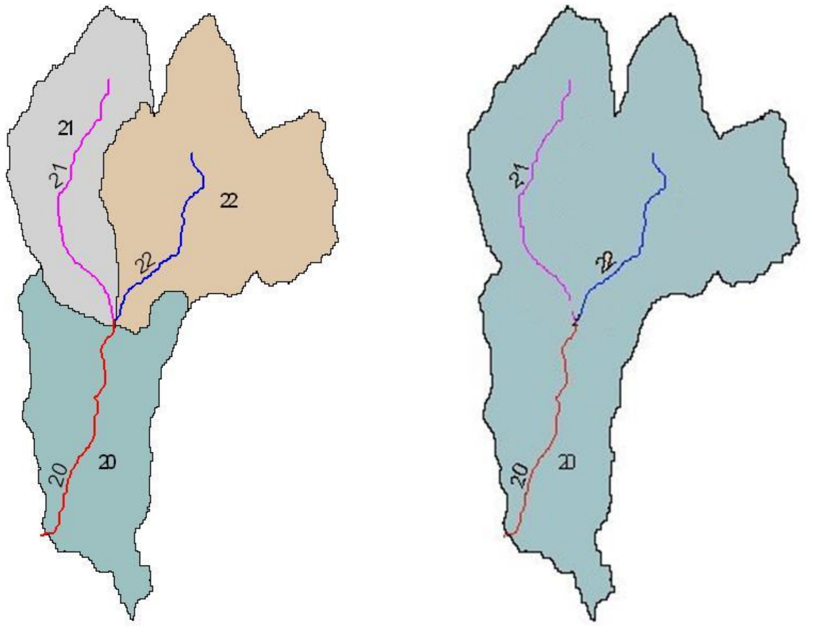
Overlay of the locations of rare aquatic species on bedrock geology classes suggested that strong relationships are apparent in among the substrates For example the Madison Cave Isopod (*Antrolana lira*), Thankless Ghost Snail (*Holsingeria unthanksensis*), Onyx Rocksnail (*Leptoxis praerosa*), Cumberland Combshell (*Epioblasma brevidens*) and Tan riffleshell (*Epioblasma florentina walkeri*) are all over 75% restricted to stream reaches in calcareous geology. Each Norton class contains 23 to 64 very restricted species and 88% of the species tracked were somewhat restricted to a single Norton class (Table 7).

Table 5: Aquatic species in relation to Norton Classes. We calculated the percent of samples of each of 470 rare aquatic species falling on each Norton type. The resultant table shows that 186 species (40%) had 75 to 100 of its occurrences restricted to a single Norton type. Norton 2 had the highest restriction percentages and the most occurrences but it also cover 50% of the region.

	Number of Rare Aquatic Species					
Strength of the association	**Norton 1**	**Norton 2**	**Norton 3**	**Norton 4**	**Sum**	**% of 470 Species**
Very restricted: 75-100% of occurrences found on this class	50	64	49	23	186	40%
Restricted: 50-74% of occurrences found on this class	57	71	78	20	226	48%
Sum	107	135	127	43	412	88%

The percentage of each geology type was calculated for both the local reach catchment and the total upstream watershed for all flowlines in the NHD-Plus dataset to account for the effect of differences in the geology within the land area draining to the stream (Figure 7). Although the geology in these larger drainage areas were sometimes the same type as the geology directly under a stream, it is important to consider the influence of geologic variation in the larger contributing area (Norton, 1980, Baker et al. 2003).

Figure 7: Example of Local Catchments and Total Upstream Watershed



A. Local Catchments for Reaches 20, 21, and 22

B. Total Upstream Watershed for Reach 20

The percentages of geology classes within the watershed were transformed into a "Norton Index Value" for each stream reach by multiplying the percentage of each geology class by its equivalent Norton Class. The index thus ranged from 100 (100% in Norton Class 1 geology classes) to 400 (100% in Norton Class 4 geology classes). Mean and variance plots of the EPA wadeable stream data pH and ANC against the local catchment and upstream watershed Norton Indices revealed that the Norton index suggested that watersheds at the two geologic extremes (Norton 1 and 4) are different in measured pH and ANC (Figure 8 and Figure 9). The results were very similar between local catchment and total upstream watershed.

Figure 8: Total Upstream Watershed Norton Index by Average pH. Points indicate the mean plus or minus two standard deviations.

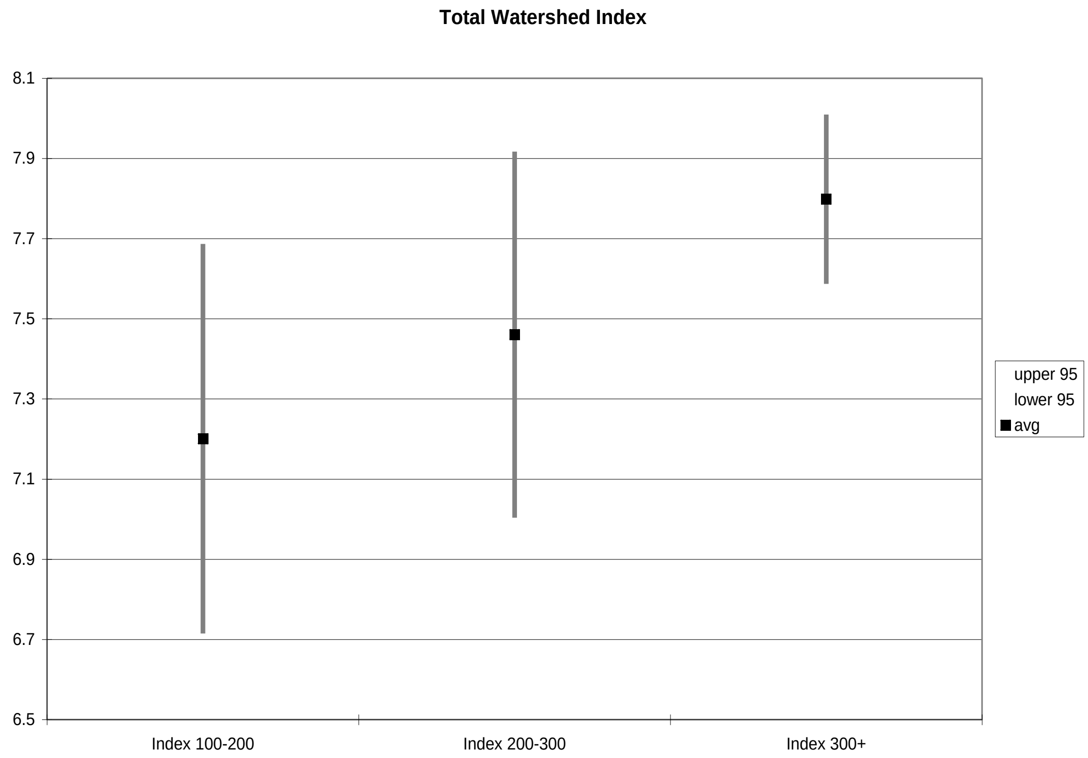
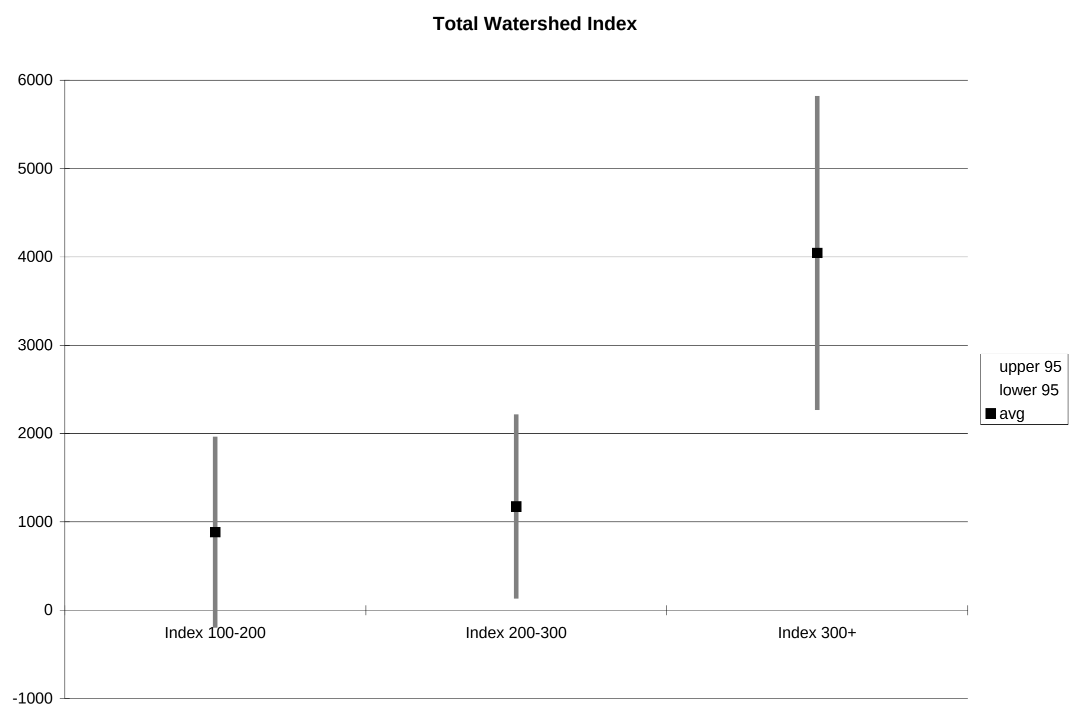


Figure 9: Total Upstream Watershed Norton Index by Average ANC Points indicate the mean plus or minus two standard deviations)

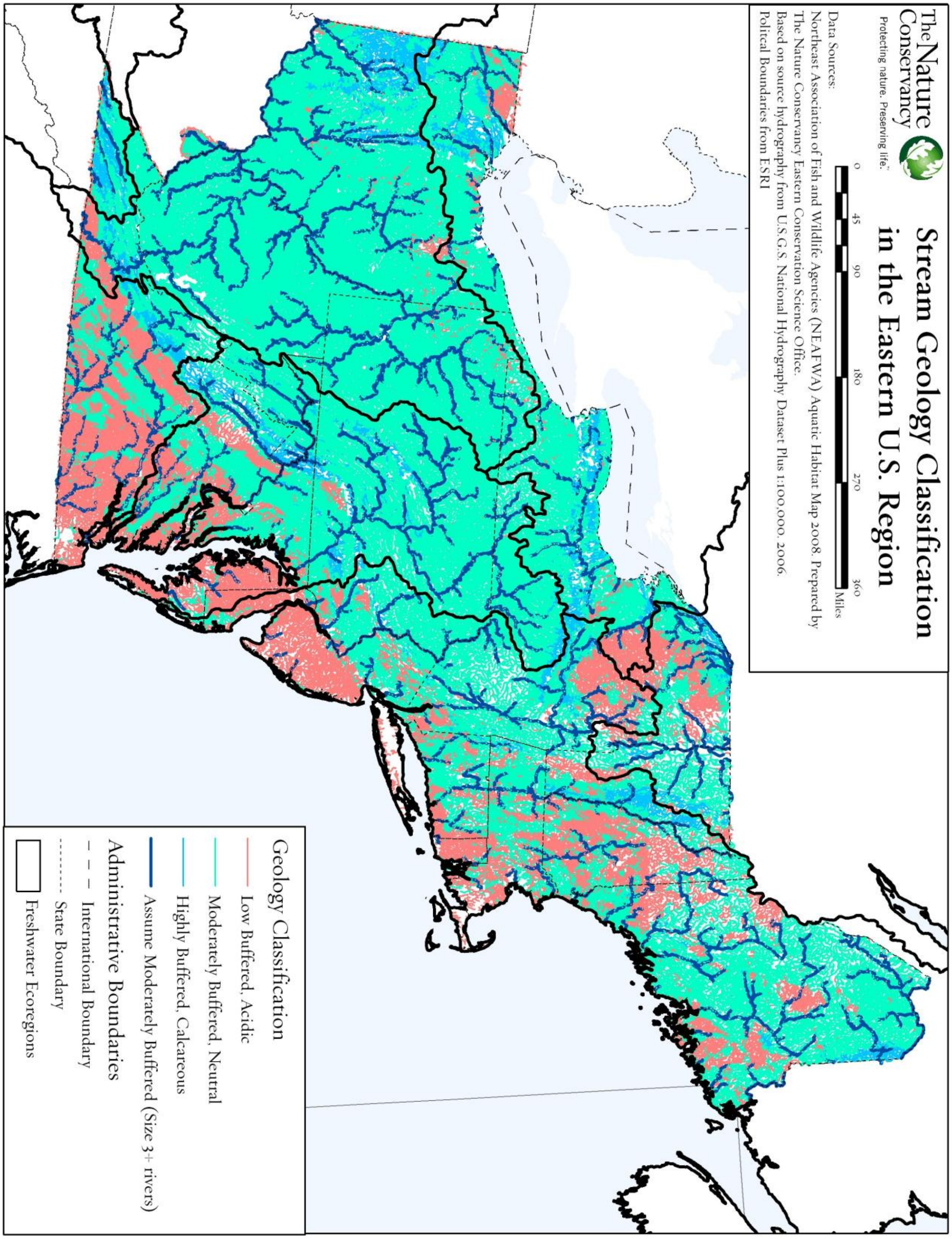


After reviewing these results and maps of the stream reaches by Norton Indices, our team agreed on three categories, very acidic, neutral, and very calcareous, be used in the NAHCS as they represented the dominant pattern in stream buffering capacity found in the region. We kept the two extreme classes narrowly defined with a broadly defined middle class. The total upstream geology Norton Index was used in final class assignment to incorporate the influence of all upstream geology types. After considerable team discussion, we assigned all streams over 200 sq.mi. in drainage area to a "neutral" class because in these larger rivers the geologic influence on buffering capacity is low and nearly all rivers of this size have adequate buffering capacity to remain continuously neutral. The final geologic classes used in the NAHCS are shown in Table 3. Please see Appendix V for a map of the region by stream geologic buffering class.

Table 6: NAHCS Stream Geology Buffering Classes

Geology Class	Description	Definition (index based on total upstream geology)	Lengh Length in region (km)
1	Acidic, Low Buffered	100-174	103949
2	Neutral, Moderately Buffered	175-324	301751
3	Calc-Neutral, Highly Buffered	325-400	18992
0	Size 3, 4, 5 rivers, Assume Neutral	any	26570

Figure 10: Map of Stream Geology Classification



Temperature: Stream temperature sets the physiological limits where stream organisms can persist (Allan 1995). Seasonal changes in water temperature often cue development or migration, influence growth rates of eggs and juveniles, and can affect the body size, and therefore the fecundity of adults. In addition to limiting effects on biological productivity, temperature extremes may directly preclude certain taxa from inhabiting a water body.

The temperature of running waters varies on seasonal and daily time scales, and among locations due to climate, elevation, and the relative importance of groundwater inputs (Allan 1995). High elevation areas with low average air temperatures tend to maintain coldwater streams year-round. In low elevation areas, groundwater inflow is particularly important to maintaining cold and cool water streams. Ground water inflow can be predicted by Darcy's Law which states that flow through a porous medium is proportional to the difference in hydraulic head over some flow path length (hydraulic slope), the area of flow, and the hydraulic conductivity of the medium (Darcy 1856, Baker et al. 2003). Thus greater groundwater inputs are expected in higher gradient or sloping stream systems (greater hydraulic head) and in streams in more porous geologies (hydraulic conductivity). Stream water temperature can also be significantly altered by the extent of streamside vegetation, watershed impervious surfaces, and dams which often raise the temperatures above the naturally expected temperature regime (Allan 1995, Stranko et al. 2007)

Many species that are important in coldwater streams are rare or absent in warmwater streams (Halliwell et al. 1999). Fish species in the northeast have been assigned to the following thermal regime preferences, coldwater (20 species), warmwater (100 species), or inhabiting both habitats (27 species) (Halliwell et al. 1999, Table 9). Many aquatic species, such as brook trout, have adapted to very specific temperature regimes, and are intolerant of even small changes in mean temperatures and/or length of exposures to temperatures above certain limits (Wehrly et al. 2007).

No widely accepted method exists for estimating the expected natural instream water temperature at the stream reach scale across our region. To account for the importance of stream temperature in structuring biological communities, we developed a model relating differences in water temperatures to differences in stream sizes, air temperatures, gradient, and groundwater inputs. Our model was developed by testing point datasets representing cold, cool, and warm water stream community sample locations against regional variables relating to stream size, gradient, baseflow index, geologies, elevations, air temperature, precipitation, ecoregion, and other variables. Over 61,500 test points were submitted by the states from their field inventories, with most point representing locations where cold water species had been found. We identified the dominant variables and thresholds associated with cold, cool, and warmwater reaches using exploratory runs of a Classification and Regression Tree Analysis (CART, Salford Systems 2007). For headwaters to small rivers (size 1a, 1b, 2), the most useful variables included the cumulative upstream air temperature, stream gradients, and the local baseflow index. For larger rivers (size 3a, 3b, 4, 5), the most predictive variables were cumulative upstream air temperature variable and stream size class.

Table 7: Fish Species by Water Temperature Preference (Halliwell et al. 1999)

COMMON NAME	TEMP	COMMON NAME	TEMP	COMMON NAME	TEMP	COMMON NAME	TEMP
Longnose Sucker	C	Alewife	C-W	Shortnose Sturgeon	W	Striped Bass	W
Cisco	C	Rock Bass	C-W	Lake Sturgeon	W	Silver Redhorse	W
Lake Whitefish	C	Fourspine Stickleback	C-W	Atlantic Sturgeon	W	River Redhorse	W
Slimy Sculpin	C	Central Stoneroller	C-W	Blueback Herring	W	Black Redhorse	W
Lake Chub	C	Mottled Sculpin	C-W	American Shad	W	Golden Redhorse	W
Northern Brook Lamprey	C	Brook Stickleback	C-W	White Catfish	W	Shorthead Redhorse	W
Mountain Brook Lamprey	C	Northern Pike	C-W	Brown Bullhead	W	Greater Redhorse	W
American Brook Lamprey	C	Muskellunge	C-W	Bowfin	W	Hornyhead Chub	W
Burbot	C	Tessellated Darter	C-W	Eastern Sand Darter	W	River Chub	W
Rainbow Trout or Steelhead	C	Mummichog	C-W	American Eel	W	Golden Shiner	W
Rainbow Smelt	C	Threespine Stickleback	C-W	Freshwater Drum	W	Bigeye Chub	W
Round Whitefish	C	Ohio Lamprey	C-W	Quillback	W	Comely Shiner	W
Atlantic Salmon	C	Silver Lamprey	C-W	Redside Dace	W	Pugnose Shiner	W
Arctic Char	C	Common Shiner	C-W	Satinfin Shiner	W	Emerald Shiner	W
Bull Trout	C	Smallmouth Bass	C-W	Spotfin Shiner	W	Bridle Shiner	W
Brook Trout	C	White Perch	C-W	Common Carp	W	Silverjaw Minnow	W
Lake Trout	C	Blacknose Shiner	C-W	Gizzard Shad	W	Bigmouth Shiner	W
Pearl Dace	C	Yellow Perch	C-W	Streamline Chub	W	Blackchin Shiner	W
Northern Redbelly Dace	C	Shield Darter	C-W	Gravel Chub	W	Spottail Shiner	W
Finescale Dace	C	Trout-perch	C-W	Creek Chubsucker	W	Silver Shiner	W
		Sea Lamprey	C-W	Redfin Pickerel	W	Swallowtail Shiner	W
		Ninespine Stickleback	C-W	Chain Pickerel	W	Rosyface Shiner	W
		Blacknose Dace	C-W	Greenside Darter	W	Sand Shiner	W
		Longnose Dace	C-W	Rainbow Darter	W	Mimic Shiner	W
		Walleye	C-W	Bluebreast Darter	W	Stonecat	W
		Creek Chub	C-W	Iowa Darter	W	Tadpole Madtom	W
		Fallfish	C-W	Fantail Darter	W	Margined Madtom	W
				Spotted Darter	W	Brindled Madtom	W
				Johnny Darter	W	Logperch	W
				Variegate Darter	W	Channel Darter	W
				Banded Darter	W	Gilt Darter	W
				Tonguetied Minnow	W	Longhead Darter	W
				Cutlip Minnow	W	Blackside Darter	W
				Banded Killifish	W	Bluntnose Minnow	W
				Western Mosquitofish	W	Fathead Minnow	W
				Eastern Mosquitofish	W	White Crappie	W
				Eastern Silvery Minnow	W	Black Crappie	W
				Northern Hog Sucker	W	Hogchoker	W
				Channel Catfish	W	Mud Sunfish	W
				Brook Silverside	W	Yellow Bullhead	W
				Longnose Gar	W	Pirate Perch	W
				Redbreast Sunfish	W	Blackbanded Sunfish	W
				Green Sunfish	W	Bluespotted Sunfish	W
				Pumpkinseed	W	Banded Sunfish	W
				Bluegill	W	Redfin Pickerel	W
				Striped Shiner	W	Swamp Darter	W
				Redfin Shiner	W	Brassy Minnow	W
				Silver Chub	W	Ironcolor Shiner	W
				Largemouth Bass	W	Central Mudminnow	W
				White Bass	W	Eastern Mudminnow	W

Final rules for assigning temperature classes to stream reaches were informed by feedback from workgroup members after examining draft maps of their respective states. We agreed upon four regional natural water temperature classes: cold, transitional cool, transitional warm, warm. Conceptual guidance descriptions for the temperature classes developed (Table 10) along with a detailed set of decision rules to place reaches into these four temperature classes based on three to four measured variables (Table 11 and Table 12). The results provided a map of the streams in the region classified with a consistent temperature classes (Figure 11).

Table 8: Major Regional Expected Natural Water Temperature Classes

Water Temperature Classes	Name	Conceptual Guidance for Threshold Between the Classes	Total Length in region (km)
1	cold	proportion of coldwater species likely >50%, proportion of habitat with temperatures supporting cold water species year round likely >50%	172973
2	transitional cool	increasing proportion of cool and warm species relative to coldwater species, decreasing proportion of habitat with temperatures supporting coldwater species year round	144945
3	transitional warm	increasing dominance of warm species relative to cool species, decreasing proportion of habitat with temperatures supporting cool species, unlikely to support resident coldwater species, (some cold water species may be able to temporarily pass through thi	102175
4	warm	proportion of warmwater species >75%, decreasing proportion of habitat supporting cool species, unlikely to support any resident cold water species, summer temperatures limit ability of cold water species to traverse through habitat	31243

Table 9: Rules used in Coding Expected Stream Water Temperature Classes: Rivers

Each stream reach was assigned to an expected natural water temperature based on the following matrix. If the reach was of size 5, 4, 3b, or 3a (across), its water temperature was assigned simply by what cumulative air temperature class it fell within. The cumulative air temperature was calculated by USGS for each reach by summing and weighting by area the PRISM modeled air temperatures falling on all lands upstream of the reach. If the reach was of size 2, its water temperature assignment was based on an initial stratification of those reaches < or >= 40% baseflow index. The expected natural water temperature class was then assigned based on variations in the cumulative air temperature class as seen in the last two columns in the table below.

RIVER MODEL: Definition of Water Temperature Classes						
Air Temp Class, with USGS PRISM AIR TEMP MODEL: exact ranges of cumulative area weighted mean annual temp in detree C * 10	**Size 5: >= 9653 sq.mi.**	**Size 4: 3861-9653 sq.mi.**	**Size 3b: 1000-3861 sq.mi.**	**Size 3a: 200-1000 sq.mi.**	**size 2 200-38 sq.mi. baseflow index < 40%**	**size 2 200-38 sq.mi. baseflow index >= 40%**
2: 15-30	transitional cool	transitional cool	transitional cool	cold	cold	cold
3: 30-45	transitional cool	transitional cool	transitional cool	cold	cold	cold
4: 45-60	transitional warm	transitional cool	transitional cool	transitional cool	transitional cool	cold
5: 60-76	transitional warm	transitional warm	transitional warm	transitional cool	transitional cool	transitional cool
6: 75-90	transitional warm	transitional warm	transitional warm	pink	transitional cool	transitional cool
7: 90-105	transitional warm	transitional warm	transitional warm	transitional warm	transitional warm	transitional cool
8: 105-120	transitional warm	transitional warm	transitional warm	transitional warm	transitional warm	pink
9: 120-135	very warm	very warm	transitional warm	transitional warm	transitional warm	pink
10: 135-150	very warm	very warm	very warm	very warm	very warm	very warm

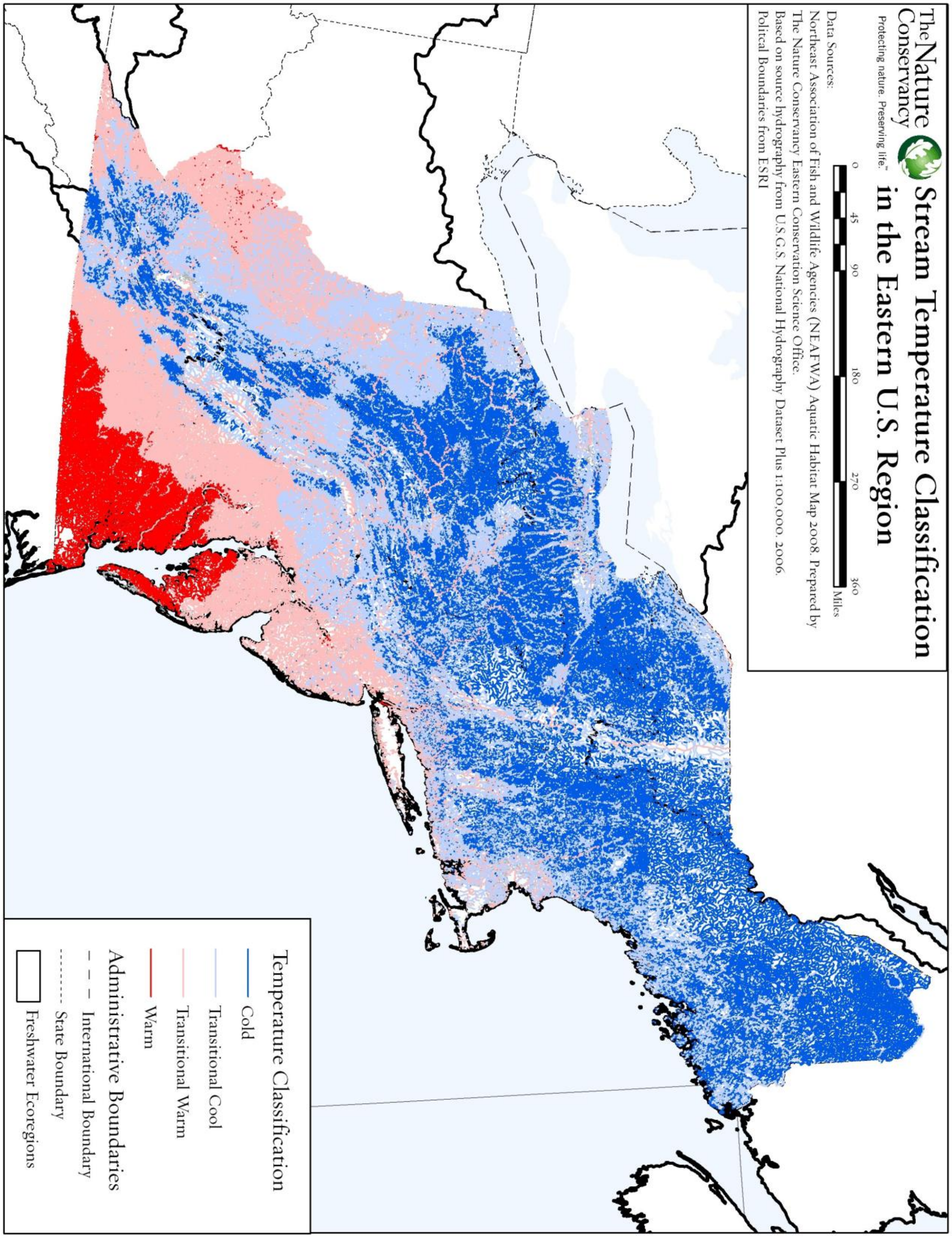
Table 10: Rules used in Coding Expected Stream Water Temperature Classes: Headwater and Creeks

Each headwater and creek reach was assigned to an expected natural water temperature based on the following matrix. If the reach fell within cumulative air temperature class 1-5 or 10 (across), its water temperature class was assigned simply by what gradient class it fell within (down). If the reach fell within cumulative air temperature class 6-9, its water temperature class was based on an initial stratification of those reaches < or >= 40% baseflow index. The expected natural air temperature for these reaches was then assigned based on variations in the gradient class (upper table for those <40% baseflow index, lower table for those >40% baseflow index).

HEADWATER AND CREEK MODEL, Size 1a: 0-3.8 sq.mi and Size 1b: 3.8-38 sq.mi										
Gradient Class down; Air Temp Class across	**1: 0-15**	**2: 15-30**	**3: 30-45**	**4: 45-60**	**5: 60-76**	**6: 75-90, baseflow index < 40%**	**7: 90-105, baseflow index < 40%**	**8:105-120, baseflow index < 40%**	**9: 120-135, baseflow index < 40%**	**10: 135-150**
1: <0.02%	cold	cold	cold	trasitional cool	trasitional cool	transitional warm	transitional warm	transitional warm	very warm	very warm
2: >= 0.02 < 0.1%	cold	cold	cold	trasitional cool	trasitional cool	transitional warm	transitional warm	transitional warm	transitional warm	very warm
3: >= 0.1 < 0.5%	cold	cold	cold	cold	trasitional cool	trasitional cool	trasitional cool	transitional warm	transitional warm	very warm
4: >=0.5 < 2%	cold	cold	cold	cold	cold	trasitional cool	trasitional cool	transitional warm	transitional warm	very warm
5: >=2 < 5%	cold	cold	cold	cold	cold	trasitional cool	trasitional cool	trasitional cool	transitional warm	very warm
6: >5%	cold	cold	cold	cold	cold	cold	trasitional cool	trasitional cool	transitional warm	very warm

	6, baseflow >= 40%	**7, baseflow >= 40%**	**8, baseflow >= 40%**	**9, baseflow >= 40%**
1: <0.02%	trasitional cool	transitional warm	transitional warm	transitional warm
2: >= 0.02 < 0.1%	trasitional cool	trasitional cool	transitional warm	transitional warm
3: >= 0.1 < 0.5%	trasitional cool	trasitional cool	transitional warm	transitional warm
4: >=0.5 < 2%	cold	trasitional cool	trasitional cool	transitional warm
5: >=2 < 5%	cold	cold	trasitional cool	transitional warm
6: >5%	cold	cold	cold	trasitional cool

Figure 11: Map of Stream Temperature Classification



Combining Variables into Types
The workgroup agreed that the four variables and their thresholds discussed above were primary in determining stream type: Size (7 classes), Gradient (6 classes), and Geologic Buffering Capacity (3 classes), and Temperature (4 classes). Of the 312 possible combinations possible given these variables, 259 unique combinations actually occurred in the 13 state region, with 208 having more than10km of length occurring (Appendix III).

Simplifying the Classification
Because of the large number of stream types across the region, we developed some consistent ways to reduce the number of aquatic habitat types for specific purposes. Three methods for simplifying the number of types were considered by the workgroup: 1) Variable Prioritization Rules that prioritize across variables (e.g. size is more important than geology), 2) Collapsing Rules that prioritize the thresholds within variables (e.g. size 1and 4 are more different than size 1a and 1b), and 3) Removing Biotically Insignificant Combinations. The workgroup saw value in all three methods of simplification and wished to have all three included in the final report, along with the full taxonomy. Users may wish to simplify the aquatic habitat types by applying one of these methods and/or combinations of them. Each method is briefly described below.

Variable Prioritization: Certain variables were deemed more important than others in terms of structuring aquatic habitats and biological communities in the northeastern U.S. Certain variables were also considered more constant and unalterable by humans and thus of more utility in a basic classification to address the expected natural aquatic habitat distributions in the northeast. The team recommends the following prioritization rules: 1st importance = stream size, 2nd importance = gradient, 3rd importance = geology, and 4th importance = expected natural water temperature. With this guidance, a user could for example display the aquatic habitats by only size of by a combination of the two most important variables, stream size classes (7) and gradient classes (6) to yield a simpler number of types (e.g. 7 size classes x 6 gradient classes = 42 possible types).

Within Variable Collapsing Rules. Each of the four major variables (size, gradient, geology, and temperature) is divided into multiple classes. Although the breaks are useful in many applications, for some applications users may want to group variation within a given variable into a smaller number of classes. The team developed recommendations of how to collapse each of the four classification variables (Table 13). For example, you could reduce the 7 original size classes into 6, 5, 4, or 3 by following the specific grouping recommendations for how to combine classes within the size classification (Table 13a). For the gradient variable, although one could collapse the gradient classes independent of other variables, the workgroup preferred using different collapsing rules for the gradient variable within streams (size 1a and 1b) vs. within rivers (size 2+) due to variation in the original distribution of gradients in streams vs. rivers (Table 13d).

Remove Biotically Insignificant Combinations: Certain combinations of variables were deemed likely biologically insignificant. For example, although larger rivers can occasionally have higher gradient sections and waterfalls, workgroup members felt in many cases the few high gradient large river reaches mapped in the classification were potentially data errors given the scale of the reach hydrography. Although members did not want to eliminate these types until further "on the ground" investigation, they felt these types should be viewed with skepticism until their unique high gradient habitat could be verified.

Table 11: Collapsing Rules for Size, Geology, Temperature, and Gradient:

11a. Size: Collapsing rules for size classes: from 7 full types to 3 summary types

NESZCL	D_NESZCL	SZCL6	D_SZCL6	SZCL5	D_SZCL5	SZCL4	D_SZCL4	SZCL3	D_SZCL3
1a	Headwater: 0<3.861 sq.mi.	1a	Headwater	1	Headwater/Creek	1	Headwater/Creek	1	Headwater/Creek/Small River
1b	Creek: >=3.861<38.61 sq.mi.	1b	Creek	1	Headwater/Creek	1	Headwater/Creek	1	Headwater/Creek/Small River
2	Small River: >= 38.61<200 sq.mi.	2	Small River	2	Small River	2	Small River	1	Headwater/Creek/Small River
3a	Medium Tributary River >=200<1000 sq.mi.	3a	Medium Tributary River	3a	Medium Tributary River	3	Medium River	3	Medium River
3b	Medium Mainstem River: >=1000<3861 sq.mi.	3b	Medium Mainstem River	3b	Medium Mainstem River	3	Medium River	3	Medium River
4	Large River >=3861<9653 sq.mi.	4	Large/Great River	4	Large/Great River	4	Large/Great River	4	Large/Great River
5	Great River: >=9653	4	Large/Great River	4	Large/Great River	4	Large/Great River	4	Large/Great River

11b. Geology: Collapsing rules for classes: from 3 full types to 2 summary types

NEGEOCL	D_NEGEOCL	GEOCL2	D_GEOCL2
1	Low Buffered, Acidic	1	Low-Moderately Buffered, Neutral to Acidic
2	Moderately Buffered, Neutral	1	Low-Moderately Buffered, Neutral to Acidic
3	Highly Buffered, Calcareous	2	Highly Buffered; Calc-Neutral
0	Assume Moderately Buffered (Size 3+ rivers)	0	Assume Moderately Buffered (Size 3+ rivers)

11c. Stream Temperature: Collapsing rules for classes: from 4 full types to 2 summary types

NETEMPCL	D_NETEMPCL	TEMPCL3	D__TEMPCL3	TEMPCL2	D_TEMPCL2
1	Cold	1	Cold	1	Cool-Cold
2	Transitional Cool	2	Transitional Cool	1	Cool-Cold
3	Transitional Warm	3	Warm	2	Warm
4	Warm	3	Warm	2	Warm

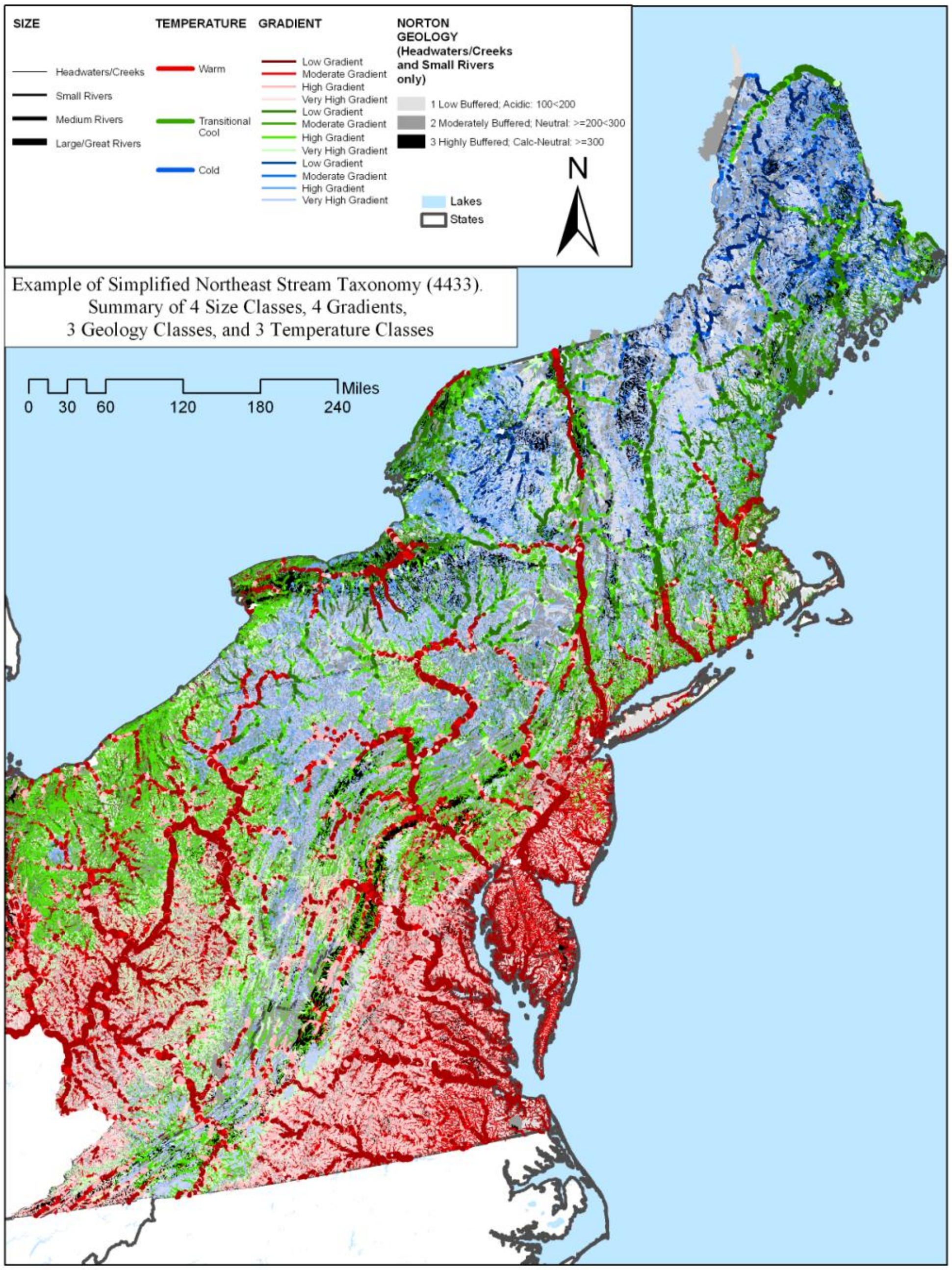
11d. Gradient: Collapsing rules for classes: from 6 full types to 3 summary types; note we recommend using different gradient class collapsing rules for streams vs. rivers.

Full 6 Gradient Classes	Description Full 6 Gradient Classes	5 Classes: Size 1a, 1b	Description 5 Classes; for size 1a, 1b: Headwaters + Creeks	5 Classes: Size 2+	Description 5 Classes; for size 2+: Rivers	4 Classes:	Description 4 Classes; for size 1a, 1b: Headwaters + Creeks	4 Classes:	Description 4 Classes; for size 2+: Rivers	3 Classes:	Description 3 Classes; for size 1a, 1b: Headwaters + Creeks	3 Classes:	Description 3 Classes; for size 2+: Rivers
NESLPCL	D_NESLPCL	SLPCL5A	D_SLPCL5A	SLPCL5B	D_SLPCL5B	SLPCL4A	D_SLPCL4A	SLPCL4B	D_SLPCL4B	SLPCL3A	D_SLPCL3A	SLPCL3B	D_SLPCL3B
1	Very Low Gradient: <0.02%	1	Low Gradient: < 0.1%	1	Low Gradient: <0.02%	1	Low Gradient: < 0.1%	1	Low Gradient: <0.02%	1	Low Gradient: < 0.5%	1	Low Gradient: <0.02%
2	Low Gradient: >= 0.02 < 0.1%	1	Low Gradient: < 0.1%	2	Low-Moderate Gradient: >= 0.02 < 0.1%	1	Low Gradient: < 0.1%	2	Low-Moderate Gradient: >= 0.02 < 0.1%	1	Low Gradient: < 0.5%	2	Moderate Gradient: >= 0.02 < 0.1%
3	Low-Moderate	2	Low-Moderate Gradient: >= 0.1	3	Moderate-High	2	Low-Moderate	3	Moderate-High	1	Low Gradient: <	3	High Gradient: >=
4	Moderate-High Gradient: >=0.5 < 2%	3	Moderate-High Gradient: >=0.5 < 2%	4	High Gradient: >=0.5 < 2%	3	Moderate-High Gradient: >=0.5 < 2%	4	High Gradient: >=0.5%	2	Moderate Gradient: >=0.5 < 2%	3	High Gradient: >= 0.1%
5	High Gradient: >=2 < 5%	4	High Gradient: >=2 < 5%	5	Very High Gradient: >=2%	4	High Gradient: >=2%	4	High Gradient: >=0.5%	3	High Gradient: >=2%	3	High Gradient: >= 0.1%
6	Very High Gradient: >5%	5	Very High Gradient: >5%	5	Very High Gradient: >=2%	4	High Gradient: >=2%	4	High Gradient: >=0.5%	3	High Gradient: >=2%	3	High Gradient: >= 0.1%

Example of a Simplified Classification

Mapping all 259 types is not always practical, nor necessary for the region. Here we provide an example of a smaller set of types (Figure 12) that retains the most important variation in each class while hiding some of the detail or the full set. This example simplification used 4 size classes, 4 gradient classes, 3 geology classes, and 3 temperature classes (e.g. CL4433). Using this simplification, 92 unique combinations actually occurred in the region, with all having more than 10 km of length (Appendix IV) The flexibility of the system allows users to develop maps and analysis for specific purposes.

Figure 12: Example of a Simplified Taxonomy (4433) using 4 Sizes, 4 Gradients, 3 Geology, and 3 Temperature Classes



Additional Attributes
Individual stream segments can be further described using the 100+ "habitat descriptors" compiled during the course of this project. These include variables directly extracted from the NHD-Plus databases (drainage area, stream order, channel elevation, channel slope, estimated mean-annual flow and velocity, PRISM model air temp, PRISM model precipitation, local and cumulative areas of NLCD92 land cover types, etc.) along with attributes calculated by TNC for use in this project (local and cumulative geology, average baseflow index, average catchment slope, area of different landform types in the catchments, etc.). Variables of particular interest that were discussed as key secondary descriptors included

1. upstream and downstream connectivity class (e.g. is the reach upstream a lake, is the reach downstream a very large river etc.),
2. average baseflow index in the local reach catchment as a measure of groundwater influence,
3. elevation, landforms and slope within the local reach catchment,
4. percentage of each of the nine geology classes present locally and cumulatively.

Metadata describing the distributed attributes is in Appendix I.

Lakes and Ponds

This project did not include a lake habitat classification, however a lake dataset and simple lake habitat classification based on size is provided. Additionally, the lake polygons are coded with useful habitat descriptors such as geology, elevation, shoreline sinuosity, and connectivity.

The mapped lakes and ponds are based on the 2006 version NHD-Plus 1:100,000 lake and pond polygons. These source pond and lake polygons provided a good representation of lakes and ponds in the region, however they contained artificial polygon boundaries at quad boundaries. The source dataset was thus dissolved across quad boundaries to yield a final regional lake and pond polygons dataset, lakes_NAHCS.shp, where each polygon represented a "whole" lake or pond.

Lake Size: Size has been found to be the best predictor of lake species richness (Minns 1989, Tonn & Magnuson 1982). The difference between a lake and a pond is often defined by size and light penetration. In a pond, sunlight reaches all the way to the bottom, whereas in a lake the light does not usually reach the bottom. The lack of light at the bottom limits plant growth, which affects the distribution of plant-eating organisms and the biological communities present in the lake (Silk and Ciruna, 2004).

The relationship between light penetration and waterbody depth, size, and turbidity are complex. We used a log scale to define size classes at incremental magnitudes of x 10 (Table 14, Figure 13). A few states in the region use a "rule of thumb" a simple size criteria to define ponds as <10 acres and lakes as > 10 acres. Our order-of-magnitude breaks also matched the size classes used by Maine DEP and NH DES in their GIS based lake classification.

Table 12: Pond and Lake Size Classes

Size Class	Acres	Description	# in the 13 state region
1	<10 acres	ponds	19744
2	10-99 acres	small lakes	12951
3	100-999 acres	medium lakes	2227
4	1000-9999 acres	large lakes	310
5	10,000 acres +	very large lakes	31

Additional Attributes Calculated for Each Lake

Geology: The acidic or alkaline nature of lake water has been noted is a key structuring variable for lacustrine communities. The pH of the water in lakes is highly influenced by the local geologic setting of the lake (Norton, 1980).

The regional geology type underlying each lake or pond polygon was calculated by querying the geology type under the polygon centroid.

Elevation: Local elevation and related climatic differences can be related to a lake or ponds' temperature regime and differences in fish, macroinvertebrate, and plant communities. For example, aquatic biological communities differ significantly between high elevation acidic lakes and low elevation acidic lakes (Langdon et al. 1998). High elevation lakes may have colder average water temperatures, however at higher elevations, ponds are also more likely to freeze to the bottom which will create fishless pond biological communities (Vaux, 2005 personal communication).

The elevation from the 30m National Elevation Dataset DEM (2001) underneath the centroid of each lake or pond polygon was calculated.

Shoreline Sinuosity: Shoreline sinuosity (Wetzel 1983) has been noted as ecologically important to distinguish lakes with more complex natural shorelines and more littoral habitats from those with less complex natural shorelines. Shoreline sinuosity is calculated as the ratio of the length of the shoreline [L] to the circumference of a circle of area [A] equal to that of the lake using the formula

$$D_L = \frac{L}{2\sqrt{\pi A_0}}$$

Each lake or pond polygon was attributed with a shoreline sinuosity value. Although these numbers vary continuously from 1-7, more round (less complex shoreline) lakes have ($DL < 2$) and complex lakes have ($DL \geq 2$) (Weitzell et al. 2003

Connectivity: The connectivity and hydrologic position of lakes is correlated a number of water chemistry attributes including conductivity, Ca^{2+}, Mg^{2+}, alkalinity, dissolved inorganic carbon and pH. These patterns are partly explained by the effect of increasing catchment area; lakes high in the watershed receive a greater proportion of input waters from precipitation than lakes lower in the landscape. The patterns are also partly explained by the systematic processing of materials in lakes and in the stream segments between lakes (Webster and Sorrano 2000, Quinlan et al 2003, Kling et al. 2000). Lakes lower in the watershed also often experience higher flushing rates and less thermal stratification than lakes of similar surface area/depth ratio located higher in hydrologic position. Seepage lakes (no inlets/outlets) and lakes positioned at the headwaters of a river drainage with only an outflow to a river have also been shown to be more sensitive to acid rain and snowmelt events (Quinlan et al. 2003). Upper headwater lakes also tend to have a more limited fauna and flora than expected by size and depth due to barriers further down in the watershed that prevent access to higher lakes. (Quinlan et al. 2003, Lewis and Magnuson 2000, Kratz et al. 1997).

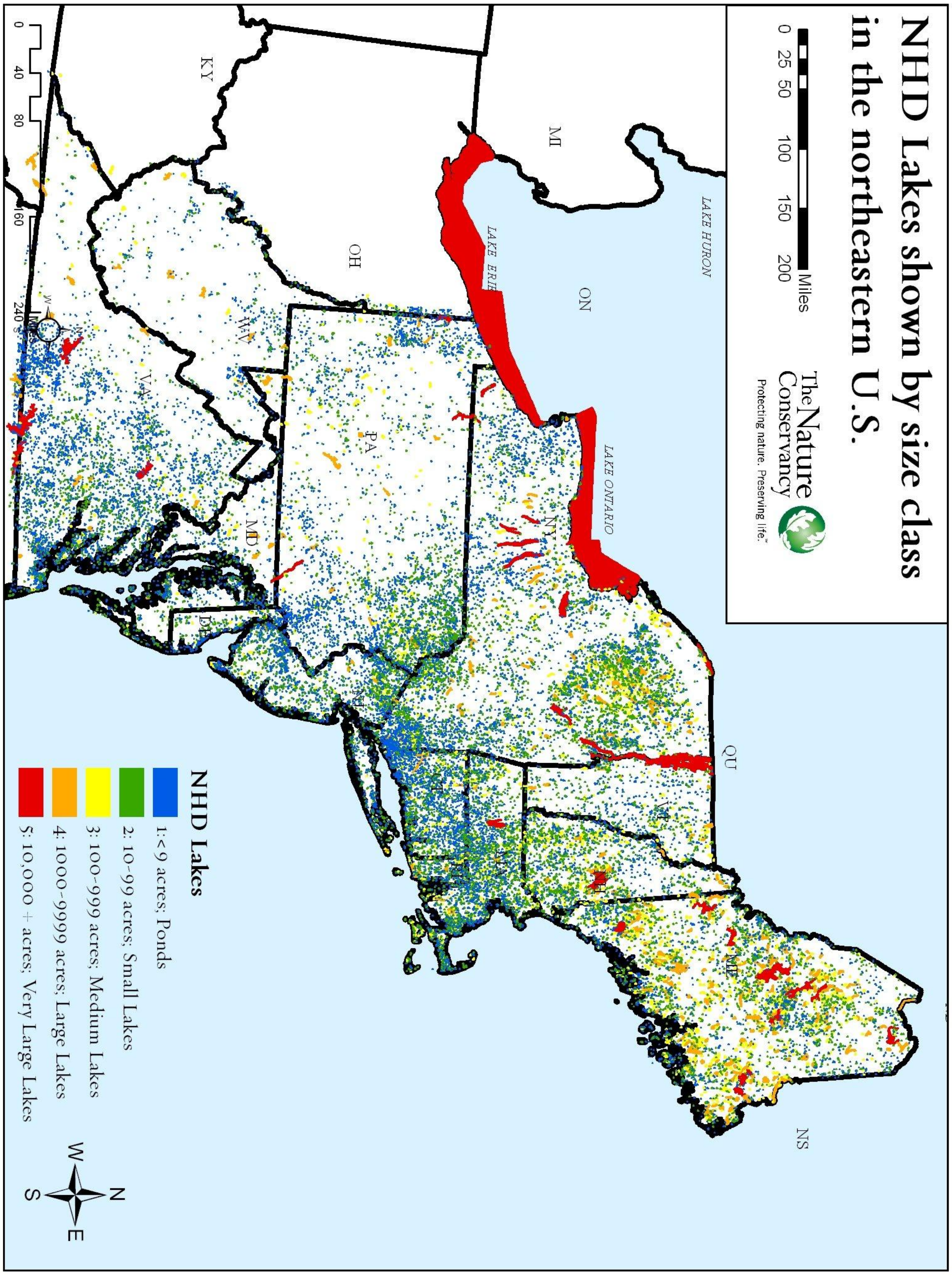
Each lake or pond polygon was coded as to whether it was disconnected from any mapped NHD-Plus streams or had a mapped NHD-Plus stream within less than two meters. This highlighted isolated seepage lakes (no connections) from lakes that are part of a stream drainage network.

Additional Attributes Not Calculated for Each Lake

Depth: Depth is a critical variable related to lake stratification and the presence of permanent cold water habitats in a lake. During the summer, lakes may stratify into 1) the epilimnion where warm water is well mixed, 2) the metalimnion of placid water where temperature drops quickly, and the 3) hypolimnion of cool/cold water at the bottom of the lake. Different biological communities are associated with the different thermal zones. Lakes shallower than 10 meters generally do not develop a stable thermal stratification during the summer as their wave action can stir water to such a depth that the thermal boundary never completely forms. At the other extreme, deeper lakes have a permanent summer thermocline and hypolimnion providing habitat for lake trout, brook trout, rainbow smelt, burbot, and landlocked Atlantic salmon that require permanent cold-water habitat (Silk and Ciruna 2004, NH SWAP, 2005).

Although depth is a very important habitat structuring variable for lakes and ponds, this variable cannot be modeled in GIS and is thus not provided as part of this project.

Figure 13: Lake Size Classes



Placement within a Larger Spatial Stratification

Biotic patterns in the Northeastern Aquatic Habitat Classification System (NAHCS) should be explored in conjunction with a spatial hierarchy of larger drainage units corresponding to zoographic regions. A number of larger stratification units such as World Wildlife Fund's Freshwater Ecoregions the Nature Conservancy's Terrestrial Ecoregions, Ecological Drainage Units, and Aquatic Ecological Systems are available.

We suggest that users consider using the Freshwater Ecoregions as defined by the World Wildlife Fund (WWF, 2008). Freshwater ecoregions are large areas encompassing one or more freshwater systems that contain a distinct assemblage of natural freshwater communities and species. The freshwater species, dynamics, and environmental conditions within a given ecoregion are more similar to each other than to those of surrounding ecoregions and together form a natural unit. The freshwater ecoregion boundaries generally - though not always - correspond with those of watersheds. Within individual ecoregions there will be turnover of species, such as when moving up or down a river system, but taken as a whole an ecoregion will typically have a distinct evolutionary history and/or ecological processes. WWF's Ecoregions were delineated based on the best available information, but data describing freshwater species and ecological processes are characterized by marked gaps and variation in quality, and improved information in the future may warrant map revisions (Abell et al. 2008) Examples in the northeastern U.S. include the Northeast US & Southeast Canada Atlantic Drainages, St.Lawrence, Laurentian Great Lakes, Chesapeake Bay, Teays - Old Ohio, Tennessee. Please see Appendix V for a map and descriptions of the Freshwater Ecoregions in this project.

Suggestions for Future Improvements and Applications of the Classification

The workgroup identified key areas for further applications and refinement of the aquatic habitat classification. Each is briefly described below.

1. Condition Reporting:

The NAHCS classification products provide an estimate of the expected natural aquatic habitat type, however it is not intended to account for variation in the occurrence of aquatic habitats due to human alteration. Many factors such as patterns in land use, damming, stream channelization, point sources and other modifications impact existing aquatic habitats, aquatic ecosystems, and the types of aquatic biota currently found at sites.

2. Biota Relationships:

Many team members would like see stream biota and fine scale habitat descriptions linked to the existing Northeastern Aquatic Habitat Classification Types. By linking aquatic biota distributions to the NAHCS, regional species patterns among the aquatic habitat types will be more transparent and better understood. Below is one examples of this kind of linkage.

Streams and Rivers
Regional Habitat Class: **Cold, high gradient, acidic, headwater stream (1b611)**
Fish: Brook trout; Brook-trout Slimy sculpin, Blacknose dace
Macroinvertebrates: acid tolerant leaf shredders, low species diversity: Caddisflies (*Parapsyche, Palegapetus*)-Stoneflies (*Capniidae*)-Non-biting midges (*Eukiefferella*), Mayflies (*Eurylophella*).Other preferential taxa Caddisflies?(*Symphitpsyche*), Stoneflies (*Leuctridae, Taenionema*, *Chloroperlidae, Peltoperla*), Water strider (pools). Possible taxa Alder flies, Beetles (*Psephenidae*), Mollusca (*Elliptio*), Mayflies (*Heptagenidae*).
Plants: acid tolerant bryophytes, algae, macrophytes
Habitat Description: Cascade and step-pool habitats where channels are narrowly confined; bed materials of bedrock, boulders, and cobbles; primarily coldwater habitats with fast moving water; low elevation/coastal variants rare

3. Sub-Freshwater Ecoregionalization: The workgroup felt further regionalization using fish zoogeographic patterns within WWF Freshwater Ecoregions would be a useful large stratification unit. Although preliminary work was done on clustering the NatureServe HUC8 fish distribution data in the U.S. within each freshwater ecoregion, further analysis is necessary to refine and agree upon the most ecologically significant splits within each freshwater ecoregion.

4. Lake Habitat Classification: Although a basic lake habitat GIS dataset was developed during the course of this project, further work is necessary to develop a regionally accepted set of lake types. Accomplishing this with the same level of collaboration would require state review, workgroup facilitation, and data testing to determine the most ecologically significant variables and thresholds for class breaks.

Appendix I: Metadata Describing Distributed GIS Datasets and Attribute Tables

<u>Distributed Geodata:</u> Each folder within \geodata contains shapefiles and .lyrs for the following geography

\full_nahcs = full 13 state region
- flowlines_nahcs.shp = stream lines and classification fields
- lakes_NAHCS.shp = lake polygons and classification fields
- catchments_NAHCS.shp = local catchments for each reach

\state = individual states + 10km buffer

/CT	/NJ
/DC	/NY
/DE	/PA
/MA	/RI
/MD	/VA
/ME	/WV
/NH	

- XX_flowlines_nahcs.shp = stream lines and classification fields for this state
- XX_lakes_NAHCS.shp = lake polygons and classification fields for this state
- XX_catchments_NAHCS.shp = local catchments for each reach

\drainge_regions = USGS drainage regions
- reg1_newengland
- /reg2_midatlantic
- /reg3_southatlantic
- /reg4_greatlakes
- /reg5_mississippi_ohio
- /reg6_mississippi_tennessee
- XX_flowlines_nahcs.shp = all flowlines for this drainage basin region; provided for those who may want to join the secondary attribute tables to a specific drainage region flowline datasets to represent the whole drainage which in some cases extends outside of our 13 state NEAFWA focus geography.

<u>Distributes .Lyr files:</u> Within each of the above geography folders, the following ArcGIS .lyr files are provided for ease of symbolization and display of the data.

For stream/river flowlines.shps:
- Size Classes.lyr
- Geology Classification.lyr
- Gradient Classification.lyr
- Temperature Classification.lyr
- Simplified Geology Classes - 2 Classes.lyr
- Simplified Size Classification - 3 Classes.lyr
- Simplified Size Classification - 4 Classes.lyr
- Simplified Size Classification - 5 Classes.lyr
- Simplified Size Classification - 6 Class.lyr
- Simplified Slope Classes - 3 Classes.lyr
- Simplified Slope Classes - 4 Classes.lyr
- Simplified Slope Classes - 5 Classes.lyr
- Simplified Temperature Classes - 2 Classes.lyr
- Simplified Temperature Classes - 3 Classes.lyr
- Simplified Taxonomy 4433.lyr

For lake.shps
- LakeSize.lyr

Distributed Tables: A list of distributed attribute tables is provided below. **Please see following pages for descriptions of the attributes in each of these tables.**

Primary Attributes related to the classification are found in the \geodata\full_neafwa or \geodata\state flowlines_NAHCS.dbf and lake_NAHCS.dbf tables which are part of the distributed shapefiles in these folders.

Secondary Attributes are found in \secondary_tables\ under the following subdirectories. The tables are named with the prefix "nahcs" for a table with all reaches in the 13 state NAHCS area. You can join this table to the full regional \geodata\full_neafwa\flowlines_nahcs.shp or the \geodata\full_neafwa\catchments_nahcs.shp on "comid". You could also use this "nahcs" prefix table to join to the provided state specific xx_flowline_nahcs.shp or xx_catchment_nahcs.shp on the "comid". Specific drainage region tables are also provided which can join to the individual flowlines.shp found in the individual \geodata\regional folders. Please note however that geology and landform attributes are not available for the portions of the drainage regions extending beyond our 13 state project area.

/Geology_cumulative
nahcs_geo_accumind.dbf
Reg01geo_accumind.dbf
Reg02geo_accumind.dbf
Reg03geo_accumind.dbf
Reg04geo_accumind.dbf
Reg05geo_accumind.dbf
Reg06geo_accumind.dbf

/Geology_local
nahcs_geo_alloind.dbf
Reg01geo_alloind.dbf
Reg02geo_alloind.dbf
Reg03geo_alloind.dbf
Reg04geo_alloind.dbf
Reg05geo_alloind.dbf
Reg06geo_alloind.dbf

/Landcover_cumulative
nahcs_flowlineattributesnlcd.dbf
Reg01_flowlineattributesnlcd.dbf
Reg02_flowlineattributesnlcd.dbf
Reg03_flowlineattributesnlcd.dbf
Reg04_flowlineattributesnlcd.dbf
Reg05_flowlineattributesnlcd.dbf
Reg06_flowlineattributesnlcd.dbf

/Landcover_local
nahcs_catchmentattributesnlcd.dbf
Reg01_catchmentattributesnlcd.dbf
Reg02_catchmentattributesnlcd.dbf
Reg03_catchmentattributesnlcd.dbf
Reg04_catchmentattributesnlcd.dbf
Reg05_catchmentattributesnlcd.dbf
Reg06_catchmentattributesnlcd.dbf

/Landforms_local
nahcs_tab_landform.dbf
Reg01_tab_landform.dbf
Reg02_tab_landform.dbf
Reg03_tab_landform.dbf
Reg04_tab_landform.dbf
Reg05_tab_landform.dbf
Reg06_tab_landform.dbf

/Source_attributes
nahcs_src.dbf
Reg01_src.dbf
Reg02_src.dbf
Reg03_src.dbf
Reg04_src.dbf
Reg05_src.dbf
Reg06_src.dbf

Report Appendices are found in \report\appendix_tables. These include the following:
AppendixI_NAHC_tables_field_definitions.xls
AppendixII_Workgroup.xls
AppendixIII_Nahcs_cl7634.xls
AppendixIV_Nahcs_cl4433.xls
Original_state_aquatic_types.xls = database of collected state aquatic habitat types used in SWAP and other previous planning work

Primary Attribute Table Streams: Gives for each reach the full taxonomy code (CLFL7634), variable classes used in the full taxonomy code, suggested simplifications of the variable classes, and an example or a simplified taxonomy code (CLSIMP4433)

Metadata for flowlines_NAHCS.dbf		
Fields	**Description**	**Additional Reference and/or Look-Up-Table**
COMID	NHD plus comid for each reach	
NESZCL	NEAFWA Full Size Classes (7 classes) 1a, 1b, 2, 3a, 3b, 4, 5: Note these represent size classes of streams and rivers where major differences in stream and river ecosystems occur in the northeastern U.S. See the report for more information on the modeling	lut_sz_simp.xls or .dbf
D_NESZCL	Description of NEAFW Full Size Classes (7 classes); 1a:Headwater: 0<3.861 sq.mi, 1b:Creek: >=3.861<38.61 sq.mi., 2:Small River: >= 38.61<200 sq.mi., 3a:Medium Tributary River: >=200<1000 sq.mi., 3b:Medium Mainstem River: >=1000<3861 sq.mi., 4:Large Riv	lut_sz_simp.xls or .dbf
NESLPCL	NEAFWA Full Slope Classes (6): 1,2,3,4,5,6: Note these represent the slope of the stream channel in percent rise over run. See report for more information on the modeling and description of these classes.	lut_slp_simp.xls or .dbf
D_NESLPCL	1:Very Low Gradient: <0.02%,2:Low Gradient: >= 0.02 < 0.1%,3:Low-Moderate Gradient: >= 0.1 < 0.5%,4:Moderate-High Gradient: >=0.5 < 2%,5:High Gradient: >=2 < 5%,6:Very High Gradient: >5%	lut_slp_simp.xls or .dbf
NEGEOCL	NEAFWA Full Geology Acid Neutralizing Classes (3): Note these are an estimate of the bedrock geology and deep surficial sediments effects on the acid neutralizing capacity of the water. See report for more information on the modeling and description of t	lut_geo_simp.lut
D_NEGEOCL	1:Low Buffered, Acidic; 2:Moderately Buffered, Neutral; 3:Highly Buffered, Calcareous;0:Assume Moderately Buffered (Size 3+ rivers);9:Unknown Buffering/Missing Geology	lut_geo_simp.lut
NETEMPCL	NEAFWA Full Temperature Classes (4): Note these are a coarse estimate of the expected water temperatures given natural conditions. See report for more information on the modeling and description of these classes.	lut_temp_simp.xls or .dbf
D_NETEMPCL	1:Cold, 2:Transitional Cool, 3:Transitional Warm, 4:Warm, 9:Missing Information Needed to Model this variable	lut_temp_simp.xls or .dbf
CLNEFL7634	NEAFWA Full Combined Type Code: This code was formed by concatenating the following full classes Neszcl (7classes) + Neslpcl (6 classes) + Negeocl (3 classes) + Netempcl (4 classes); note those with code 9_9_9_9 are the uninitialized NHD stream segments which were missing directionality and thus all classification attributes	lut_clnefl7634_desc.xls or .dbf
D_NE7634	Description of NEAFWA Full Combined Type Code: Text concatenation.	lut_clnefl7634_desc.xls or .dbf
CLSIMP4433	Example of A Simplified Combined Type Code: This example was created by concatenating the following Szcl4 + Slpcl4f + + Negeocl + + Tempcl3	lut_clsimp4433_desc.xls or .dbf
D_NE4433	Description of The Simplified Combined Type Code 4433: Text concatenation	lut_clsimp4433_desc.xls or .dbf
SZCL6	Simplified Size Classes (6 Classes): 1a, 1b, 2, 3a, 3b, 4	lut_sz_simp.xls or .dbf
D_SZCL6	Description of Simplified Size Classes (6 Classes): 1a, 1b, 2, 3a, 3b, 41a:Headwater, 1b:Creek, 2:Small River, 3a:Medium Tributary River, 3b:Medium Mainstem River, 4:Large/Great River	lut_sz_simp.xls or .dbf
SZCL5	Simplified Size Classes (5 Classes): 1, 2, 3a, 3b, 4	lut_sz_simp.xls or .dbf
D_SZCL5	Description of Simplified Size Classes (5 Classes):1:Headwater/Creek, 2:Small River, 3a:Medium Tributary River,3b:Medium Mainstem River,4:Large/Great River	lut_sz_simp.xls or .dbf

SZCL4	Simplified Size Classes (4 Classes): 1, 2, 3, 4	lut_sz_simp.xls or .dbf
D_SZCL4	Description of Simplified Size Classes (4 Classes):1:Headwater/Creek, 2:Small River, 3:Medium River,4:Large/Great River	lut_sz_simp.xls or .dbf
SZCL3	Simplified Size Classes (3 Classes): 1, 3, 4	lut_sz_simp.xls or .dbf
D_SZCL3	Description of Simplified Size Classes (3 Classes):1:Headwater/Creek/Small River, 3:Medium River, 4:Large/Great River	lut_sz_simp.xls or .dbf
SLPCL5F	Simplified Slope Classes (5 Classes): Note the class assignment rules used for assignment are SPECIFIC to the size of the river. Class breaks described as D_SLPCL5A applied to rivers of size 1a and 1b streams, while Rules as described as D_SLPCL5B applie	lut_slp_simp.xls or .dbf
D_SLPCL5F	Description of Simplified Slope Classes (5 Classes): Note the class assignment rules used for assignment are SPECIFIC to the size of the river. Class breaks described as D_SLPCL5A applied to rivers of size 1a and 1b streams, while Rules as described as D	lut_slp_simp.xls or .dbf
SLPCL4F	Simplified Slope Classes (4 Classes): Note the class assignment rules used for this assignment are SPECIFIC to the size of the river. Class breaks described as D_SLPCL4A applied to rivers of size 1a and 1b streams, while Rules as described as D_SLPCL4B a	lut_slp_simp.xls or .dbf
D_SLPCL4F	Description of Simplified Slope Classes (4 Classes): Note the class assignment rules used for this assignment are SPECIFIC to the size of the river. Class breaks described as D_SLPCL4A applied to rivers of size 1a and 1b streams, while Rules as described	lut_slp_simp.xls or .dbf
SLPCL3F	Simplified Slope Classes (3 Classes): Note the class assignment rules used for this assignment are SPECIFIC to the size of the river. Class breaks described as D_SLPCL3A applied to rivers of size 1a and 1b streams, while Rules as described as D_SLPCL3B a	lut_slp_simp.xls or .dbf
D_SLPCL3F	Description of Simplified Slope Classes (3 Classes): Note the class assignment rules used for this assignment are SPECIFIC to the size of the river. Class breaks described as D_SLPCL3A applied to rivers of size 1a and 1b streams, while Rules as described	lut_slp_simp.xls or .dbf
GEOCL2	Simplified Geology (2 Classes)	lut_geo_simp.lut
D_GEOCL2	Description of Simplified Geology (2 Classes) D_GEOCL2: 1:Low-Moderately Buffered, Neutral to Acidic, 2: Highly Buffered; Calc-Neutral, 0: Assume Moderately Buffered (Size 3+ rivers), 9: Unknown Buffering/Missing Geology	lut_geo_simp.lut
TEMPCL3	Simplified Temperature Classes (3 Classes)	lut_temp_simp.xls or .dbf
D_TEMPCL3	Description of Simplified Temperature Classes (3 Classes): 1:Cold, 2:Transitional Cool, 3:Warm, 9:Missing	lut_temp_simp.xls or .dbf
TEMPCL2	Simplified Temperature Classes (2 Classes)	lut_temp_simp.xls or .dbf
D_TEMPCL2	Description of Simplified Temperature Classes (2 Classes): 1:Cool and Cold, 2:Warm, 9:Missing	lut_temp_simp.xls or .dbf

Primary Attribute Table Lakes: Gives for each lake or pond polygon the following attributes are provided:

Metadata for lakes_NAHCS.dbf	
Fields	**Description**
AGG_UNIQID	unique id for each lake or pond polygon after internal polygons w ere dissolved in GIS
N_NHDLK	number of source NHD-Plus lake polygons that w ere dissolved to create this regional lake or pond polygon (note touching polygons in the source NHD-PlUS w ere dissolved to create an accurate lake/pond polygon upon w hich total area and shape metrics could be
AREA	area of the polygon in sq.meters
PERIMETER	perimeter of the polygon in meters
LINKCOMID	w aterbody comid from the largest source NHD-Plus polygon w ithin
GNIS_ID	Geographic Names Information System id from the largest source NHD-Plus polygon w ithin
GNIS_NAME	Geographic Names Information System name from the largest source NHD-Plus polygon w ithin
REACHCODE	Reachcode from the largest source NHD-Plus polygon w ithin
FTYPE	Feature types from the largest source NHD-Plus polygon w ithin (lake or reservoir)
FCODE	Feature code from the largest source NHD-Plus polygon w ithin (lake or reservoir)
GEO	Regional Geology Type underneath the polygon centroid; 100 = acidic sedimentary/metasedimentary, 200 = acidic shale, 300 = calcareous sedimentary/metasedimentary, 400 = moderately calcareous sedimentary/metasedimentary, 500 = acidic granitic, 600 = mafic/
DEM_M	Elevation in meters from National Elevation Dataset, 2001, underneath the polygon centroid
SHORECOMP	$$D_L = \frac{L}{2\sqrt{\pi A_0}}$$ Shoreline complexity,
CONNECT2M	0 = w as disconnected from mapped NHD-Plus streams, 1 = had a mapped NHD-Plus stream w ithin < 2 meters.
ACRES	size of the lake in acres
SIZE_CL	size class of the lake in acres 1 = 0-9, 2 = 10-99, 3 = 100-999, 4 = 1000-9,999, 5 = 10,000+

Secondary Table: Source Attributes: Additional useful raw variable attributes

metadata for reg0X_src.dbf		
Field	**Description**	**Source: If attributes is from a NHD-Plus table, the source table is listed; otherwise TNC or other source is listed**
COMID	NHD plus comid for each reach	nhdflowline_us.dbf
FDATE	feature date	nhdflowline_us.dbf
RESOLUTION	scale of NHD	nhdflowline_us.dbf
GNIS_ID	numeric id from Geographic Names Information System	nhdflowline_us.dbf
GNIS_NAME	Feature Name from the Geographic Names Information System	nhdflowline_us.dbf
LENGTHKM	Feature length in kilometers	nhdflowline_us.dbf
REACHCODE	reach code	nhdflowline_us.dbf
FTYPE	NHD Feature Type	nhdflowline_us.dbf
SINUOUSITY	reach sinuosity as calculated from Hawth tools by TNC	TNC
FRACDIM	reach fractal dimension as calculated from Hawth tools by TNC	TNC
PROD_UNIT	Production Unit	cat.dbf
GRID_CODE	Grid value for the catchment	catchmentattributestempprecip.dbf
PRECIP	Mean annual precipitation in mm	catchmentattributestempprecip.dbf
TEMP	Mean annual temperature in degrees centigrade * 10	catchmentattributestempprecip.dbf
AREAWTMAP	Area Weighted Mean Annual Precipitation at bottom of flowline in mm	flowlineattributestempprecip.dbf
AREAWTMAT	Area Weighted Mean Annual Temperature at bottom of flowline in degree C * 10	flowlineattributestempprecip.dbf
CUMDRAINAG	Cumulative drainage area in square kilometers(sq km) at bottom of flowline	flowlineattributesflow.dbf
MAFLOWU	Mean Annual Flow in cubic feet per second (cfs) at bottom of flowline as computed by Unit Runoff Method	flowlineattributesflow.dbf
MAFLOWV	Mean Annual Flow (cfs) at bottom of flowline as computed by Vogel Method	flowlineattributesflow.dbf
MAVELU	Mean Annual Velocity (fps) at bottom of flowline as computed by Unit Runoff Method	flowlineattributesflow.dbf
MAVELV	Mean Annual Velocity (fps) at bottom of flowline as computed by Unit Runoff Method	flowlineattributesflow.dbf
INCRFLOWU	Incremental Flow (cfs) for Flowline as computed by the Unit Runoff Method	flowlineattributesflow.dbf
MAXELEVSMO	Maximum elevation (smoothed) in meters	flowlineattributesflow.dbf
MINELEVSMO	Minimum elevation (smoothed) in meters	flowlineattributesflow.dbf
SLOPE	Slope of flowline (m/m)	flowlineattributesflow.dbf
SQMI	Cumdrainag converted to sq.mi.	flowlineattributesflow.dbf
HYDROSEQ	Hydrologic sequence number	nhdflowlinevaa.dbf
STREAMLEVE	Stream level	nhdflowlinevaa.dbf
STREAMORDE	Strahler stream order	nhdflowlinevaa.dbf
LEVELPATHI	Hydrologic sequence number of most downstream flowline in level path	nhdflowlinevaa.dbf
UPHYDROSEQ	mainpath upstream reach hydroseq	nhdflowlinevaa.dbf
DNHYDROSEQ	mainpath downstream reach hydroseq, calculated by TNC via queries	nhdflowjnpull.dbf

BSFLMEAN	mean baseflow index within NHD+ local catchment as calculated by TNC	"This 1-kilometer raster (grid) dataset for the conterminous United States was created by interpolating base-flow index (BFI) values estimated at U.S. Geological Survey (USGS) streamgages. Base flow is the component of streamflow that can be attributed to
SLPMEAN	mean localcatchment slope as calculated by TNC from the USGS NED 30m digital elevation model 2001. http://ned.usgs.gov/	USGS NED 30m digital elevation model 2001. http://ned.usgs.gov/
PERMMEAN	mean permeability from STATSGO as calculated by TNC; original polygon data was converted into 30m cell size grid in U.S. Albers projection for analysis.	"PERM = permeability rates (inches/hour). First, we compute the average of the high and low values for those variables expressed as a range. We then average the varaiables over all layers using the layer thickness (laydeph - laydepl) as weights. The fi
NEBSFLCL	Mean Baseflow Index Class within Local Catchment as calculated by TNC taking the BSFLMEAN values and classifing into groups as follows; 1:0-35, 2:35-40, 3:40-45, 4:45-50, 5:50-60, 6:60-65, 7:65-100, 0/9/9999: not available. These values were used in the	"This 1-kilometer raster (grid) dataset for the conterminous United States was created by interpolating base-flow index (BFI) values estimated at U.S. Geological Survey (USGS) streamgages. Base flow is the component of streamflow that can be attributed to
NEWMATCL	The continuous AREAWTMAT data (AREA WEIGHTED MEAN ANNUAL AIR TEMPERATURE CLASS (degree C * 10)) was put into major class which were used in the water temperature class assignment; 1:0-15, 2:15-30, 3:30-45, 4:45-60, 5:60-75, 6:75-90, 7:90-105, 8:105-120,	flowlineattributestempprecip.dbf, grouped by TNC
NEELVCL	The USGS NHD Plus MINELEVSMO continuous minimum elevation data was put into classes as follows for a regional elevation classification: 1:coastal zone <20ft, 2:low elevation 20-800ft., 3:mid-to-lower elevation transitional 800-1700ft., 4:mid-to-upper elev	flowlineattributesflow.dbf, grouped by TNC
STATE	State the centroid of the reach is within	TNC
PU_NAME	Terrestrial Ecoregion (TNC modified Baily) for northeastern U.S.	TNC
HUC8	8-digit Hydrologic Unit Code, also know as Subbasin code (formerly known as Cataloging Unit code)	subbasin.dbf
HUC8_NAME	text name of Subbasin	subbasin.dbf
ECO_ID	Freshwater Ecoregions of the World, Ecoregion ID	Freshwater Ecoregions of the World, Copyright 2008 by The Nature Conservancy and World Wildlife Fund, Inc.
ECOREGION	Freshwater Ecoregions of the World, Ecoregion Name	Freshwater Ecoregions of the World, Copyright 2008 by The Nature Conservancy and World Wildlife Fund, Inc.

Secondary Tables: Geology

Local Catchment Geology Table

Metadata for geo_alloind.dbf; LOCAL CATCHMENT ALLOCATION	
Fields	**Description**
COMID	NHD plus comid for each reach
MISSDATAA	1 = area missing from geology grid
V0A	no geology area in sq.meters
V0P	no geology %
V100A	Acidic sed/metased area in sq.meters
V100P	Acidic sed/metased %
V200A	Acidic shale area in sq.meters
V200P	Acidic shale %
V300A	Calcareous sed/metased area in sq.meters
V300P	Calcareous sed/metased %
V400A	Mod calcareous sed/metased area in sq.meters
V400P	Mod calcareous sed/metased %
V500A	Acidic granitic area in sq.meters
V500P	Acidic granitic %
V600A	Mafic/intermediate granitic area in sq.meters
V600P	Mafic/intermediate granitic %
V700A	Ultramafic area in sq.meters
V700P	Ultramafic %
V800A	Coarse sediments area in sq.meters
V800P	Coarse sediments %
V900A	Fine sediments area in sq.meters
V900P	Fine sediments %
HYDROSEQ	hydrologic sequence number
GEO_ALLO	Weighting geology type based on acidity to create an index used on classification; geo_allo = (V100p * 2) + (V200p * 2) + (V300p * 4) + (V400p * 3) + (V500p * 1) + (V600p * 3) + (V700p * 3) + (V800p * 1) + (V900p * 3)

Cumulative Upstream Geology Table

Metadata for regX_geo_accumind.dbf, TOTAL CUMULATION OF UPSTREAM LOCAL CATCHMENTS

Fields	**Description**
COMID	NHD plus comid for each reach
MISSDATAA	1 = area missing from geology grid
V0AC	no geology area in sq.meters
V0PC	no geology %
V100AC	Acidic sed/metased area in sq.meters
V100PC	Acidic sed/metased %
V200AC	Acidic shale area in sq.meters
V200PC	Acidic shale %
V300AC	Calcareous sed/metased area in sq.meters
V300PC	Calcareous sed/metased %
V400AC	Mod calcareous sed/metased area in sq.meters
V400PC	Mod calcareous sed/metased %
V500AC	Acidic granitic area in sq.meters
V500PC	Acidic granitic %
V600AC	Mafic/intermediate granitic area in sq.meters
V600PC	Mafic/intermediate granitic %
V700AC	Ultramafic area in sq.meters
V700PC	Ultramafic %
V800AC	Coarse sediments area in sq.meters
V800PC	Coarse sediments %
V900AC	Fine sediments area in sq.meters
V900PC	Fine sediments %
HYDROSEQ	hydrologic sequence number
GEO_ACCUM	Weighting geology type based on acidity to create an index used on classification; geo_accum = (V100pc * 2) + (V200pc * 2) + (V300pc * 4) + (V400pc * 3) + (V500pc * 1) + (V600pc * 3) + (V700pc * 3) + (V800pc * 1) + (V900pc * 3)

Secondary Table: Landforms

Local Catchment Landform Table

Metadata for regx_tab_landform.dbf	
Field	**Description**
VALUE	GRID_CODE, Grid value for the catchment of the comid
LF_1	Summit/ridgetop area in sq.meter
LF_2	Cliff/steep slope area in sq.meter
LF_3	Sideslope area in sq.meter
LF_4	Cove/footslope area in sq.meter
LF_5	Hill/valley: gentle slope area in sq.meter
LF_6	Dry flats area in sq.meter
LF_7	Wet flats area in sq.meter
LF_8	Open water area in sq.meter
TOTALAREA	sum of all areas contained in the LF_## columns of the table if you do not define an existing totalarea column for the script to use
N1	Count of all Value columns > 0
H	Shannon's Diversity
LAMBDA	Lambda Diversity
N2	e to the H power
N3	1 / Lambda
TOTALP	Total percent covered by the landform data
PLF_1	Summit/ridgetop %
PLF_2	Cliff/steep slope %
PLF_3	Sideslope %
PLF_4	Cove/footslope %
PLF_5	Hill/valley: gentle slope %
PLF_6	Dry flats %
PLF_7	Wet flats %
PLF_8	Open water %

Secondary Tables: Land Cover, National Land Cover 1992

Local Land Cover Catchment Table

Fields in regx_catchmentattributesnlcd.dbf; LOCAL CATCHMENT ALLOCATION	
Fields	**Description**
COMID	NHD plus comid for each reach
GRID_CODE	GRID_CODE, Grid value for the catchment
NLCD_11	11. Open Water
NLCD_12	12. Perennial Ice/Snow
NLCD_21	21. Low Intensity Residential
NLCD_22	22. High Intensity Residential
NLCD_23	23. Commercial/Industrial/Transportation
NLCD_31	31. Bare Rock/Sand/Clay
NLCD_32	32. Quarries/Strip Mines/Gravel Pits
NLCD_33	33. Transitional
NLCD_41	41. Deciduous Forest
NLCD_42	42. Evergreen Forest
NLCD_43	43. Mixed Forest
NLCD_51	51. Shrubland
NLCD_61	61. Orchards/Vineyards/Other
NLCD_71	71. Grasslands/Herbaceous
NLCD_81	81. Pasture/Hay
NLCD_82	82. Row Crops
NLCD_83	83. Small Grains
NLCD_84	84. Fallow
NLCD_85	85. Urban/Recreational Grasses
NLCD_91	91. Woody Wetlands
NLCD_92	92. Emergent Herbaceous Wetlands
PCT_CN	% of catchment in Canada and not classsified in NLCD
PCT_MX	% of catchment in Mexico and not classified in NLCD
SUM_PCT	Sum of the % cumulative drainage areas
P_WAT	total % water, NLCD_11 + NLCD_12
P_DEVLOW	total % low intensity development; NLCD_21
P_DEVHI	total % high intensity development; NLCD_22 + NLCD_23
P_DEVTOT	total % all development classes; NLCD_21 + NLCD_22 + NLCD_23
P_DIST	total % distrubed; NLCD_32 + NLCD_33
P_FORSHRUB	total % forest and shrub; NLCD_41 + NLCD_42 + NLCD_43 + NLCD_51
P_OPENNAT	total % open natural; NLCD_31 + NLCD_71
P_AGLOW	total NLCD_84 + NLCD_81 + NLCD_85 + NLCD_61
P_AGHI	total % high intensity agriculture; NLCD_82 + NLCD_83
P_AGTOT	total % agriculture; NLCD_82 + NLCD_83 + NLCD_84 + NLCD_81 + NLCD_85 + NLCD_61
P_WET	total % wetlands, NLCD_92 + NLCD_91
P_NAT	total % natural cover; NLCD_92 + NLCD_91 + NLCD_31 + NLCD_71 + NLCD_41 + NLCD_42 + NLCD_43 + NLCD_51 + NLCD_11 + NLCD_12

Cumulative Upstream Land Cover Table

Metadata for regx_flowlineattributesnlcd.dbf, TOTAL CUMULATION OF UPSTREAM LOCAL CATCHMENTS	
Fields	**Description**
COMID	NHD plus comid for each reach
GRID_CODE	GRID_CODE, Grid value for the catchment
CUMNLCD_11	11. Open Water
CUMNLCD_12	12. Perennial Ice/Snow
CUMNLCD_21	21. Low Intensity Residential
CUMNLCD_22	22. High Intensity Residential
CUMNLCD_23	23. Commercial/Industrial/Transportation
CUMNLCD_31	31. Bare Rock/Sand/Clay
CUMNLCD_32	32. Quarries/Strip Mines/Gravel Pits
CUMNLCD_33	33. Transitional
CUMNLCD_41	41. Deciduous Forest
CUMNLCD_42	42. Evergreen Forest
CUMNLCD_43	43. Mixed Forest
CUMNLCD_51	51. Shrubland
CUMNLCD_61	61. Orchards/Vineyards/Other
CUMNLCD_71	71. Grasslands/Herbaceous
CUMNLCD_81	81. Pasture/Hay
CUMNLCD_82	82. Row Crops
CUMNLCD_83	83. Small Grains
CUMNLCD_84	84. Fallow
CUMNLCD_85	85. Urban/Recreational Grasses
CUMNLCD_91	91. Woody Wetlands
CUMNLCD_92	92. Emergent Herbaceous Wetlands
Cumpct_CN	% of cumulative drainage area in Canada and not classsified in NLCD
Cumpct_MX	% of cumulative drainage area in Mexico and not classified in NLCD
CUMSUM_PCT	Sum of the % cumulative drainage areas
PC_WAT	total % water, CumNLCD_11 + vCumNLCD_12
PC_DEVLOW	total % low intensity development; CumNLCD_21
PC_DEVHI	total % high intensity development; CumNLCD_22 + CumNLCD_23
PC_DEVTOT	total % all development classes; CumNLCD_21 + CumNLCD_22 + CumNLCD_23
PC_DIST	total % distrubed; CumNLCD_32 + CumNLCD_33
PC_FORSHRU	total % forest and shrub; CumNLCD_41 + CumNLCD_42 + CumNLCD_43 + CumNLCD_51
PC_OPENNAT	total % open natural; CumNLCD_31 + CumNLCD_71
PC_AGLOW	total CumNLCD_84 + CumNLCD_81 + CumNLCD_85 + CumNLCD_61
PC_AGHI	total % high intensity agriculture; CumNLCD_82 + CumNLCD_83
PC_AGTOT	total % agriculture; CumNLCD_82 + CumNLCD_83 + CumNLCD_84 + CumNLCD_81 + CumNLCD_85 + CumNLCD_61
PC_WET	total % wetlands, CumNLCD_92 + CumNLCD_91
PC_NAT	total % natural cover; CumNLCD_92 + CumNLCD_91 + CumNLCD_31 + CumNLCD_71 + CumNLCD_41 + CumNLCD_42 + CumNLCD_43 + CumNLCD_51 + CumNLCD_11 + CumNLCD_12

Appendix II: Workgroup Members

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Appendix III: Full Riverine Aquatic Habitat Types (7764), 259 types

	CLNEFL7634	LENGTHKM	DESCRIPTION
1	1a_1_1_1	274.5	Headwater; Very Low Gradient; Low Buffered, Acidic; Cold
2	1a_1_1_2	1093.2	Headwater; Very Low Gradient; Low Buffered, Acidic; Transitional Cool
3	1a_1_1_3	2239.9	Headwater; Very Low Gradient; Low Buffered, Acidic; Transitional Warm
4	1a_1_1_4	2684.5	Headwater; Very Low Gradient; Low Buffered, Acidic; Warm
5	1a_1_2_1	376.2	Headwater; Very Low Gradient; Moderately Buffered, Neutral; Cold
6	1a_1_2_2	2605.7	Headwater; Very Low Gradient; Moderately Buffered, Neutral; Transitional Cool
7	1a_1_2_3	1698.8	Headwater; Very Low Gradient; Moderately Buffered, Neutral; Transitional Warm
8	1a_1_2_4	630.4	Headwater; Very Low Gradient; Moderately Buffered, Neutral; Warm
9	1a_1_3_1	23.0	Headwater; Very Low Gradient; Highly Buffered, Calcareous; Cold
10	1a_1_3_2	190.6	Headwater; Very Low Gradient; Highly Buffered, Calcareous; Transitional Cool
11	1a_1_3_3	68.2	Headwater; Very Low Gradient; Highly Buffered, Calcareous; Transitional Warm
12	1a_1_3_4	0.2	Headwater; Very Low Gradient; Highly Buffered, Calcareous; Warm
13	1a_2_1_0	0.3	Headwater; Low Gradient; Low Buffered, Acidic; Cold
14	1a_2_1_1	83.7	Headwater; Low Gradient; Low Buffered, Acidic; Cold
15	1a_2_1_2	664.6	Headwater; Low Gradient; Low Buffered, Acidic; Transitional Cool
16	1a_2_1_3	1202.4	Headwater; Low Gradient; Low Buffered, Acidic; Transitional Warm
17	1a_2_1_4	838.8	Headwater; Low Gradient; Low Buffered, Acidic; Warm
18	1a_2_2_1	152.1	Headwater; Low Gradient; Moderately Buffered, Neutral; Cold
19	1a_2_2_2	1213.5	Headwater; Low Gradient; Moderately Buffered, Neutral; Transitional Cool
20	1a_2_2_3	585.9	Headwater; Low Gradient; Moderately Buffered, Neutral; Transitional Warm
21	1a_2_2_4	156.5	Headwater; Low Gradient; Moderately Buffered, Neutral; Warm
22	1a_2_3_1	4.5	Headwater; Low Gradient; Highly Buffered, Calcareous; Cold
23	1a_2_3_2	133.9	Headwater; Low Gradient; Highly Buffered, Calcareous; Transitional Cool
24	1a_2_3_3	28.8	Headwater; Low Gradient; Highly Buffered, Calcareous; Transitional Warm
25	1a_3_1_1	715.4	Headwater; Low-Moderate Gradient; Low Buffered, Acidic; Cold
26	1a_3_1_2	2085.1	Headwater; Low-Moderate Gradient; Low Buffered, Acidic; Transitional Cool
27	1a_3_1_3	5294.8	Headwater; Low-Moderate Gradient; Low Buffered, Acidic; Transitional Warm
28	1a_3_1_4	4046.1	Headwater; Low-Moderate Gradient; Low Buffered, Acidic; Warm
29	1a_3_2_1	1530.7	Headwater; Low-Moderate Gradient; Moderately Buffered, Neutral; Cold
30	1a_3_2_2	7338.6	Headwater; Low-Moderate Gradient; Moderately Buffered, Neutral; Transitional Cool
31	1a_3_2_3	1788.4	Headwater; Low-Moderate Gradient; Moderately Buffered, Neutral; Transitional Warm
32	1a_3_2_4	947.0	Headwater; Low-Moderate Gradient; Moderately Buffered, Neutral; Warm
33	1a_3_3_1	95.4	Headwater; Low-Moderate Gradient; Highly Buffered, Calcareous; Cold
34	1a_3_3_2	990.1	Headwater; Low-Moderate Gradient; Highly Buffered, Calcareous; Transitional Cool
35	1a_3_3_3	109.4	Headwater; Low-Moderate Gradient; Highly Buffered, Calcareous; Transitional Warm
36	1a_4_1_1	7071.3	Headwater; Moderate-High Gradient; Low Buffered, Acidic; Cold
37	1a_4_1_2	3884.1	Headwater; Moderate-High Gradient; Low Buffered, Acidic; Transitional Cool
38	1a_4_1_3	7075.7	Headwater; Moderate-High Gradient; Low Buffered, Acidic; Transitional Warm
39	1a_4_1_4	7109.0	Headwater; Moderate-High Gradient; Low Buffered, Acidic; Warm
40	1a_4_2_1	24193.3	Headwater; Moderate-High Gradient; Moderately Buffered, Neutral; Cold
41	1a_4_2_2	18990.7	Headwater; Moderate-High Gradient; Moderately Buffered, Neutral; Transitional Cool
42	1a_4_2_3	15841.7	Headwater; Moderate-High Gradient; Moderately Buffered, Neutral; Transitional Warm
43	1a_4_2_4	3174.0	Headwater; Moderate-High Gradient; Moderately Buffered, Neutral; Warm
44	1a_4_3_1	1714.5	Headwater; Moderate-High Gradient; Highly Buffered, Calcareous; Cold
45	1a_4_3_2	2049.4	Headwater; Moderate-High Gradient; Highly Buffered, Calcareous; Transitional Cool
46	1a_4_3_3	452.1	Headwater; Moderate-High Gradient; Highly Buffered, Calcareous; Transitional Warm
47	1a_5_1_1	8318.1	Headwater; High Gradient; Low Buffered, Acidic; Cold
48	1a_5_1_2	1137.2	Headwater; High Gradient; Low Buffered, Acidic; Transitional Cool
49	1a_5_1_3	2458.6	Headwater; High Gradient; Low Buffered, Acidic; Transitional Warm
50	1a_5_1_4	678.3	Headwater; High Gradient; Low Buffered, Acidic; Warm
51	1a_5_2_1	36437.0	Headwater; High Gradient; Moderately Buffered, Neutral; Cold
52	1a_5_2_2	26141.3	Headwater; High Gradient; Moderately Buffered, Neutral; Transitional Cool
53	1a_5_2_3	6670.7	Headwater; High Gradient; Moderately Buffered, Neutral; Transitional Warm
54	1a_5_2_4	317.5	Headwater; High Gradient; Moderately Buffered, Neutral; Warm
55	1a_5_3_1	1998.3	Headwater; High Gradient; Highly Buffered, Calcareous; Cold
56	1a_5_3_2	1016.8	Headwater; High Gradient; Highly Buffered, Calcareous; Transitional Cool
57	1a_5_3_3	874.0	Headwater; High Gradient; Highly Buffered, Calcareous; Transitional Warm
58	1a_5_3_4	1.7	Headwater; High Gradient; Highly Buffered, Calcareous; Warm
59	1a_6_1_1	4989.3	Headwater; Very High Gradient; Low Buffered, Acidic; Cold
60	1a_6_1_2	699.5	Headwater; Very High Gradient; Low Buffered, Acidic; Transitional Cool

61	1a_6_1_3	12.5	Headwater; Very High Gradient; Low Buffered, Acidic; Transitional Warm
62	1a_6_1_4	6.9	Headwater; Very High Gradient; Low Buffered, Acidic; Warm
63	1a_6_2_1	25742.9	Headwater; Very High Gradient; Moderately Buffered, Neutral; Cold
64	1a_6_2_2	7057.4	Headwater; Very High Gradient; Moderately Buffered, Neutral; Transitional Cool
65	1a_6_2_3	1416.7	Headwater; Very High Gradient; Moderately Buffered, Neutral; Transitional Warm
66	1a_6_2_4	3.8	Headwater; Very High Gradient; Moderately Buffered, Neutral; Warm
67	1a_6_3_1	1100.5	Headwater; Very High Gradient; Highly Buffered, Calcareous; Cold
68	1a_6_3_2	264.7	Headwater; Very High Gradient; Highly Buffered, Calcareous; Transitional Cool
69	1a_6_3_3	59.9	Headwater; Very High Gradient; Highly Buffered, Calcareous; Transitional Warm
70	1b_1_1_1	369.5	Creek; Very Low Gradient; Low Buffered, Acidic; Cold
71	1b_1_1_2	1589.7	Creek; Very Low Gradient; Low Buffered, Acidic; Transitional Cool
72	1b_1_1_3	2295.8	Creek; Very Low Gradient; Low Buffered, Acidic; Transitional Warm
73	1b_1_1_4	2608.7	Creek; Very Low Gradient; Low Buffered, Acidic; Warm
74	1b_1_2_1	832.9	Creek; Very Low Gradient; Moderately Buffered, Neutral; Cold
75	1b_1_2_2	3750.6	Creek; Very Low Gradient; Moderately Buffered, Neutral; Transitional Cool
76	1b_1_2_3	2721.6	Creek; Very Low Gradient; Moderately Buffered, Neutral; Transitional Warm
77	1b_1_2_4	840.3	Creek; Very Low Gradient; Moderately Buffered, Neutral; Warm
78	1b_1_3_1	19.0	Creek; Very Low Gradient; Highly Buffered, Calcareous; Cold
79	1b_1_3_2	244.6	Creek; Very Low Gradient; Highly Buffered, Calcareous; Transitional Cool
80	1b_1_3_3	80.2	Creek; Very Low Gradient; Highly Buffered, Calcareous; Transitional Warm
81	1b_1_3_4	4.0	Creek; Very Low Gradient; Highly Buffered, Calcareous; Warm
82	1b_2_1_1	136.8	Creek; Low Gradient; Low Buffered, Acidic; Cold
83	1b_2_1_2	946.3	Creek; Low Gradient; Low Buffered, Acidic; Transitional Cool
84	1b_2_1_3	1020.9	Creek; Low Gradient; Low Buffered, Acidic; Transitional Warm
85	1b_2_1_4	914.1	Creek; Low Gradient; Low Buffered, Acidic; Warm
86	1b_2_2_1	338.5	Creek; Low Gradient; Moderately Buffered, Neutral; Cold
87	1b_2_2_2	2376.6	Creek; Low Gradient; Moderately Buffered, Neutral; Transitional Cool
88	1b_2_2_3	1348.3	Creek; Low Gradient; Moderately Buffered, Neutral; Transitional Warm
89	1b_2_2_4	156.4	Creek; Low Gradient; Moderately Buffered, Neutral; Warm
90	1b_2_3_1	5.2	Creek; Low Gradient; Highly Buffered, Calcareous; Cold
91	1b_2_3_2	199.2	Creek; Low Gradient; Highly Buffered, Calcareous; Transitional Cool
92	1b_2_3_3	74.0	Creek; Low Gradient; Highly Buffered, Calcareous; Transitional Warm
93	1b_3_1_1	1274.7	Creek; Low-Moderate Gradient; Low Buffered, Acidic; Cold
94	1b_3_1_2	2147.2	Creek; Low-Moderate Gradient; Low Buffered, Acidic; Transitional Cool
95	1b_3_1_3	4250.0	Creek; Low-Moderate Gradient; Low Buffered, Acidic; Transitional Warm
96	1b_3_1_4	2062.6	Creek; Low-Moderate Gradient; Low Buffered, Acidic; Warm
97	1b_3_2_1	3379.3	Creek; Low-Moderate Gradient; Moderately Buffered, Neutral; Cold
98	1b_3_2_2	11861.9	Creek; Low-Moderate Gradient; Moderately Buffered, Neutral; Transitional Cool
99	1b_3_2_3	7251.8	Creek; Low-Moderate Gradient; Moderately Buffered, Neutral; Transitional Warm
100	1b_3_2_4	760.1	Creek; Low-Moderate Gradient; Moderately Buffered, Neutral; Warm
101	1b_3_3_1	183.3	Creek; Low-Moderate Gradient; Highly Buffered, Calcareous; Cold
102	1b_3_3_2	1083.5	Creek; Low-Moderate Gradient; Highly Buffered, Calcareous; Transitional Cool
103	1b_3_3_3	741.4	Creek; Low-Moderate Gradient; Highly Buffered, Calcareous; Transitional Warm
104	1b_4_1_1	4886.5	Creek; Moderate-High Gradient; Low Buffered, Acidic; Cold
105	1b_4_1_2	1838.5	Creek; Moderate-High Gradient; Low Buffered, Acidic; Transitional Cool
106	1b_4_1_3	1338.8	Creek; Moderate-High Gradient; Low Buffered, Acidic; Transitional Warm
107	1b_4_1_4	471.3	Creek; Moderate-High Gradient; Low Buffered, Acidic; Warm
108	1b_4_2_1	22315.1	Creek; Moderate-High Gradient; Moderately Buffered, Neutral; Cold
109	1b_4_2_2	13274.8	Creek; Moderate-High Gradient; Moderately Buffered, Neutral; Transitional Cool
110	1b_4_2_3	5540.3	Creek; Moderate-High Gradient; Moderately Buffered, Neutral; Transitional Warm
111	1b_4_2_4	142.4	Creek; Moderate-High Gradient; Moderately Buffered, Neutral; Warm
112	1b_4_3_1	1333.1	Creek; Moderate-High Gradient; Highly Buffered, Calcareous; Cold
113	1b_4_3_2	1513.3	Creek; Moderate-High Gradient; Highly Buffered, Calcareous; Transitional Cool
114	1b_4_3_3	313.6	Creek; Moderate-High Gradient; Highly Buffered, Calcareous; Transitional Warm
115	1b_5_1_1	2544.7	Creek; High Gradient; Low Buffered, Acidic; Cold
116	1b_5_1_2	201.1	Creek; High Gradient; Low Buffered, Acidic; Transitional Cool
117	1b_5_1_3	43.8	Creek; High Gradient; Low Buffered, Acidic; Transitional Warm
118	1b_5_1_4	1.8	Creek; High Gradient; Low Buffered, Acidic; Warm
119	1b_5_2_1	9907.0	Creek; High Gradient; Moderately Buffered, Neutral; Cold
120	1b_5_2_2	3084.0	Creek; High Gradient; Moderately Buffered, Neutral; Transitional Cool

121	1b_5_2_3	175.1	Creek; High Gradient; Moderately Buffered, Neutral; Transitional Warm
122	1b_5_2_4	1.7	Creek; High Gradient; Moderately Buffered, Neutral; Warm
123	1b_5_3_1	538.8	Creek; High Gradient; Highly Buffered, Calcareous; Cold
124	1b_5_3_2	102.5	Creek; High Gradient; Highly Buffered, Calcareous; Transitional Cool
125	1b_5_3_3	71.5	Creek; High Gradient; Highly Buffered, Calcareous; Transitional Warm
126	1b_6_1_1	609.3	Creek; Very High Gradient; Low Buffered, Acidic; Cold
127	1b_6_1_2	2.9	Creek; Very High Gradient; Low Buffered, Acidic; Transitional Cool
128	1b_6_1_3	0.8	Creek; Very High Gradient; Low Buffered, Acidic; Transitional Warm
129	1b_6_1_4	0.3	Creek; Very High Gradient; Low Buffered, Acidic; Warm
130	1b_6_2_1	1377.3	Creek; Very High Gradient; Moderately Buffered, Neutral; Cold
131	1b_6_2_2	174.4	Creek; Very High Gradient; Moderately Buffered, Neutral; Transitional Cool
132	1b_6_2_3	2.8	Creek; Very High Gradient; Moderately Buffered, Neutral; Transitional Warm
133	1b_6_2_4	0.3	Creek; Very High Gradient; Moderately Buffered, Neutral; Warm
134	1b_6_3_1	39.7	Creek; Very High Gradient; Highly Buffered, Calcareous; Cold
135	1b_6_3_2	0.2	Creek; Very High Gradient; Highly Buffered, Calcareous; Transitional Cool
136	1b_6_3_3	0.0	Creek; Very High Gradient; Highly Buffered, Calcareous; Transitional Warm
137	2_1_1_1	608.8	Small River; Very Low Gradient; Low Buffered, Acidic; Cold
138	2_1_1_2	679.2	Small River; Very Low Gradient; Low Buffered, Acidic; Transitional Cool
139	2_1_1_3	1092.2	Small River; Very Low Gradient; Low Buffered, Acidic; Transitional Warm
140	2_1_1_4	672.8	Small River; Very Low Gradient; Low Buffered, Acidic; Warm
141	2_1_2_1	1079.3	Small River; Very Low Gradient; Moderately Buffered, Neutral; Cold
142	2_1_2_2	2627.3	Small River; Very Low Gradient; Moderately Buffered, Neutral; Transitional Cool
143	2_1_2_3	1903.8	Small River; Very Low Gradient; Moderately Buffered, Neutral; Transitional Warm
144	2_1_2_4	265.8	Small River; Very Low Gradient; Moderately Buffered, Neutral; Warm
145	2_1_3_1	19.0	Small River; Very Low Gradient; Highly Buffered, Calcareous; Cold
146	2_1_3_2	122.8	Small River; Very Low Gradient; Highly Buffered, Calcareous; Transitional Cool
147	2_1_3_3	41.4	Small River; Very Low Gradient; Highly Buffered, Calcareous; Transitional Warm
148	2_2_1_1	269.9	Small River; Low Gradient; Low Buffered, Acidic; Cold
149	2_2_1_2	315.4	Small River; Low Gradient; Low Buffered, Acidic; Transitional Cool
150	2_2_1_3	457.5	Small River; Low Gradient; Low Buffered, Acidic; Transitional Warm
151	2_2_1_4	199.2	Small River; Low Gradient; Low Buffered, Acidic; Warm
152	2_2_2_1	620.4	Small River; Low Gradient; Moderately Buffered, Neutral; Cold
153	2_2_2_2	1488.5	Small River; Low Gradient; Moderately Buffered, Neutral; Transitional Cool
154	2_2_2_3	1079.7	Small River; Low Gradient; Moderately Buffered, Neutral; Transitional Warm
155	2_2_2_4	46.7	Small River; Low Gradient; Moderately Buffered, Neutral; Warm
156	2_2_3_1	22.4	Small River; Low Gradient; Highly Buffered, Calcareous; Cold
157	2_2_3_2	82.3	Small River; Low Gradient; Highly Buffered, Calcareous; Transitional Cool
158	2_2_3_3	55.6	Small River; Low Gradient; Highly Buffered, Calcareous; Transitional Warm
159	2_3_1_1	490.1	Small River; Low-Moderate Gradient; Low Buffered, Acidic; Cold
160	2_3_1_2	605.4	Small River; Low-Moderate Gradient; Low Buffered, Acidic; Transitional Cool
161	2_3_1_3	983.8	Small River; Low-Moderate Gradient; Low Buffered, Acidic; Transitional Warm
162	2_3_1_4	130.2	Small River; Low-Moderate Gradient; Low Buffered, Acidic; Warm
163	2_3_2_1	1584.6	Small River; Low-Moderate Gradient; Moderately Buffered, Neutral; Cold
164	2_3_2_2	6272.5	Small River; Low-Moderate Gradient; Moderately Buffered, Neutral; Transitional Cool
165	2_3_2_3	3483.4	Small River; Low-Moderate Gradient; Moderately Buffered, Neutral; Transitional Warm
166	2_3_2_4	56.8	Small River; Low-Moderate Gradient; Moderately Buffered, Neutral; Warm
167	2_3_3_1	84.8	Small River; Low-Moderate Gradient; Highly Buffered, Calcareous; Cold
168	2_3_3_2	263.4	Small River; Low-Moderate Gradient; Highly Buffered, Calcareous; Transitional Cool
169	2_3_3_3	359.6	Small River; Low-Moderate Gradient; Highly Buffered, Calcareous; Transitional Warm
170	2_4_1_1	714.2	Small River; Moderate-High Gradient; Low Buffered, Acidic; Cold
171	2_4_1_2	351.9	Small River; Moderate-High Gradient; Low Buffered, Acidic; Transitional Cool
172	2_4_1_3	89.7	Small River; Moderate-High Gradient; Low Buffered, Acidic; Transitional Warm
173	2_4_1_4	6.1	Small River; Moderate-High Gradient; Low Buffered, Acidic; Warm
174	2_4_2_1	857.5	Small River; Moderate-High Gradient; Moderately Buffered, Neutral; Cold
175	2_4_2_2	2785.9	Small River; Moderate-High Gradient; Moderately Buffered, Neutral; Transitional Cool
176	2_4_2_3	774.1	Small River; Moderate-High Gradient; Moderately Buffered, Neutral; Transitional Warm
177	2_4_2_4	3.5	Small River; Moderate-High Gradient; Moderately Buffered, Neutral; Warm
178	2_4_3_1	81.1	Small River; Moderate-High Gradient; Highly Buffered, Calcareous; Cold
179	2_4_3_2	60.8	Small River; Moderate-High Gradient; Highly Buffered, Calcareous; Transitional Cool
180	2_4_3_3	64.5	Small River; Moderate-High Gradient; Highly Buffered, Calcareous; Transitional Warm

181	2_5_1_1	33.1	Small River; High Gradient; Low Buffered, Acidic; Cold
182	2_5_1_2	20.1	Small River; High Gradient; Low Buffered, Acidic; Transitional Cool
183	2_5_1_3	2.2	Small River; High Gradient; Low Buffered, Acidic; Transitional Warm
184	2_5_1_4	0.4	Small River; High Gradient; Low Buffered, Acidic; Warm
185	2_5_2_1	51.4	Small River; High Gradient; Moderately Buffered, Neutral; Cold
186	2_5_2_2	82.4	Small River; High Gradient; Moderately Buffered, Neutral; Transitional Cool
187	2_5_2_3	39.3	Small River; High Gradient; Moderately Buffered, Neutral; Transitional Warm
188	2_5_2_4	0.0	Small River; High Gradient; Moderately Buffered, Neutral; Warm
189	2_5_3_1	8.5	Small River; High Gradient; Highly Buffered, Calcareous; Cold
190	2_5_3_2	2.2	Small River; High Gradient; Highly Buffered, Calcareous; Transitional Cool
191	2_6_1_1	1.4	Small River; Very High Gradient; Low Buffered, Acidic; Cold
192	2_6_1_2	1.1	Small River; Very High Gradient; Low Buffered, Acidic; Transitional Cool
193	2_6_1_3	0.0	Small River; Very High Gradient; Low Buffered, Acidic; Transitional Warm
194	2_6_1_4	0.0	Small River; Very High Gradient; Low Buffered, Acidic; Warm
195	2_6_2_1	3.1	Small River; Very High Gradient; Moderately Buffered, Neutral; Cold
196	2_6_2_2	9.0	Small River; Very High Gradient; Moderately Buffered, Neutral; Transitional Cool
197	2_6_2_3	7.3	Small River; Very High Gradient; Moderately Buffered, Neutral; Transitional Warm
198	2_6_3_3	0.2	Small River; Very High Gradient; Highly Buffered, Calcareous; Transitional Warm
199	3a_1_0_1	772.8	Medium Tributary River; Very Low Gradient; Assume Moderately Buffered; Cold
200	3a_1_0_2	2191.2	Medium Tributary River; Very Low Gradient; Assume Moderately Buffered; Transitional cool
201	3a_1_0_3	4297.2	Medium Tributary River; Very Low Gradient; Assume Moderately Buffered; Transitional warm
202	3a_1_0_4	473.1	Medium Tributary River; Very Low Gradient; Assume Moderately Buffered; Warm
203	3a_2_0_1	260.9	Medium Tributary River; Low Gradient; Assume Moderately Buffered; Cold
204	3a_2_0_2	766.3	Medium Tributary River; Low Gradient; Assume Moderately Buffered; Transitional Cool
205	3a_2_0_3	1534.8	Medium Tributary River; Low Gradient; Assume Moderately Buffered; Transitional Warm
206	3a_2_0_4	86.2	Medium Tributary River; Low Gradient; Assume Moderately Buffered; Warm
207	3a_3_0_1	377.9	Medium Tributary River; Low-Moderate Gradient; Assume Moderately Buffered; Cold
208	3a_3_0_2	1541.7	Medium Tributary River; Low-Moderate Gradient; Assume Moderately Buffered; Transitional cool
209	3a_3_0_3	2694.0	Medium Tributary River; Low-Moderate Gradient; Assume Moderately Buffered; Transitional warm
210	3a_3_0_4	55.0	Medium Tributary River; Low-Moderate Gradient; Assume Moderately Buffered; Warm
211	3a_4_0_1	108.6	Medium Tributary River; Moderate-High Gradient; Assume Moderately Buffered; Cold
212	3a_4_0_2	458.9	Medium Tributary River; Moderate-High Gradient; Assume Moderately Buffered; Transitional cool
213	3a_4_0_3	467.2	Medium Tributary River; Moderate-High Gradient; Assume Moderately Buffered; Transitional warm
214	3a_4_0_4	3.1	Medium Tributary River; Moderate-High Gradient; Assume Moderately Buffered; Warm
215	3a_5_0_1	4.9	Medium Tributary River; High Gradient; Assume Moderately Buffered; Cold
216	3a_5_0_2	23.0	Medium Tributary River; High Gradient; Assume Moderately Buffered; Transitional Cool
217	3a_5_0_3	23.8	Medium Tributary River; High Gradient; Assume Moderately Buffered; Transitional Warm
218	3a_6_0_1	2.0	Medium Tributary River; Very High Gradient; Assume Moderately Buffered; Cold
219	3a_6_0_2	7.3	Medium Tributary River; Very High Gradient; Assume Moderately Buffered; Transitional cool
220	3a_6_0_3	4.7	Medium Tributary River; Very High Gradient; Assume Moderately Buffered; Transitional warm
221	3b_1_0_2	879.1	Medium Mainstem River; Very Low Gradient; Assume Moderately Buffered; Transitional cool
222	3b_1_0_3	2685.1	Medium Mainstem River; Very Low Gradient; Assume Moderately Buffered; Transitionanal warm
223	3b_1_0_4	226.0	Medium Mainstem River; Very Low Gradient; Assume Moderately Buffered; Warm
224	3b_2_0_2	224.5	Medium Mainstem River; Low Gradient; Assume Moderately Buffered; Transitional Cool
225	3b_2_0_3	661.7	Medium Mainstem River; Low Gradient; Assume Moderately Buffered; Transitional Warm
226	3b_2_0_4	38.9	Medium Mainstem River; Low Gradient; Assume Moderately Buffered; Warm
227	3b_3_0_2	389.0	Medium Mainstem River; Low-Moderate Gradient; Assume Moderately Buffered; Transititional cool
228	3b_3_0_3	783.2	Medium Mainstem River; Low-Moderate Gradient; Assume Moderately Buffered; Transitional warm
229	3b_3_0_4	4.3	Medium Mainstem River; Low-Moderate Gradient; Assume Moderately Buffered; Warm
230	3b_4_0_2	62.3	Medium Mainstem River; Moderate-High Gradient; Assume Moderately Buffered; Transitional cool
231	3b_4_0_3	92.1	Medium Mainstem River; Moderate-High Gradient; Assume Moderately Buffered; Transitional warm
232	3b_4_0_4	1.0	Medium Mainstem River; Moderate-High Gradient; Assume Moderately Buffered; Warm
233	3b_5_0_2	9.2	Medium Mainstem River; High Gradient; Assume Moderately Buffered; Transitional Cool
234	3b_5_0_3	7.7	Medium Mainstem River; High Gradient; Assume Moderately Buffered; Transitional Warm
235	3b_6_0_2	1.4	Medium Mainstem River; Very High Gradient; Assume Moderately Buffered; Transition Cool
236	3b_6_0_3	1.9	Medium Mainstem River; Very High Gradient; Assume Moderately Buffered; Transition Warm
237	4_1_0_2	526.9	Large River; Very Low Gradient; Assume Moderately Buffered; Transitional Cool
238	4_1_0_3	1244.7	Large River; Very Low Gradient; Assume Moderately Buffered; Transitional Warm
239	4_1_0_4	316.4	Large River; Very Low Gradient; Assume Moderately Buffered; Warm
240	4_2_0_2	70.1	Large River; Low Gradient; Assume Moderately Buffered; Transitional Cool

241	4_2_0_3	261.3	Large River; Low Gradient; Assume Moderately Buffered; Transitional Warm
242	4_2_0_4	14.3	Large River; Low Gradient; Assume Moderately Buffered; Warm
243	4_3_0_2	44.0	Large River; Low-Moderate Gradient; Assume Moderately Buffered; Transitional Cool
244	4_3_0_3	183.2	Large River; Low-Moderate Gradient; Assume Moderately Buffered; Transitional Warm
245	4_3_0_4	15.9	Large River; Low-Moderate Gradient; Assume Moderately Buffered; Warm
246	4_4_0_2	11.2	Large River; Moderate-High Gradient; Assume Moderately Buffered; Transitional Cool
247	4_4_0_3	24.2	Large River; Moderate-High Gradient; Assume Moderately Buffered; Transitional Warm
248	4_4_0_4	3.7	Large River; Moderate-High Gradient; Assume Moderately Buffered; Warm
249	4_5_0_3	1.4	Large River; High Gradient; Assume Moderately Buffered; Transitional Warm
250	4_5_0_4	0.3	Large River; High Gradient; Assume Moderately Buffered; Warm
251	4_6_0_3	0.2	Large River; Very High Gradient; Assume Moderately Buffered; Transitional Warm
252	4_6_0_4	0.3	Large River; Very High Gradient; Assume Moderately Buffered; Warm
253	5_1_0_3	1429.5	Great River; Very Low Gradient; Assume Moderately Buffered; Transitional Warm
254	5_1_0_4	21.3	Great River; Very Low Gradient; Assume Moderately Buffered; Warm
255	5_2_0_3	101.4	Great River; Low Gradient; Assume Moderately Buffered; Transitional Warm
256	5_3_0_3	69.5	Great River; Low-Moderate Gradient; Assume Moderately Buffered; Transitional Warm
257	5_4_0_3	6.2	Great River; Moderate-High Gradient; Assume Moderately Buffered; Transitional Warm
258	5_5_0_3	1.4	Great River; High Gradient; Assume Moderately Buffered; Transitional Warm
259	5_6_0_3	0.7	Great River; Very High Gradient; Assume Moderately Buffered; Transitional Warm

Appendix IV: Simplifed Aquatic Habitat Types (4433), 92 types

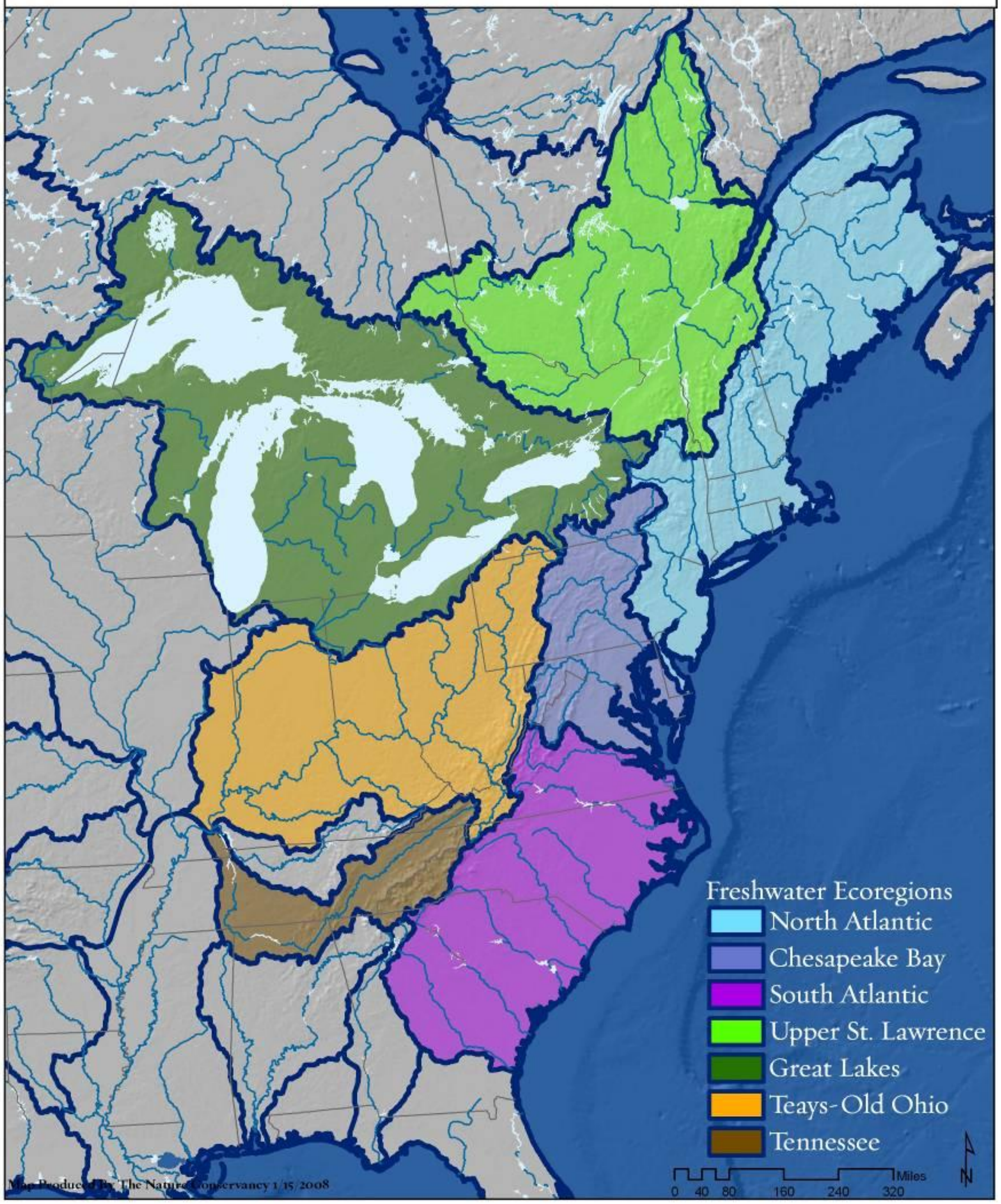
	CLSIMP4433	LENGTHKM	DESCRIPTION
1	1_1_1_1	864.8	Headwater/Creek; Low Gradient; Low Buffered, Acidic; Cold
2	1_1_1_2	4293.9	Headwater/Creek; Low Gradient; Low Buffered, Acidic; Transitional Cool
3	1_1_1_3	13805.1	Headwater/Creek; Low Gradient; Low Buffered, Acidic; Warm
4	1_1_2_1	1699.7	Headwater/Creek; Low Gradient; Moderately Buffered, Neutral; Cold
5	1_1_2_2	9946.3	Headwater/Creek; Low Gradient; Moderately Buffered, Neutral; Transitional Cool
6	1_1_2_3	8138.4	Headwater/Creek; Low Gradient; Moderately Buffered, Neutral; Warm
7	1_1_3_1	51.7	Headwater/Creek; Low Gradient; Highly Buffered, Calcareous; Cold
8	1_1_3_2	768.4	Headwater/Creek; Low Gradient; Highly Buffered, Calcareous; Transitional Cool
9	1_1_3_3	255.4	Headwater/Creek; Low Gradient; Highly Buffered, Calcareous; Warm
10	1_2_1_1	1990.1	Headwater/Creek; Low-Moderate Gradient; Low Buffered, Acidic; Cold
11	1_2_1_2	4232.3	Headwater/Creek; Low-Moderate Gradient; Low Buffered, Acidic; Transitional Cool
12	1_2_1_3	15653.6	Headwater/Creek; Low-Moderate Gradient; Low Buffered, Acidic; Warm
13	1_2_2_1	4910.0	Headwater/Creek; Low-Moderate Gradient; Moderately Buffered, Neutral; Cold
14	1_2_2_2	19200.5	Headwater/Creek; Low-Moderate Gradient; Moderately Buffered, Neutral; Transitional Cool
15	1_2_2_3	10747.3	Headwater/Creek; Low-Moderate Gradient; Moderately Buffered, Neutral; Warm
16	1_2_3_1	278.7	Headwater/Creek; Low-Moderate Gradient; Highly Buffered, Calcareous; Cold
17	1_2_3_2	2073.6	Headwater/Creek; Low-Moderate Gradient; Highly Buffered, Calcareous; Transitional Cool
18	1_2_3_3	850.8	Headwater/Creek; Low-Moderate Gradient; Highly Buffered, Calcareous; Warm
19	1_3_1_1	11957.8	Headwater/Creek; Moderate-High Gradient; Low Buffered, Acidic; Cold
20	1_3_1_2	5722.7	Headwater/Creek; Moderate-High Gradient; Low Buffered, Acidic; Transitional Cool
21	1_3_1_3	15994.8	Headwater/Creek; Moderate-High Gradient; Low Buffered, Acidic; Warm
22	1_3_2_1	46508.5	Headwater/Creek; Moderate-High Gradient; Moderately Buffered, Neutral; Cold
23	1_3_2_2	32265.6	Headwater/Creek; Moderate-High Gradient; Moderately Buffered, Neutral; Transitional Cool
24	1_3_2_3	24698.4	Headwater/Creek; Moderate-High Gradient; Moderately Buffered, Neutral; Warm
25	1_3_3_1	3047.6	Headwater/Creek; Moderate-High Gradient; Highly Buffered, Calcareous; Cold
26	1_3_3_2	3562.7	Headwater/Creek; Moderate-High Gradient; Highly Buffered, Calcareous; Transitional Cool
27	1_3_3_3	765.7	Headwater/Creek; Moderate-High Gradient; Highly Buffered, Calcareous; Warm
28	1_4_1_1	16461.5	Headwater/Creek; High Gradient; Low Buffered, Acidic; Cold
29	1_4_1_2	2040.7	Headwater/Creek; High Gradient; Low Buffered, Acidic; Transitional Cool
30	1_4_1_3	3203.0	Headwater/Creek; High Gradient; Low Buffered, Acidic; Warm
31	1_4_2_1	73464.2	Headwater/Creek; High Gradient; Moderately Buffered, Neutral; Cold
32	1_4_2_2	36457.1	Headwater/Creek; High Gradient; Moderately Buffered, Neutral; Transitional Cool
33	1_4_2_3	8588.6	Headwater/Creek; High Gradient; Moderately Buffered, Neutral; Warm
34	1_4_3_1	3677.3	Headwater/Creek; High Gradient; Highly Buffered, Calcareous; Cold
35	1_4_3_2	1384.3	Headwater/Creek; High Gradient; Highly Buffered, Calcareous; Transitional Cool
36	1_4_3_3	1007.1	Headwater/Creek; High Gradient; Highly Buffered, Calcareous; Warm
37	2_1_1_1	608.8	Small River; Low Gradient; Low Buffered, Acidic; Cold
38	2_1_1_2	679.2	Small River; Low Gradient; Low Buffered, Acidic; Transitional Cool
39	2_1_1_3	1765.1	Small River; Low Gradient; Low Buffered, Acidic; Warm
40	2_1_2_1	1079.3	Small River; Low Gradient; Moderately Buffered, Neutral; Cold
41	2_1_2_2	2627.3	Small River; Low Gradient; Moderately Buffered, Neutral; Transitional Cool
42	2_1_2_3	2169.6	Small River; Low Gradient; Moderately Buffered, Neutral; Warm
43	2_1_3_1	19.0	Small River; Low Gradient; Highly Buffered, Calcareous; Cold
44	2_1_3_2	122.8	Small River; Low Gradient; Highly Buffered, Calcareous; Transitional Cool
45	2_1_3_3	41.4	Small River; Low Gradient; Highly Buffered, Calcareous; Warm
46	2_2_1_1	269.9	Small River; Low-Moderate Gradient; Low Buffered, Acidic; Cold
47	2_2_1_2	315.4	Small River; Low-Moderate Gradient; Low Buffered, Acidic; Transitional Cool
48	2_2_1_3	656.7	Small River; Low-Moderate Gradient; Low Buffered, Acidic; Warm
49	2_2_2_1	620.4	Small River; Low-Moderate Gradient; Moderately Buffered, Neutral; Cold
50	2_2_2_2	1488.5	Small River; Low-Moderate Gradient; Moderately Buffered, Neutral; Transitional Cool
51	2_2_2_3	1126.4	Small River; Low-Moderate Gradient; Moderately Buffered, Neutral; Warm
52	2_2_3_1	22.4	Small River; Low-Moderate Gradient; Highly Buffered, Calcareous; Cold
53	2_2_3_2	82.3	Small River; Low-Moderate Gradient; Highly Buffered, Calcareous; Transitional Cool
54	2_2_3_3	55.6	Small River; Low-Moderate Gradient; Highly Buffered, Calcareous; Warm
55	2_3_1_1	490.1	Small River; Moderate-High Gradient; Low Buffered, Acidic; Cold
56	2_3_1_2	605.4	Small River; Moderate-High Gradient; Low Buffered, Acidic; Transitional Cool
57	2_3_1_3	1114.0	Small River; Moderate-High Gradient; Low Buffered, Acidic; Warm
58	2_3_2_1	1584.6	Small River; Moderate-High Gradient; Moderately Buffered, Neutral; Cold
59	2_3_2_2	6272.5	Small River; Moderate-High Gradient; Moderately Buffered, Neutral; Transitional Cool
60	2_3_2_3	3540.1	Small River; Moderate-High Gradient; Moderately Buffered, Neutral; Warm

61	2_3_3_1	84.8	Small River; Moderate-High Gradient; Highly Buffered, Calcareous; Cold
62	2_3_3_2	263.4	Small River; Moderate-High Gradient; Highly Buffered, Calcareous; Transitional Cool
63	2_3_3_3	359.6	Small River; Moderate-High Gradient; Highly Buffered, Calcareous; Warm
64	2_4_1_1	748.7	Small River; High Gradient; Low Buffered, Acidic; Cold
65	2_4_1_2	373.1	Small River; High Gradient; Low Buffered, Acidic; Transitional Cool
66	2_4_1_3	98.4	Small River; High Gradient; Low Buffered, Acidic; Warm
67	2_4_2_1	911.9	Small River; High Gradient; Moderately Buffered, Neutral; Cold
68	2_4_2_2	2877.3	Small River; High Gradient; Moderately Buffered, Neutral; Transitional Cool
69	2_4_2_3	824.2	Small River; High Gradient; Moderately Buffered, Neutral; Warm
70	2_4_3_1	89.6	Small River; High Gradient; Highly Buffered, Calcareous; Cold
71	2_4_3_2	63.0	Small River; High Gradient; Highly Buffered, Calcareous; Transitional Cool
72	2_4_3_3	64.6	Small River; High Gradient; Highly Buffered, Calcareous; Warm
73	3_1_0_1	772.8	Medium River; Low Gradient; Assume Moderately Buffered;Cold
74	3_1_0_2	3070.3	Medium River; Low Gradient; Assume Moderately Buffered;Transitional Cool
75	3_1_0_3	7681.4	Medium River; Low Gradient; Assume Moderately Buffered;Warm
76	3_2_0_1	260.9	Medium River; Low-Moderate Gradient; Assume Moderately Buffered;Cold
77	3_2_0_2	990.8	Medium River; Low-Moderate Gradient; Assume Moderately Buffered;Transitional Cool
78	3_2_0_3	2321.6	Medium River; Low-Moderate Gradient; Assume Moderately Buffered;Warm
79	3_3_0_1	377.9	Medium River; Moderate-High Gradient; Assume Moderately Buffered;Cold
80	3_3_0_2	1930.7	Medium River; Moderate-High Gradient; Assume Moderately Buffered;Transitional Cool
81	3_3_0_3	3536.5	Medium River; Moderate-High Gradient; Assume Moderately Buffered;Warm
82	3_4_0_1	115.6	Medium River; High Gradient; Assume Moderately Buffered;Cold
83	3_4_0_2	562.1	Medium River; High Gradient; Assume Moderately Buffered;Transitional Cool
84	3_4_0_3	601.5	Medium River; High Gradient; Assume Moderately Buffered;Warm
85	4_1_0_2	526.9	Large/Great River; Low Gradient; Assume Moderately Buffered;Transitional Cool
86	4_1_0_3	3012.0	Large/Great River; Low Gradient; Assume Moderately Buffered;Warm
87	4_2_0_2	70.1	Large/Great River; Low-Moderate Gradient; Assume Moderately Buffered;Transitional Cool
88	4_2_0_3	376.9	Large/Great River; Low-Moderate Gradient; Assume Moderately Buffered;Warm
89	4_3_0_2	44.0	Large/Great River; Moderate-High Gradient; Assume Moderately Buffered;Transitional Cool
90	4_3_0_3	268.6	Large/Great River; Moderate-High Gradient; Assume Moderately Buffered;Warm
91	4_4_0_2	11.2	Large/Great River; High Gradient; Assume Moderately Buffered;Transitional Cool
92	4_4_0_3	38.2	Large/Great River; High Gradient; Assume Moderately Buffered;Warm

Appendix V: Freshwater Ecoregions

Freshwater Ecoregions of the Eastern United States

(World Wildlife Fund, 2003)



Freshwater Ecoregion Descriptions

from Freshwater Ecoregions of the World as of 8/2008 (http://www.feow.org/index.php).

North Atlantic:

118: Northeast US & Southeast Canada Atlantic Drainages
Major Habitat Type: temperate coastal rivers
Author: Mary Burridge
Countries: Canada; United States

Boundaries:
This ecoregion stretches from Delaware in the United States to the Gaspé Peninsula of Quebec and New Brunswick in Canada.

Drainages flowing into:
The drainages flow into the Atlantic Ocean via the Gulf of St. Lawrence and the Bay of Fundy.

Topography:
This ecoregion lies within the ancient, eroded Appalachian Mountains. Glaciers shaped these mountains, forming plateaus, granite outcrops, and river valleys. In the Gaspé Peninsula peaks reach above 1000 m, whereas the New Brunswick Highlands range from 200-500 m above sea level. To the east are lowlands of sandstone and shale, with small bedrock outcrops forming hills. Southern New Brunswick is characterized by rolling terrain with stony till plains.

Freshwater habitats:
The St. John River originates in the forests of Maine and slowly loops into New Brunswick where it flows through the St. John River valley. It drains into the Bay of Fundy where strong tides push back the river and create the famous Reversing Falls. The St. Croix River and the Upper Restigouche River are classified as Canadian Heritage Rivers. The St. Croix River consists of a widespread system of lakes around its headwaters, and extensive wetlands downstream. The Restigouche River is a gently meandering river with floodplains, terraces, islands, rock outcrops, and deep pools.

Terrestrial Habitats:
This ecoregion is a good example of temperate broadleaf and mixed forests, and is a transition zone between boreal spruce-fir forest to the north and deciduous forest to the south. The Atlantic Ocean strongly influences vegetation, especially in coastal areas. Tundra meadows occur on a few mountain peaks in the Christmas Mountains in New Brunswick. Low mountain slopes support a mixed forest of red spruce (*Picea rubens*), white spruce (*P. glauca*), balsam fir (*Abies balsamea*), red pine (*Pinus resinosa*), sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), and yellow birch (*Betula allegheniensis*). Eastern hemlock (*Tsuga canadensis*) and eastern white pine (*P. strobus*) are also present. Along the east coast within the Gulf of St. Lawrence Lowland Forests terrestrial ecoregion, warm summers give rise to hardwood forests of sugar maple, yellow birch, and American beech. Eastern hemlock, balsam fir, and white pine (*P. strobus*) are also common in the lowlands.

Fish Fauna:
The fish fauna of this ecoregion is largely comprised of species originating in the Atlantic Coastal refugium, which was less speciose than the Mississippian refugium. As a result, the fauna is depauparate relative to the faunas of central Canada, although it is moderately rich compared to other temperate coastal river ecoregions. It is dominated by secondary freshwater fishes such as sturgeons (*Acipenser* spp.), shads (*Alosa* spp.), smelts (Osmeridae), American eel (*Anguilla rostrata*), sticklebacks (Gasterosteidae), killifishes (*Fundulus* spp.), and temperate basses (*Morone* spp.).

Description of endemic fishes:
An endemic dwarf smelt (*Osmerus* spp.) in Lake Utopia, New Brunswick has been identified, but not formally described.

Other noteworthy fishes:
Some landlocked freshwater populations of the primarily marine tomcod (*Microgadus tomcod*) are found in this ecoregion.

Ecological phenomena:
Many species in this ecoregion exhibit diadromy including lampreys (*Lampetra* spp.), sturgeons (*Acipenser* spp.), shads (*Alosa* spp.), smelts (Osmeridae), American eel (*Anguilla rostrata*), Atlantic salmon (*Salmo salar*), and temperate basses (*Morone* spp.).

Justification for delineation:
The ecoregions of Canada were identified based on the faunal similarity of 166 major watersheds based on a cluster analysis of freshwater fish occurrences in these watersheds. The extent of the Northeast US and Southeast Canada Atlantic Drainages ecoregion was determined by including fish occurrence data for watersheds in contiguous watersheds of the northeast United States. The North Atlantic Ecoregion is comprised of watersheds that flow into Gulf of St. Lawrence and the Bay of Fundy in Canada, and directly into the Atlantic Ocean in the United States. The fish fauna of this ecoregion is largely comprised of species originating in the Atlantic Coastal refugium, which was less speciose than the Mississippian refugium. As a result, the fauna is depauparate relative to the faunas of central Canada, and is dominated by saltwater-tolerant freshwater fishes.

Level of taxonomic exploration:
Fair

References/sources:

Abell, R., Olson, D., et al. (2000). "Freshwater ecoregions of North America" Washington, D.C.: Island Press.

Eswg (1995) "A national ecological framework for Canada". Ottawa/Hull, Ontario, Canada. Agriculture and Agri-food Canada, Research Branch, Centre for Land and Biological Resources Research; and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch..

Ricketts, Taylor H. Dinerstein Eric Olson David M. Loucks Colby J. (1999). "Terrestrial ecoregions of North America: A conservation assessment" Washington, D.C.: World Wildlife Fund.

Scott, W. B.,Crossman, E. J. (1998). "Freshwater fishes of Canada" Fisheries Research Board of Canada Bulletin **184** 966 + xvii..

St. Lawrence:

117: St.Lawrence
Major Habitat Type: temperate coastal rivers
Author: Text modified from Abell et al. 2000. Freshwater Ecoregions of North America: A Conservation Assessment. Island Press, Washington, DC, USA.
Reviewers: Nicholas Mandrak, Centre of Expertise for Aquatic Risk Assessment,
Countries: Canada; United States

Boundaries:
This ecoregion is defined largely by the St. Lawrence River drainage from the point where the St. Lawrence River leaves Lake Ontario to the Gulf of St. Lawrence. It is bounded by the Ottawa River drainage to the west and Saguenay River drainage to the east. It also covers part of northern New York, northern Vermont, southern Quebec, and southern Ontario.

Drainages flowing into:
All drainages flow into the Atlantic Ocean.

Main rivers or other water bodies:
The St. Lawrence River drains the Great Lakes, forming part of the largest freshwater system in the world. Major tributaries in the ecoregion include the Ottawa River; Saint-Maurice River; Richelieu River, which drains Lake Champlain; and Saguenay River, which drains Lac Saint-Jean. The ecoregion also includes Lake Saint-Louis, Lac Saint-François, and Lac Saint-Pierre, located on the St. Lawrence River.

Topography:
This ecoregion forms part of the St. Lawrence geomorphic province (McNab & Avers 1994). The Laurentian Mountains are composed mainly of Precambrian granites and gneisses, and are incised by southward-draining rivers (ESWG 1995). Steep slopes rise abruptly above the St. Lawrence River, and the interior is undulating and covered by glacial drift. To the south lie the Adirondack Mountains in northern New York State. Elevations in the ecoregion extend from sea level to over 1000 m.

Climate:
In general, this ecoregion experiences warm summers and cold, snowy winters, with precipitation exceeding 1000 mm between Quebec City and the Saguenay River.

Freshwater habitats:
Most of the ecoregion's freshwater habitats were created by glaciation, and include numerous lakes, rivers and wetlands.

Terrestrial Habitats:
The ecoregion is comprised of temperate broadleaf and mixed forests, as well as boreal forests. The majority of vegetation is characterized by mixedwood forests dominated by white spruce

(*Picea glauca*), balsam fir (*Abies balsamea*), quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), and yellow birch (*B. allegheniensis*). The eastern side of the ecoregion around Lac St. Jean valley is dominated by sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), and yellow birch on upland sites. Eastern hemlock (*Tsuga canadensis*), balsam fir, eastern white pine (*Pinus strobus*), and white spruce are the dominant species in valleys (ESWG 1995).

Fish Fauna:
The fish fauna of this ecoregion is relatively diverse as a result of close proximity to two glacial refugia - the Atlantic refugium and the Mississippian refugium. As a result of close proximity to the St. Lawrence River, many species in this ecoregion are secondary freshwater species such as American eel (*Anguilla rostrata*), Atlantic salmon (*Salmo salar*), rainbow smelt (*Osmerus mordax*), shads (*Alosa* spp.), sticklebacks (Gasterosteidae), trouts (*Salvelinus* spp.), and whitefishes (*Coregonus* spp.). The primary freshwater fishes are largely comprised of minnow (Cyprinidae), sunfishes (Centrarchidae), suckers (Catostomidae) and perch (Percidae) species.

Description of endemic fishes:
The copper redhorse (*Moxostoma hubbsi*) is endemic to this ecoregion. The spring cisco (*Coregonus* sp.) of uncertain taxonomy is considered endemic to Lac des Écorces, Quebec.

Other noteworthy fishes:
In Canada, the chain pickerel (*Esox niger)*, redfin pickerel (*Esox americanus americanus*), bridle shiner (*Notropis bifrenatus*), cutlip minnow (*Exoglossum maxillingua*) and eastern silvery minnow (*Hybognathus regius*) are largely limited to this ecoregion, and all likely originated from an Atlantic refugium.

Ecological phenomena:
This ecoregion was noted for runs of catadromous American eel and anadromous Atlantic salmon; however, stocks of both these species are declining.

Evolutionary phenomena:
Populations of a glacial relict, the deepwater sculpin (*Myoxocephalus thompsonii*) are found in several deep lakes in the Gatineau drainage, which drains into the Ottawa River.

Justification for delineation:
The ecoregions of Canada were identified based on the faunal similarity of 166 major watersheds based on a cluster analysis of freshwater fish occurrences in these watersheds. The St. Lawrence Ecoregion contains watersheds that drain into the St. Lawrence River, a dispersal corridor for freshwater fishes. Given its close proximity to glacial refugia and moderate climate, the fish fauna of this ecoregion is relatively diverse and most characteristic of the fauna derived from the closest refugium – the Atlantic refugium.

Level of taxonomic exploration:
Good

References/sources:

Abell, R., Olson, D., et al. (2000). "Freshwater ecoregions of North America" Washington, D.C.: Island Press.
Eswg (1995) "A national ecological framework for Canada". Ottawa/Hull, Ontario, Canada. Agriculture and Agri-food Canada, Research Branch, Centre for Land and Biological Resources Research; and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch..
McNab, W. H.,Avers, P. E. (1994) "Ecological subregions of the United States". U.S. Forest Service, ECOMAP Team, WO-WSA-5. Online. http://www.fs.fed.us/land/pubs/ecoregions/index.html..
Ricketts, Taylor H. Dinerstein Eric Olson David M. Loucks Colby J. (1999). "Terrestrial ecoregions of North America: A conservation assessment" Washington, D.C.: World Wildlife Fund.

Great Lakes:

116: Laurentian Great Lakes
Major Habitat Type: large lakes
Author: Text modified from Abell et al. 2000. Freshwater Ecoregions of North America: A Conservation Assessment. Island Press, Washington, DC, USA. Text also provided by Mary Burridge.
Countries: Canada; United States

Boundaries:
Encompassing portions of southern Ontario and eight American states, this ecoregion is comprised of the watersheds of the five Great Lakes (Superior, Michigan, Huron, Ontario, and Erie).

Drainages flowing into:
Positioned between the Arctic drainages to the north and the Mississippi and Atlantic drainages in eastern North America, the entire system drains into the Atlantic Ocean—the majority of water by way of the Gulf of St. Lawrence. In all, this area contains approximately one-fifth of the Earth’s freshwater.

Main rivers or other water bodies:
Lakes Superior, Michigan, Huron, Erie, and Ontario form the Great Lakes. With a total surface area of 245,000 km^2, these are the largest group of freshwater lakes in the world. Other large lakes in the ecoregion include lakes Nipigon, Nipissing, Simcoe, and Lake St. Clair. Numerous small rivers and streams, which often are segmented by barrier falls, flow into Lake Superior—the largest, deepest, and coldest of the five Great Lakes, and the largest temperate freshwater lake (in terms of surface area) in the world. Among the larger rivers feeding Lake Superior include the Nipigon, St. Louis, and Pigeon rivers. Large rivers draining Lake Huron include the Spanish, French, Mississagi, and Saugeen rivers. Among the rivers feeding Lake Erie are the Thames and Grand rivers in Ontario, the Detroit River between Michigan and Ontario, and the Portage River in Ohio. Main rivers draining into Lake Ontario are the Niagara, Moira, and Oswego rivers. Lake Ontario receives the entire outflow of the other four Great Lakes. The smallest of the Great Lakes, Lake Ontario is second only to Superior in average depth.

Topography:
Until approximately 10,000 to 15,000 years ago the entire region was covered by glaciers associated with the Wisconsinan Age, and the basins of the Great Lakes were created by the movements and the erosional forces of these glaciers. This has resulted in gently rolling topography with elevations below 250 m across much of the landscape, although a few ranges along the northern and western border reach upwards of 600 m (McNab & Avers 1994).

Much of this region is underlain by the acidic, Archean bedrock of the Canadian Shield. Bedrock outcroppings are common, and may be covered with sandy to loamy till in the north, and a thin, acidic sandy till in the south. The glaciers that once covered this ecoregion left areas now mantled with thick deposits of glacial drift. Limestone and dolomite cliffs of the Niagara Escarpment extend from Lake Michigan's northern shoreline, northeast to Manitoulin Island, and southward along the Bruce Peninsula to Niagara Falls. Lakes Erie and Ontario are underlain by Palaeozoic bedrock and have low relief with poorly drained depressions, morainic hills, drumlins, eskers, and outwash plains as a result of glaciation.

Climate:
The effects of the Great Lakes on climate, commonly called "lake effect," influences average temperatures, extreme temperatures, and the amount and timing of precipitation. Lake effect snow is common across the region, ranging from 1800 to over 8000 mm in some parts (McNab & Avers 1994). Climate tends to be continental to modified continental. Because the prevailing winds move from west to southeast, Lake Superior, the westernmost lake, is also the coldest of the Great Lakes, and as a result has a less ameliorating effect on temperature than that of the other Great Lakes (Ricketts et al. 1999).

Freshwater habitats:
The five Laurentian Great Lakes comprise the largest freshwater ecosystem in the world, holding over 20% of world's surface freshwater. In addition to numerous streams, rivers, lakes (including pothole and kettle lakes), springs, spring ponds, and wetlands, over 35,000 islands are found within the Great lakes. There are also unique freshwater features, such as Manitoulin Island, the largest freshwater island in the world; St. Clair River Delta, the largest freshwater river delta in the world; and the most sand dunes of freshwater origin in the world (TNC 2000).

The extensive interior wetlands and sand dune systems, such as Lake Ontario's Presqu'ile, Lake Erie's Long Point, Rondeau, and Point Pelee, support unique plant communities on large sand pits. Some of these wetlands are also recognized internationally for their outstanding biological significance, including Long Point and Point Pelee on the north shore of Lake Erie, and the National Wildlife Area on Lake St. Clair. Long Point is designated a UNESCO Biosphere Reserve.

Terrestrial Habitats:
The northwestern part of the ecoregion is dominated by mixed forest characterized by white and black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana*), trembling aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*). Here, forest fires are an important natural disturbance (ESWG 1995). To the south deciduous forest dominates, with species such as sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), American beech

(*Fagus grandifolia*), hop hornbeam (*Ostrya virginiana*), basswood (*Tilia americana*), yellow birch (*Betula alleghaniensis*), and eastern hemlock (*Tsuga canadensis*). In the eastern edge of the ecoregion rare alvar communities support prairie species that are at their eastern extremity, and are globally endangered. Ancient eastern white cedars on the limestone cliffs of the Niagara Escarpment have been aged at 700 to 800 years, making them some of the oldest in eastern North America (Ricketts et al. 1999).

Fish Fauna:
From a biogeographic perspective this ecoregion is quite young (Underhill 1986). During the last glacial retreat, fish fauna colonized the Great Lakes from neighboring drainages, including the Upper Mississippi Basin, Hudson Bay, Ohio River valley, and Atlantic coast (TNC 2000). The proximity and multiple connections to these refugia, as well as a relatively moderate climate and diversity of habitats (from small headwater streams to wetlands and deep offshore areas of large lakes) resulted in the ecoregion's rich diversity of fishes, despite the relatively few endemics. It does, however, contain unique forms of widely distributed species. This region's freshwater species, and particularly its fish, tend to be adapted to one of two habitat types: lacustrine (lake) or lotic (river and stream) (Underhill 1986). Minnows (Cyprinidae) represent the most diverse fish family in this ecoregion, followed by the salmons, trouts and whitefishes (Salmonidae), perches (Percidae), sunfishes (Centrarchidae), suckers (Catostomidae), and bullhead catfishes (Ictaluridae).

Description of endemic fishes:
An endemic cisco species flock consisting of bloater (*Coregonus hoyi*), blackfin cisco (*C. nigripinnis*), deepwater cisco (*C. johannae*), and shortnose cisco (*C. reighardi*) has been described in the Great Lakes. All of these species are extirpated in one or more of the Great Lakes in which they originally occurred, and the deepwater and shortnose ciscoes are considered to be extinct. All of these species are thought to have evolved from a common ancestor, lake cisco (*C. artedi*), within the Great Lakes since their most recent formation c. 14,000 years ago. Siskiwit lake cisco (*Coregonus bartlettii*) and Ives lake cisco (*Coregonus hubbsi*) are two other endemics, although experts disagree whether they are separate species from *C. artedi*. A subspecies of walleye (*Sander vitreus vitreus*) known as the blue pike (*Sander vitreus glaucus*) was once endemic to lakes Erie and Ontario, but is now considered extinct.

Other noteworthy fishes:
Many of the over 150 native fish species in the Great Lakes ecoregion are considered to be at risk. Habitat alteration, invasive species, and overexploitation are considered to be the greatest threats to fishes in the Great Lakes Basin. In addition to the endemic fishes listed above, notable fish species at risk in this ecoregion include the extirpated Atlantic salmon (*Salmo salar*), American eel (*Anguilla rostrata*), which is virtually extirpated, and the lake sturgeon (*Acipenser fulvescens*), which has exhibited a precipitous decline (>95% population decline) since the late 18th century. In addition to the many native species at risk, many introduced species have become established in the Great Lakes Basin, including common carp (*Cyprinus carpio*), goldfish (*Carassius auratus*), brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), Pacific salmons (*Oncorhynchus* spp.), sea lamprey (*Petromyzon marinus*), rainbow smelt (*Osmerus mordax*), alewife (*Alosa pseudoharengus*), ruffe (*Gymnocephalus cernuus*), and round

goby (*Neogobius melanostomus*). Many of these species have had substantial negative impacts on the ecosystems of the Great Lakes Basin.

Other noteworthy aquatic biotic elements:
The Great Lakes ecoregion contains a unique assemblage of aquatic insects, mussels, and planktonic species with both freshwater and marine origins. This has resulted from both glacial advancements, which brought arctic marine and brackish water invertebrates that adapted to the freshwater environment, as well as new freshwater species that colonized the region from other drainages as glaciers receded (TNC 2000).
Many of the mussels are endangered as a result of habitat alteration and invasive species, and many aquatic invertebrate species have been introduced into this ecoregion, largely through ballast water release. These species include the spiny water flea (*Bythotrephes longimanus*), fishhook water flea (*Cercopagis penoi*), and zebra mussel (*Dreissena polymorpha*). These species have also had substantial negative impacts on the ecosystems of the Great Lakes Basin.

Ecological phenomena:
Historically, the lake sturgeon and American eel undertook long spawning migrations, and the lake cisco and lake whitefish (*Coregonus clupeaformis*) likely formed large spawning schools in the larger lakes. The wetlands of the lower Great Lakes as well as Lake Superior and Lake Huron are crucial for migrating birds and serve as stopovers and major breeding areas.

Evolutionary phenomena:
Morphological radiation related to depth and prey has been identified in lake trout (*Salvelinus namaycush*) in some of the Great Lakes. Many fish species exhibit morphological variation across this ecoregion as the result of populations being isolated following the last Ice Age and, subsequently, adapting to local environments.

Justification for delineation:
Ecoregion boundaries are taken from Abell et al. (2000) and are based on subregions defined by Maxwell et al. (1995). The boundaries were then modified based on the faunal similarity of 166 major watersheds based on a cluster analysis of freshwater fish occurrences in these watersheds. The Laurentian Great Lakes ecoregion includes the watersheds that drain into the Great Lakes and the Great Lakes themselves. This ecoregion has the greatest fish species richness of any ecoregion in Canada. This is a result of proximity and multiple connections to the Mississippian and Atlantic Coastal refugia, relatively moderate climate, and diversity of habitats.

Level of taxonomic exploration:
Good

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Chesapeake Bay:

158: Chesapeake Bay
Major Habitat Type: temperate coastal rivers
Author: Text modified from Abell et al. 2000. Freshwater Ecoregions of North America: A Conservation Assessment. Island Press, Washington, DC, USA.
Countries: United States

Boundaries:
The extent of this ecoregion is defined by the river drainages of the Chesapeake Bay. The ecoregion covers most of northern Virginia, the eastern extension of West Virginia, most of Maryland, part of southwestern Delaware, roughly the central one-third of Pennsylvania, and part of western New York.

Drainages flowing into:
The Chesapeake Bay drainage flows to the Atlantic Ocean.

Main rivers or other water bodies:
Major rivers in the southern portion of the ecoregion include the Potomac and Rappahannock rivers. Rivers originating on the Delmarva Peninsula include the Sassafras, Chester, Choptank, and Nanticoke. The largest tributary to the Chesapeake is the Susquehanna River, contributing 50% of the freshwater in the Bay. The headwaters of the Susquehanna originate on the Appalachian Plateau. Together, the Susquehanna and its tributaries cut through select mountain ridges of the Ridge and Valley province on their way to the Piedmont Plateau. Unlike the other major rivers in this ecoregion, the Susquehanna does not reach the Coastal Plain until just before its confluence with the Chesapeake itself.

Topography:
The ecoregion includes the Appalachian Plateau and Ridge and Valley physiographic provinces in the western and northern portions of the ecoregion, the Piedmont Plateau in the south central portion, and the Atlantic Coastal Plain in the southeastern portion of the ecoregion. Elevation ranges from sea level to over 1400 m.

Climate:
The climate in the southern portions of the ecoregion surrounding the bay is humid subtropical, with hot, humid summers and cold to mild winters. Towards the northern reaches the climate is humid continental. Average annual temperatures within the ecoregion range from 8 – 14 °C, and average annual precipitation ranges from 1020 – 1270 mm (McNab & Avers 1994).

Freshwater habitats:
The Chesapeake Bay represents the largest estuary in the United States, and its drainage includes a diversity of wetlands, marshes, riparian forests, rivers and streams.

Terrestrial Habitats:
The Chesapeake Bay ecoregion spans six terrestrial ecoregions that includes coastal forests and temperate broadleaf and mixed forests. Hemlock (*Tsuga canadensis*) and beech (*Fagus grandifolia*) once dominated the presettlement forests of the Allegheny Highlands, whereas massive tulip poplars (*Liriodendron tulipifera*), chestnuts (*Castanea dentata*), red spruce (*Picea rubens*), and oaks (*Quercus* spp.) once dominated the mid-elevations of the Appalachian/Blue Ridge forests. The Northeastern coastal forests are characterized by white oak (*Quercus alba*) and northern red oak (*Q. rubra*). Around the mouth of the Bay, Southeastern mixed forests and Mid-Atlantic coastal forests are the predominant vegetation types (Ricketts et al. 1999).

Fish Fauna:
This ecoregion supports over 100 native freshwater fishes, of which one is endemic. Like other coastal ecoregions, the Chesapeake is host to several species of widely distributed anadromous fishes. Among these are the American shad (*Alosa sapidissima*), alewife (*A. pseudoharengus*), blueback herring (*A. aestivalis*), white perch (*Morone americana*), and striped bass (*M. saxatilis*). Known locally as rockfish, the striped bass has historically been an important commercial fish. After experiencing serious declines, due largely to overfishing, populations are beginning to respond to stricter conservation measures.

Description of endemic fishes:
The only endemic is the Maryland darter (*Etheostoma sellare*), restricted to one small section of a stream in central Maryland.

Other noteworthy aquatic biotic elements:
This ecoregion supports over ten species of native crayfish and over twenty species of unionid mussels, 20% of which are endemic.

Justification for delineation:
Ecoregion boundaries are modified from Abell et al. (2000), which based its units on subregions defined by Maxwell et al. (1995). Modifications to this ecoregion were made following

recommendations from the Endangered Species Committee of the American Fisheries Society. The James River was moved from the Chesapeake Bay to the Appalachian Piedmont [157] based on a dissimilarity analysis that showed greater faunal similarities between the James and rivers south of it than those to the north and in the Chesapeake Bay ecoregion.

References/sources:

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Upper Ohio:

150: Teays - Old Ohio

Major Habitat Type: temperate upland rivers

Author: Text modified from Abell et al. 2000. Freshwater Ecoregions of North America: A Conservation Assessment. Island Press, Washington, DC, USA.

Countries: United States

Boundaries:

Predominantly within the physiographic provinces of the Appalachian Plateau in the east, the Central Lowlands, and the Interior Low Plateau in the southwest, this ecoregion is defined largely by the watershed of the present day Ohio River. Three other provinces, the Ridge and Valley, Blue Ridge, and a small part of the Gulf Coastal Plain, occur here as well. In total, the ecoregion covers parts of ten states: Illinois, Indiana, Ohio, Kentucky, West Virginia, Tennessee, North Carolina, Virginia, Maryland, Pennsylvania, and New York.

Drainages flowing into:

The Ohio River originates in western Pennsylvania at the confluence of the Monongahela and Allegheny rivers. It flows 1570 km where it joins the Mississippi River in southern Illinois (Robison 1986).

The historic Teays River once followed the ancient course of the Ohio River prior to the last ice age. Before advancing glaciers blocked their flows, many of the rivers in the eastern part of the region, including the Allegheny and Monongahela, flowed northward into the Laurentian system that today is composed of the St. Lawrence River and its tributaries. Consequently, fishes that had been confined to the Hudson Bay and Laurentian System were displaced into the Old Ohio during glaciation (Burr & Page 1986).

Main rivers or other water bodies:

In addition to the Ohio River, other major rivers in this ecoregion include the Wabash in Indiana, the Green River and Kentucky River in Kentucky, the Scioto and Muskingum rivers in Ohio, the New River in West Virginia, and the Monongahela, Youghiogheny, and Allegheny rivers in Pennsylvania.

Topography:
The region was more topographically diverse during the Pliocene than it is today due to glaciation that began in the Oligocene and ended during the Pleistocene. It was once dominated by rolling hills over much of the landscape, but today includes large areas of low relief in the formerly glaciated southern Central Lowlands. To the south and eastern edge of the ecoregion topography is more varied and includes the rugged relief of the Appalachian Plateau as well as the rolling hills of the Interior Low Plateau (Robison 1986).

Terrestrial Habitats:
Historically, much of this ecoregion was forested, including areas where rich soils were deposited by the last glaciers. The ecoregion is primarily characterized as deciduous broadleaf forests dominated by oak-hickory communities in the west and sugar maple (*Acer saccharum*) and beech (*Fagus grandifolia*) in the north. To the east lie Appalachian mixed mesophytic forests, which were once widespread and served as mesic refuges during drier glacial periods (Ricketts et al. 1999). Much of the lower, downstream portion of the ecoregion, which was not glaciated, includes an extension of the Mississippi alluvial plain, where bottomland hardwood forests and swamps were once common (U.S. Fish and Wildlife Service 1995).

Fish Fauna:
The Teays-Old Ohio ecoregion is considered globally outstanding due to the sheer numbers of aquatic species found within it. With over 225 native fish species, as well as abundant unionid mussels, crayfish, and native amphibians and aquatic reptiles, this ecoregion has one of the highest total number of species in North America. This high level of richness is derived principally from the diversity of upland and lowland habitats, and the presence of both glaciated and unglaciated areas (Burr & Page 1986).

Description of endemic fishes:
Endemism is moderately high in the ecoregion, and certain basins have markedly higher endemism than others. For instance, the upper Green River drainage has an endemic sucker and three endemic darters (*Thoburnia atripinnis*, *Etheostoma barbouri*, *E. bellum*, and *E. rafinesquei*), while the Wabash River has no endemics (Burr & Page 1986). Within the entire ecoregion, the endemic fish fauna includes minnow, catfish, cave springfish, chub, shiner, and darter, among others. Several of these endemics are also found in the Tennessee [152] and Cumberland [151] ecoregions to the south, but have such limited distributions that they can be considered endemic within this small region.

Other noteworthy aquatic biotic elements:
Fourteen percent of mussels, 47% of crayfish, and 5% of herpetofauna are endemic. Endemism in herpetofauna is limited to three species of salamanders: the Black Mountain salamander (*Desmognathus welteri*), West Virginia spring salamander *(Gyrinophilus subterraneus*), and streamside salamander (*Ambystoma barbouri*). Like some of the endemic fishes, the Black

Mountain salamander has a restricted range that falls within the southeastern portion of this ecoregion and the northeastern part of the Tennessee-Cumberland. In general, the fauna of this ecoregion is more cosmopolitan than that of the Tennessee [152] and Cumberland [151] ecoregions.

A native Ohio River crayfish species known as the rusty crayfish (*Orconectes rusticus*) is of special interest. Much like the flathead catfish, this voracious predator has been introduced into numerous other rivers and streams across the United States, primarily by bait dealers. Evidence suggests that this crayfish generally threatens to eliminate native crayfishes wherever it is introduced (Clancy 1997; Taylor pers. comm.).

Ecological phenomena:
The Teays-Old Ohio ecoregion is considered globally outstanding for its extraordinary species richness (Abell et al. 2000), especially in fish (208 species) and mussels (122 species).

Justification for delineation:
Ecoregion boundaries are taken from Abell et al. (2000) and are based on subregions defined by Maxwell et al. (1995).

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Tennessee:

152: Tennessee
Major Habitat Type: temperate upland rivers
Author: Text modified from Abell et al. 2000. Freshwater Ecoregions of North America: A Conservation Assessment. Island Press, Washington, DC, USA.
Countries: United States

Boundaries:

The watershed of the Tennessee River, which drains to the larger Mississippi Basin, defines this ecoregion. The majority of this area is centered in Tennessee; the river also drains parts of southwestern Kentucky, southwestern Virginia, western North Carolina, two disjunct areas in northern Georgia, northern Alabama, and the extreme northeastern corner of Mississippi.

Drainages flowing into:
The Tennessee River is the largest tributary of the Ohio River, and drains the eastern side of the lower Mississippi Basin.

Main rivers or other water bodies:
Originating in the Appalachian Highlands of Virginia, the Tennessee River drainage covers more than 103,600 km^2 (Ono et al. 1983). Major tributaries to the Tennessee include the Clinch, Powell, Holston, French Broad, Duck, Elk, Buffalo, Bear Creek, Paint-Rock, Sequatchie, Little Tennessee, and Hiwassee rivers.
Although the Tennessee and Cumberland rivers flow quite close to each other near their confluence with the Ohio, they were not physically linked historically. Today, dam construction on both rivers has changed this situation. The construction of Barkley Dam impounded the Cumberland, forming Lake Barkley, while just a few miles away the Kentucky Dam was built to impound the Tennessee River, thereby creating Kentucky Lake. This alone was not enough to link the two reservoirs, so a channel was cut not far from the head of each lake to link them together. Other mainstem and tributary reservoirs constructed by the Tennessee Valley Authority for flood storage and power generation are also major surface water features.

Topography:
The topography of the ecoregion is varied, rising from the Coastal Plain in the west to the Blue Ridge Mountains in the east. Tributaries drain the southern portion of the Highland Rim province, an upland area between 250 – 300 m elevation that encircles the Nashville Basin. East of the Cumberland Plateau lies the Ridge and Valley province, which is characterized by northeast-southwest trending long, even ridges and valleys. The Blue Ridge Mountains run parallel to the Ridge and Valley to the east and drain the high basins (600 – 800 m) within the ecoregion, with headwaters reaching elevations up to 1700 m (Starnes & Etnier 1986).

Climate:
The ecoregion generally experiences a temperate climate with precipitation distributed evenly throughout the year (Hampson et al. 2000).

Freshwater habitats:
From west to east, the Tennessee ecoregion traverses a number of physiographic provinces, creating a broad diversity of freshwater habitats. The lower Tennessee River basin drains a small portion of the coastal plain, and in this area streams are moderate to lower gradient. Swamps occur in the Big Sandy system, a major lower tributary to the Tennessee in the northwest corner of the ecoregion. Cave and spring habitats are abundant in the Highland Rim province, which covers most of the western half of the ecoregion. To the east of the Highland Rim is the Cumberland Plateau, and to the east of that is the Ridge and Valley province. Finally, the southeastern headwaters of the Tennessee drainage are found in the Blue Ridge province, where streams are typically high gradient and cold (Starnes & Etnier 1986).

Terrestrial Habitats:
Much of the ecoregion is covered in forest, particularly in the Jefferson, Pisgah, Cherokee, Nantahala, and Chattahoochee National Forests. Agriculture also accounts for a major land use, with most agricultural land used for pasture (Hampson 1995).

Fish Fauna:
The Tennessee and Cumberland [151] ecoregions contain the highest level of freshwater diversity in North America and are possibly the most diverse temperate freshwater ecoregions in the world (Starnes 1986; Olson and Dinerstein 1998). In fish, mussel, and crayfish species, the region is the most species-rich and has the highest number of endemics in North America. This high diversity is derived largely from the range of habitat types represented in the ecoregions, as well as their location adjacent to Atlantic Slope, eastern Gulf Slope, lower Mississippi River, and Ohio River drainages, all with distinctive faunas (Starnes et Etnier1986).

The Tennessee ecoregion is perhaps best known for its fish fauna, which numbers over 230 species and 30 endemics, the highest in North America. This contrasts with the Cumberland [151], which houses less than 10 endemic species. This is thought to be attributed to a larger drainage area, as well as greater physiographic diversity and drainage history.

Description of endemic fishes:
These endemics are made up of a large number of darters, as well as minnows, chubs, madtom catfishes, a cave-fish, pygmy sunfish and sculpins (Starnes & Etnier 1986). Of the many physiographic provinces in this ecoregion, the Highland Rim and Ridge and Valley tend to support the largest numbers of fish species. Many species with the most restricted ranges are found where provinces meet and overlap; for instance, the palezone shiner (*Notropis* sp.), smoky madtom (*Noturus baileyi*), and duskytail darter (*Etheostoma* sp.) all apparently require habitat created by the combination of features in two provinces (Starnes & Etnier 1986). New species of fish continue to be discovered and described in this ecoregion, despite fairly extensive historical study of the region’s fauna (Starnes & Etnier 1986; Burr pers. comm).

Justification for delineation:
Ecoregion boundaries are modified from Abell et al. (2000), which based its units on subregions defined by Maxwell et al. (1995). Modifications to this ecoregion were made following recommendations from the Endangered Species Committee of the American Fisheries Society. Based on faunal data from Hocutt & Wiley (1986), the Endangered Species Committee decided there was a significant number of species exclusively endemic to the Cumberland [151] and Tennessee [152] drainages to warrant separate ecoregions.

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151: Cumberland
Major Habitat Type: temperate upland rivers
Author: Text modified from Abell et al. 2000. Freshwater Ecoregions of North America: A Conservation Assessment. Island Press, Washington, DC, USA
Countries: United States

Boundaries:
The ecoregion is defined by the watershed of the Cumberland River, which drains to the larger Mississippi Basin. The ecoregion borders Tennessee and Kentucky, covering much of southern Kentucky and north-central Tennessee.

Drainages flowing into:
The Cumberland River drains to the larger Mississippi Basin by way of the Ohio River.

Main rivers or other water bodies:
In the northern portion of the ecoregion, the mainstem Cumberland River originates at the confluence of the Poor and Clover forks; in total, the Cumberland drains more than 46,000 km^2 before joining the Ohio River at Smithland, Kentucky (Ono et al. 1983). Tributaries to the Cumberland include the Big South Fork, Rockcastle, and Little rivers.
Although the Tennessee and Cumberland rivers flow quite close to each other near their confluence with the Ohio, they were not physically linked historically. Today, dam construction on both rivers has changed this situation. The construction of Barkley Dam impounded the Cumberland, forming Lake Barkley, while just a few miles away the Kentucky Dam was built to impound the Tennessee River, thereby creating Kentucky Lake. This alone was not enough to link the two reservoirs, so a channel was cut not far from the head of each lake to link them together. Other mainstem and tributary reservoirs constructed by the Tennessee Valley Authority for flood storage and power generation are also major surface water features.

Topography:

The topography of the ecoregion is diverse, with valleys, ridges, and falls downcut by major streams. Topographical features include the Highland Rim, a crater rising 250 – 300 m that encircles the Nashville basin. It is characterized by deep channels incised by the lower Cumberland River. Rising 300- 900 m altitude in the east lies the Cumberland Plateau, which consists of sandstones, shales and coals. Here, falls have formed over resistant sandstone substrates, with Cumberland Falls being the most notable (Starnes & Etnier 1986).

Climate:
The ecoregion's climate is temperate, with precipitation averaging around 1,200 mm. Temperature averages 13 ^{o}C (McNab & Avers 1994).

Freshwater habitats:
The region's physiographic and geological diversity accounts for much of the faunal diversity of the ecoregion. The Highland Rim is characterized by numerous caves, springs, surface streams, falls, and a labyrinth of subterranean channels. Streambeds of the Nashville basin are typically low gradient, meandering, and highly productive. Except for the headwaters of the Cumberland, which drain the steep slopes of the Cumberland Mountains, streams of the Cumberland Plateau are generally incised, meandering, with low productivity (Starnes & Etnier 1986).

Terrestrial Habitats:
The western half of the ecoregion is characterized by deciduous broadleaf forests, dominated by oak-hickory communities. Appalachian mixed mesophytic forests are the dominant communities on the eastern side of the ecoregion. These relict stands were once widespread across temperate North America, and served as mesic refuges during drier glacial periods (Ricketts et al. 1999).

Fish Fauna:
The Tennessee and Cumberland ecoregions together contain the highest level of freshwater diversity in North America and are possibly the most diverse temperate freshwater ecoregions in the world (Starnes 1986; Olson and Dinerstein 1998). In fish, mussel, and crayfish species, the region is the most species-rich and has the highest number of endemics in North America. This high diversity is derived largely from the range of habitat types represented in the ecoregions, as well as their location adjacent to Atlantic Slope, eastern Gulf Slope, lower Mississippi River, and Ohio River drainages, all with distinctive faunas (Starnes 1986).

Although not as rich as the Tennessee drainage [152], the Cumberland ecoregion harbors a large diversity of freshwater taxa. Stream capture, the process by which the headwaters of a drainage basin are naturally diverted to a neighboring one, has affected distributional patterns between the Cumberland and Green rivers and between the Cumberland and Tennessee rivers (Starnes & Etnier 1986).

Description of endemic fishes:
Species endemic to the ecoregion include a couple of darters (*Etheostoma forbesi* and *E. luteovinctum*), two shiners (*Notropis albizonatus* and *N. rupestris*), blotched chub (*Erimystax insignis*), barrens topminnow (*Fundulus julisia*) and the blackside dace (*Phoxinus cumberlandensis*), which is restricted to the upper Cumberland drainage above Big South Fork (Starnes & Etnier 1986).

Other noteworthy aquatic biotic elements:
The Tennessee [152] and Cumberland ecoregions contain globally high richness and endemism in mussels, crayfish, and other invertebrates.

Justification for delineation:
Ecoregion boundaries are modified from Abell et al. (2000), which based its units on subregions defined by Maxwell et al. (1995). Modifications to this ecoregion were made following recommendations from the Endangered Species Committee of the American Fisheries Society. Based on faunal data from Hocutt & Wiley (1986), the Endangered Species Committee decided there was a significant number of species exclusively endemic to the Cumberland [151] and Tennessee [152] drainages to warrant separate ecoregions.

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South Atlantic:

157: Appalachian Piedmont
Major Habitat Type: temperate coastal rivers
Author: Text modified from Abell et al. 2000. Freshwater Ecoregions of North America: A Conservation Assessment. Island Press, Washington, DC, USA.
Countries: United States

Boundaries:
This Appalachian Piedmont ecoregion ranges from eastern Georgia to southern Virginia, covering all of South Carolina and most of North Carolina.

Drainages flowing into:
The drainages of this ecoregion flow into the Atlantic Ocean.

Main rivers or other water bodies:
Major rivers include the Altamaha and its two tributaries, the Oconee and Ocmulgee, in Georgia; the Savannah River that forms the border between South Carolina and Georgia; the Cooper-Santee river system and Pee Dee in South Carolina; the Cape Fear River in North Carolina; and the Roanoke River in North Carolina and Virginia.

Topography:
Many of the rivers begin their journey to the Atlantic as small fast-flowing mountain streams in the eastern slopes of the Blue Ridge physiographic province of the Appalachian Mountains. From the hills and mountains they flow across the Piedmont Plateau until they reach the Fall Line, descending and flowing through the southern portion of the Atlantic Coastal Plain.

Climate:
The ecoregion experiences a humid subtropical climate with average annual temperatures ranging from 14-18°C in the Piedmont section and 13 – 14 °C along the Coastal Plain. Average annual precipitation ranges from 1100 to 1400 mm (McNab & Avers 1994).

Freshwater habitats:
As a result of the broad flat coastal plain and a high water table, this ecoregion contains an abundance of wetlands (McNab & Avers 1994). Approximately 9,816 km^2 of coastal marsh exist on the Atlantic Coast (Alexander et al. 1986), and roughly three-fourths occurs predominantly within this ecoregion in the states of North Carolina, South Carolina, and Georgia (Chabreck 1988). The ecoregion also includes swamps, bogs, freshwater marshes, and shallow lakes (McNab & Avers 1994). A subset of these lakes, including Lake Waccamaw, are concentrated primarily along the coast from southern North Carolina to eastern Georgia. They are collectively known as the Carolina Bays. These features were formed by the impact of extraterrestrial bodies. The unusual chemical makeup of Lake Waccamaw may be attributable to the lake’s origins, and may have played a part in the evolution of the lake’s distinctive fauna as well as its high productivity (Eyton & Parkhurst 1975; Stager & Cahoon 1987).

Terrestrial Habitats:
The ecoregion is dominated by oak-hickory-pine forests along the piedmont, longleaf pine (*Pinus palustris*) towards the south, and coastal forests that feature some of the most majestic plant communities of the United States (Ricketts et al. 1999). River swamp forests, or bottomland forests, were once prominent in this ecoregion and are characterized by bald cypress (*Taxodium distichum*) and swamp tupelo (*Nyssa sylvatica* var. *biflora*). Eastern or Atlantic white cedar (*Chamaecyparis thyoides*) occurs along blackwater rivers, most commonly on organic substrates underlain by sand (Wharton et al. 1982). Other unique communities include bogs and pocosins, which are extensive flat, damp, sandy or peaty areas far from streams with scattered pond pine (*Pinus serotina*) and evergreen shrubs (often gallberry, *Ilex glabra*) (Ricketts et al. 1999).

Fish Fauna:
For a temperate ecoregion, the Appalachian Piedmont contains noteworthy levels of richness and endemism, but the outstanding nature of its biodiversity is particularly evident when compared

with other temperate coastal ecoregions. The Appalachian Piedmont is the fifth richest ecoregion for fish in North America and is the richest in the temperate coastal rivers, lakes, and springs MHT. Like the other ecoregions radiating from the Appalachian Mountains, age, favorable climate, and geologic stability have provided a wealth of varied habitats, allowing for a diverse aquatic fauna to evolve and survive (Rohde et al. 1994).

Several species of anadromous fish that are widely distributed along the East Coast, including alewife (*Alosa pseudoharengus*), American shad (*A. sapidissima*), and blueback herring (*A. aestivalis*), return in the spring to the coastal rivers of this ecoregion where they were born.

Description of endemic fishes:
Among the endemic species are the federally endangered Cape Fear shiner (*Notropis mekistocholas*), restricted to a small section of the upstream portion of the Cape Fear River; the Waccamaw silverside (*Menidia extensa*), restricted solely to Lake Waccamaw; the Waccamaw killifish (*Fundulus waccamensis*), known only from Lake Waccamaw and Lake Phelps; and the Waccamaw darter (*Etheostoma perlongum*), found in Lake Waccamaw and headwaters of the Waccamaw River. This concentration of endemics in and around Lake Waccamaw gives further distinction to this ecoregion, as does the large degree of endemism encountered in the Roanoke River drainage near the northern boundary of the ecoregion.

Other endemic fish include two of the six species of pygmy sunfishes in the family Elassomatidae, which is restricted to the southeastern United States (Rohde et al. 1994). These species are the blue barred pygmy sunfish (*Elassoma okatie*) and the Carolina pygmy sunfish (*E. boehlkei*). The ecoregion is also home to a newly discovered species, a relative of the golden redhorse (*Moxostoma erythrurum*), tentatively known as the Carolina redhorse (*Moxostoma* sp.) (Southeastern Fishes Council 1997). It should be noted that new species may yet be discovered, because of all the southeastern U.S. regions, this is perhaps the least studied biologically—"a veritable black hole of life history knowledge for fishes," according to one expert (Burkhead pers. comm.).

Other noteworthy aquatic biotic elements:
Non-fish aquatic diversity is equally impressive within the ecoregion; 32% of its unionid mussel species are endemic, as are an extraordinary 70% of its crayfish species.
The Appalachian Piedmont also harbors a number of endemic amphibians, five of which are salamanders. Two of these belong to the Plethodontidae family. They are the many-lined salamander (*Stereocheilus marginatus*) and the shovelnose salamander (*Leurognathus marmoratus*), whose restricted range also occupies the neighboring Tennessee [152] ecoregion. Mabee's salamander (*Ambystoma mabeei*), the dwarf waterdog (*Necturus punctatus*), and the Neuse River waterdog (*Necturus lewisi*) are the other three endemic salamanders found in the ecoregion. The final endemic amphibian is the pine barrens tree frog (*Hyla andersonii*). Although this treefrog is found further north in the pine barrens of southern New Jersey and in the western panhandle of Florida (Conant & Collins 1991), its total range is so small that it is considered endemic to all three of these ecoregions.

Justification for delineation:

Ecoregion boundaries are modified from Abell et al. (2000), which based its units on subregions defined by Maxwell et al. (1995). Modifications to this ecoregion were made following recommendations from the Endangered Species Committee of the American Fisheries Society. The James River was moved from the Chesapeake Bay [158] to the Appalachian Piedmont ecoregion based on a dissimilarity analysis that showed greater faunal similarities between the James and rivers south of it than those to the north and in the Chesapeake Bay ecoregion.

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