CHAPTER

7

Stream and Rivers

Condition and Conservation Status

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Streams and rivers are flowing water ecosystems. From a tiny trickle in a headwater stream to the vast volume of water flowing in our mighty rivers, these systems provide habitat for a tremendous diversity of life. For centuries, people have depended on streams and rivers for drinking water, food, transportation, recreation, hydropower, and waste disposal. As we struggle to balance human needs for water with the needs of stream biota, an assessment of the current condition of these ecosystems is imperative. Here we begin to examine their conditions and conservation status, with respect to development, damming, and non-indigenous aquatic species.

Summary of Findings

Biotic Integrity: The region contains over 200,000 miles of streams and rivers supporting over 1,000 aquatic species. The majority of the region's watersheds still retain 95-100 of their native fish species, but are also home to up to 37 non-indigenous species. The range of native brook trout, a species that prefers cold high-quality streams, has been reduced by 60 percent. Direct indicators of biological integrity (IBI scores) suggest that while 44 percent of the wadeable streams are undisturbed, another 30 percent are severely disturbed, and this correlates with the amount of impervious surfaces in the watershed.

Conversion and Securement in the Riparian Zone: Riparian areas, the narrow 100 m zone flanking all streams and rivers, are important for stream function and habitat. Currently, conversion of this natural habitat exceeds securement 2:1, as 27 percent of stream riparian area is converted to development or agriculture and 14 percent is secured for biodiversity or multiple uses.

Dams and Connected Networks: Historically, 41 percent of the region's streams were linked into huge interconnected networks, each over 5,000 miles long. Today none of those large networks remain, and even the smaller ones over 1,000 miles long have been reduced by half. There has been a corresponding increase in short 1-25 mile networks that now account for 23 percent of all stream miles, up from 3 percent historically. This highly fragmented pattern reflects the density of barriers, which currently averages 7 dams and 106 road-stream crossings per 100 miles of stream.

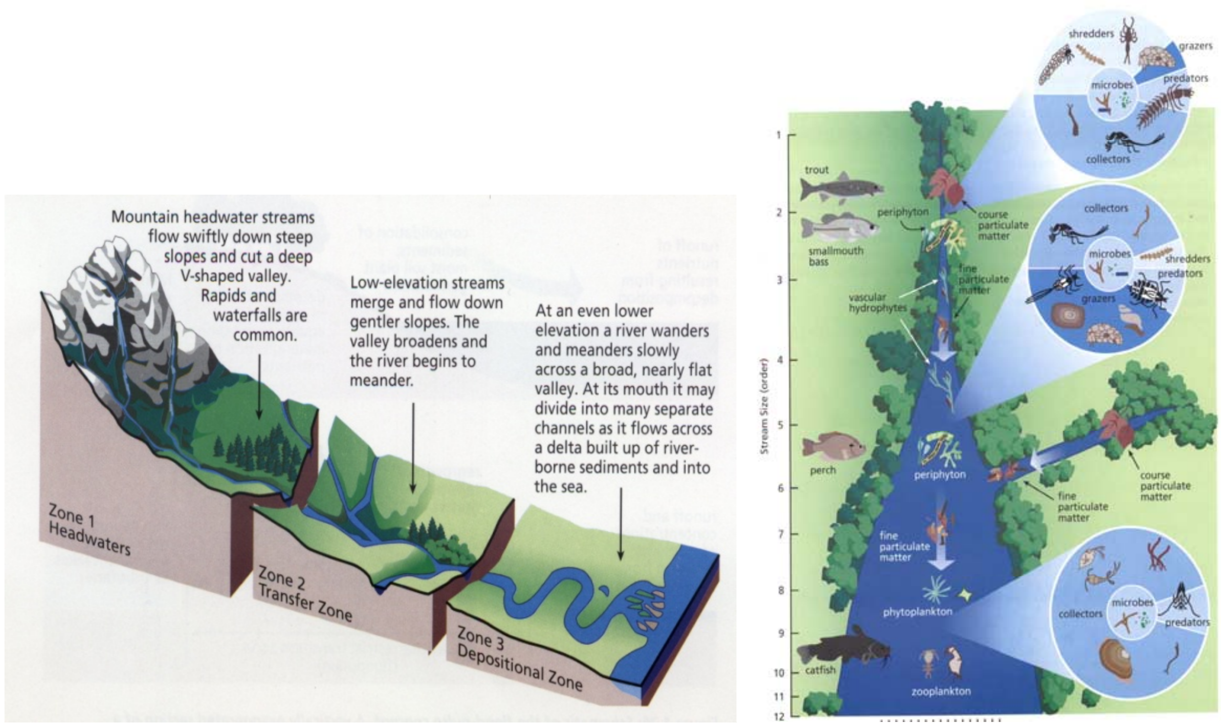
Water Flow: Flow is the essence of a stream ecosystem, but 61 percent of the region's streams have flow regimes that are altered enough to result in biotic impacts. One-third of all headwater streams have diminished minimum flow (they dry up), that translates into a reduction of habitat. Seventy percent of the large rivers have reduced maximum flow (smaller floods) that decreases the amount of nutrient laden water delivered to their floodplains.

Stream Types and Associated Species

Streams and rivers are dynamic features; they change temporally with seasonal changes in precipitation and temperature, and they change spatially from headwaters, to large river mouths. The well known "river continuum concept" provides a framework for how the physical size of the stream relates to major ecosystem processes, resulting in predictable changes in the species composition (Figure 1, Vannote et al. 1980). In narrow, shady, headwater streams, coarse particulate organic matter (e.g. leaves, twigs etc.) from the riparian zone provides the energy base for shredding insects. As a river broadens, more sunlight reaches the stream supporting significant algal growth and grazing insects. As the river further increases in size, reduced channel gradient and finer sediments form suitable conditions for the establishment of rooted plants. In larger rivers, turbidity, depth and fast current render it unsuitable for rooted plants or algal growth, and eventually, delta deposition increases until inputs from outside the stream channel again become a primary energy source.

Changes in physical habitat and energy source are correlated with predictable changes in riverine biological communities (Vannote et al. 1980). As streams increase in size they increase in fish diversity and their species composition changes (Box 1). In this region, fish of small, cold, clear streams with rocky substrates include brook trout and slimy sculpin. In larger streams, coolwater fish communities develop that include additional species such as blacknose dace, goldern shiner, and white sucker. As rivers broaden and flatten, warm water fish communities begin to develop until, in the lower coastal sections of large rivers the fish communities include a variety of anadromous and diadromous fish. In the very large rivers draining to the Ohio River there are additional species restricted to the Ohio-Mississippian basin.

Figure 1. River Continuium Concept (Vanotte et al., 1980).



Besides nearly 300 species of freshwater and anadromous fish, northeast rivers and streams also support a diversity of other biota including: 112 freshwater mussels species, 105 freshwater snail species, 36 crayfish species, 91 amphibian species, 523 caddisfly species, 228 mayfly species, 206 stonefly species, 243 dragonfly and damselfly species, and a myriad of aquatic plants, algae, sponges, worms, other invertebrates and microscopic life (NatureServe 2010). Freshwater dependent species are among the most threatened group of species in the region and are of great conservation concern. Globally rare or endangered species (G1 to G3 species) include: 47 species of freshwater and anadromous fish, 49 species of freshwater mussels, 26 species of freshwater snails, 8 species of crayfish, 13 species of amphibians, 91 species of caddisflies, 38 species of stoneflies, and 39 species of mayflies.

Box 1: Common Northeastern Stream and River Habitats, with examples of some associated fish species

Cold, rocky, swift streams: brook trout and slimy sculpin.

Cool streams and small rivers with moderate gradient: blacknose dace, white sucker, golden shiner, longnose dace, pearl dace, fathead minnow, common shiner, tessellated darter, mottled sculpin, fallfish.

Warm small to medium rivers with low gradients: river chub, longnose dace, central stoneroller, northern hogsucker, cutlips minnow, margined madtom, creek chub, rosyface shiner, fantail darter, and greenside darter, banded sunfish, redfin pickerel, swamp darter, creek chubsucker,

Warm large rivers with low gradients: redbreast sunfish, rock bass, spotfin shiner, smallmouth bass, spottail shiner, common shiner, tessellate darter, pumpkinseed, bluntnose minnow, bluegill, green sunfish, satinfin shiner, swallowtail shiner, yellow bullhead, shield darter, largemouth bass, river chub, rainbow darter, johnny darter, fantail darter, variegate darter, logperch, stonecat, silver shiner, blackside darter, striped shiner, golden redhorse, sand shiner, mimic shiner.

Large rivers near the Atlantic coast: blueback herring, striped bass, gizzard shad, American shad, Atlantic sturgeon, shortnose sturgeon, sea lamprey, banded killifish, white perch, eastern silvery minnow, and white catfish.

Very large rivers in the Ohio basin: channel catfish, sauger, common carp, gizzard shad, freshwater drum, walleye, white bass, shorthead redhorse, spotted bass, silver redhorse, quillback carpsucker, emerald shiner, flathead catfish, black crappie, smallmouth buffalo, river redhorse, and mooneye.

Adapted from Walsh et al, 2007; Stuart, 2003; Langdon et al 1998;

To encompass these diversity patterns, we classified and mapped the streams and rivers into seven size classes that roughly correspond to these major ecosystem changes. These size classes use upstream catchment area as a proxy for stream size because watershed area is mappable across the entire region and the width, depth, and volume of water in a stream channel on-the-ground increases in predictable ways with increasing watershed area. This classification follows the Northeast Aquatic Habitat Classification (Olivero and Anderson 2008), and to keep the terminology clear, we use the term “river” for rivers with catchments over 39 square miles and “stream” for those with smaller catchments (Table 1). We use “streams” when referring to all types collectively.

Table 1. River and Stream Size Classes used in this report (from Olivero and Anderson 2008).

Streams	
1a: Headwater:	1 to 3.9 sq.mi. (10 sq.km) catchment
1b: Creek:	3.9 to 39 sq.mi. (100 sq.km) catchment
Rivers	
2: Small River:	39 to 200 sq.mi. (518 sq.km) catchment
3a: Medium Tributary River	200 to 1,000 sq.mi. (2590 sq.km) catchment
3b: Medium Mainstem River	1,000 to 3,861 sq.mi. (10,000 sq.km) catchment
4: Large River	3,861 to 9,653 sq.mi. (25,000 sq.km) catchment
5: Great River:	greater than 9,653 sq.mi. (25,000 sq.km) catchment

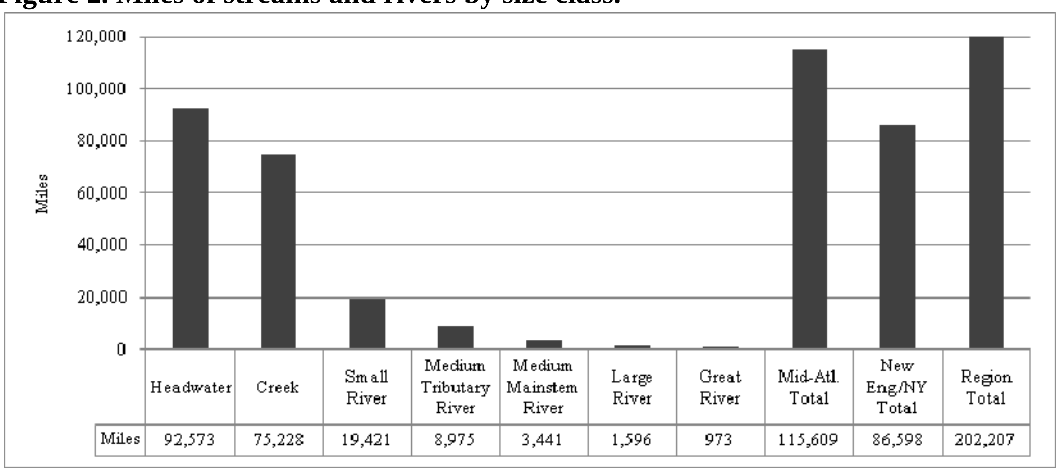
The region contains over 200,000 miles of streams and rivers that drain three major basins, the North Atlantic, Great Lakes, or Ohio-Mississippian (Map 1). Major river systems include the Penobscot, Kennebec, Merrimack, Connecticut, Hudson, Delaware, Susquehanna, Potomac, James, Roanoke, Allegheny, Monongahela, and New River.

In this document, we report on trends for perennial streams and rivers with catchments of one square mile or larger; smaller streams are too inconsistently mapped. The majority of streams and river miles are headwater and creeks with small catchment areas (83 percent). Small rivers account for another 10 percent and the larger river types collectively account for the remaining 7 percent (Figure 2). The percentage distribution of miles by size class is nearly identical between the New England and New York and the Mid-Atlantic, although, the Mid-Atlantic contains more stream and river miles given its larger geographic size.

Conversion and Securement of the Riparian Zone

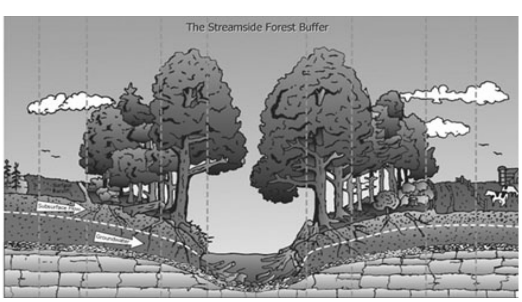
The riparian zone is the land area directly adjacent to a stream or river and subject to its influence. This dynamic zone is an ecologically rich environment, supporting many rare and common species, and numerous natural communities. Vegetated riparian zones provide bank stabilization, water temperature moderation, and sediment filtering, and they are important sources of dissolved particulate and coarse organic matter for adjacent waters (Figure 3). In this section, we assessed the riparian zone of each stream and river by creating (in GIS) a standard 100 m (~300 ft.) buffer on either side of each stream and river in the region. The 100 m distance was chosen to encompass the types of riparian functions noted for eastern riparian zones (Palone et al. 1997).

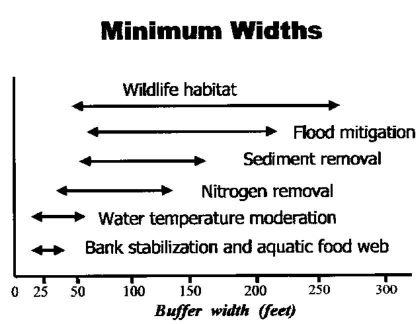
Figure 2. Miles of streams and rivers by size class.



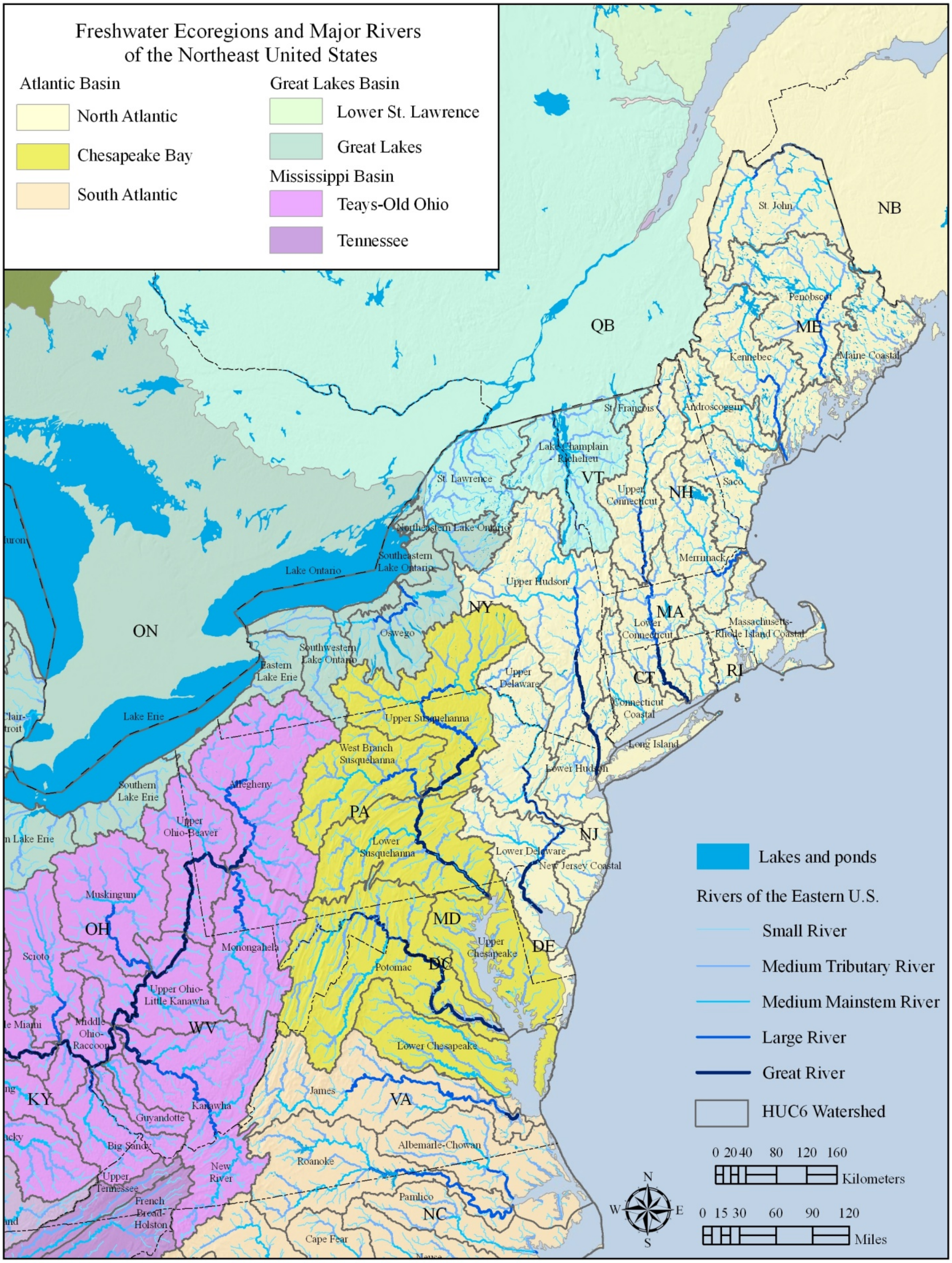
	Headwater	Creek	Small River	Medium Tributary River	Medium Mainstem River	Large River	Great River	Mid-Atl. Total	New Eng/NY Total	Region Total
Miles	92,573	75,228	19,421	8,975	3,441	1,596	973	115,609	86,598	202,207

Figure 3. A. Riparian Zone Conceptual Model (Welsch 1997, Palone et al. 1997).





Map 1. Freshwater ecoregions and major rivers of the northeast United States.

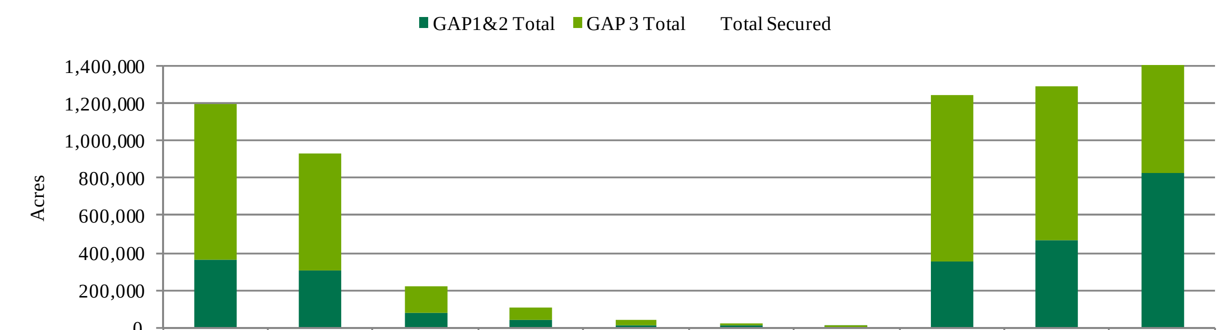


Secured Land in the Riparian Buffer: To evaluate the securement status of each stream's riparian zone we overlaid the TNC secured lands data set (see details in chapter 2) on the 100m (~300ft) riparian buffer zone and tabulated the amount of area secured primarily for nature or secured for multiple uses. The results of this overlay indicated that just over 2.5 million acres of riparian buffer was permanently secured against conversion to development; 14 percent of all the riparian area in the region (Figure 4). The vast majority of this secured acreage, 84 percent, was associated with small headwaters and creeks. This makes sense given that these small streams numerically dominate the miles of stream and river systems in the region.

We summarized the percent of secured riparian buffer in every small watershed (HUC12, e.g. 12 digit Hydrologic Cataloging Unit), and this revealed that few watersheds had 75-100 percent of their riparian buffers secured (Map 2). These watersheds were in northern and downeast Maine, northern New Hampshire, the Adirondack region of New York, the Allegheny mountains of Pennsylvania, the Central Appalachian mountains of West Virginia and Virginia, and in the Pinelands of New Jersey. In other areas of the region, although individual small sections of rivers may benefit from adjacent riparian secured lands, the larger network of streams and rivers of which they were a part had much less securement from conversion in their riparian zone.

Condition of the Riparian Buffer: Natural vegetated buffers along streams provide a suite of benefits to aquatic systems, but agricultural and urban development in the riparian zone is associated with elevated levels of nitrogen, phosphorus, pesticides, and bacteria in streams. We calculated the amount of agriculture and developed land within each riparian buffer zone by overlaying the 2001 National Land Cover dataset (Homer et al. 2004) on the 100 m riparian buffers and tabulating the acreage of each land use. Results show that the percent of riparian land in natural cover decreased with increasing stream size from a high of 73 percent for headwaters to a low of 60 percent for great rivers (Figure 5). Development showed the opposite pattern from natural cover, increasing from a low of 9 percent for headwaters to a high of 26 percent for great rivers. The percent of agricultural cover had a narrow range of variation across stream sizes, from a high of 18 percent for headwaters to a low of 14 percent for great rivers.

Figure 4. Acres of riparian buffer (100m) by secured land status.



	Headwater	Creek	Small River	Medium Tributary River	Medium Mainstem River	Large River	Great River	Mid-Atlantic Total	New England & New York Total	Region Total
Total Secured	1,198,760	931,137	224,982	104,196	38,110	21,023	16,929	1,240,674	1,294,461	2,535,136
GAP 3 Total	831,837	624,552	144,648	64,187	24,700	12,664	10,153	889,463	823,277	1,712,740
GAP1&2 Total	366,924	306,585	80,334	40,009	13,410	8,359	6,776	351,212	471,184	822,396

Map 2. Amount of secured riparian buffer by small watersheds.

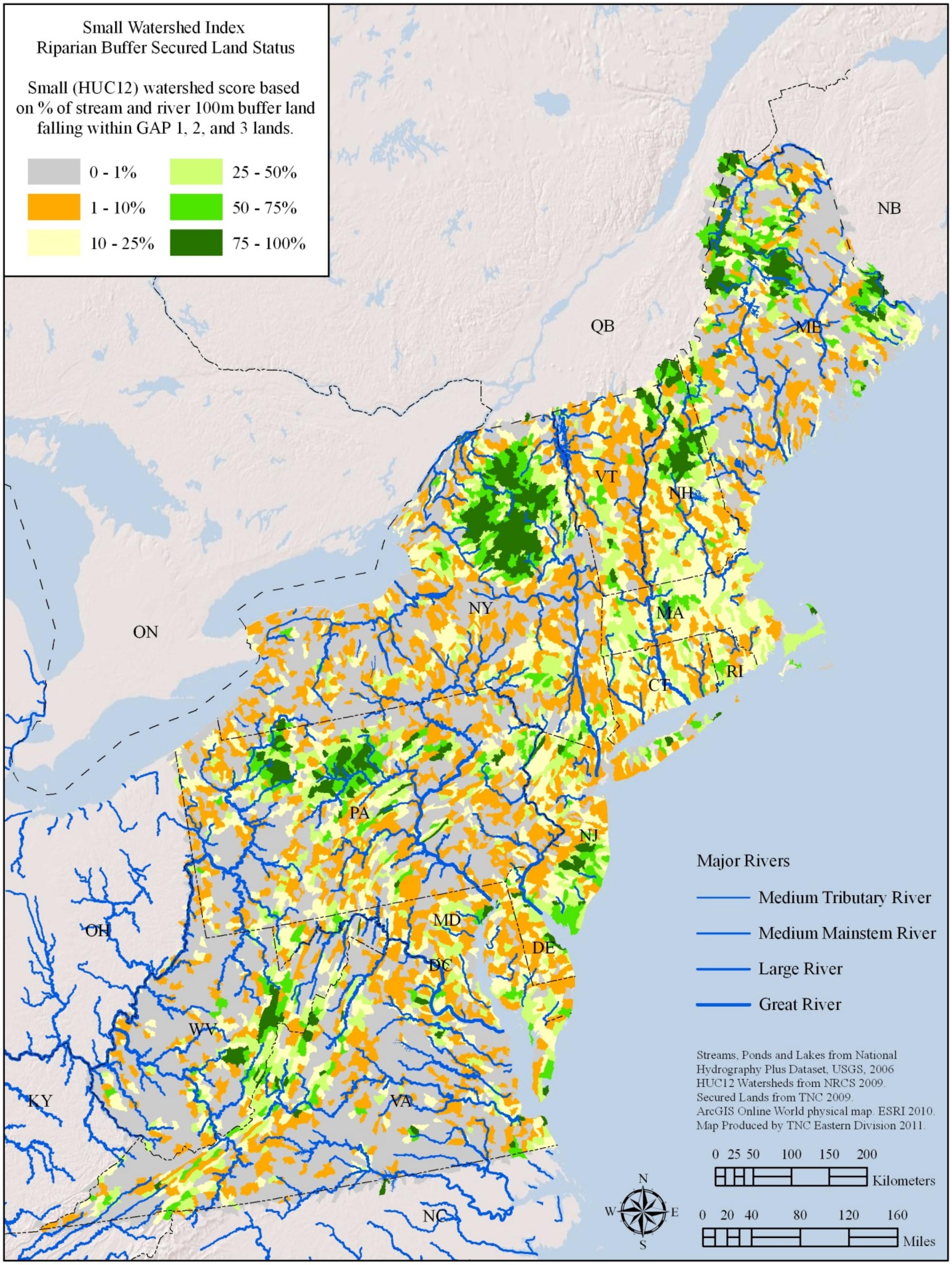
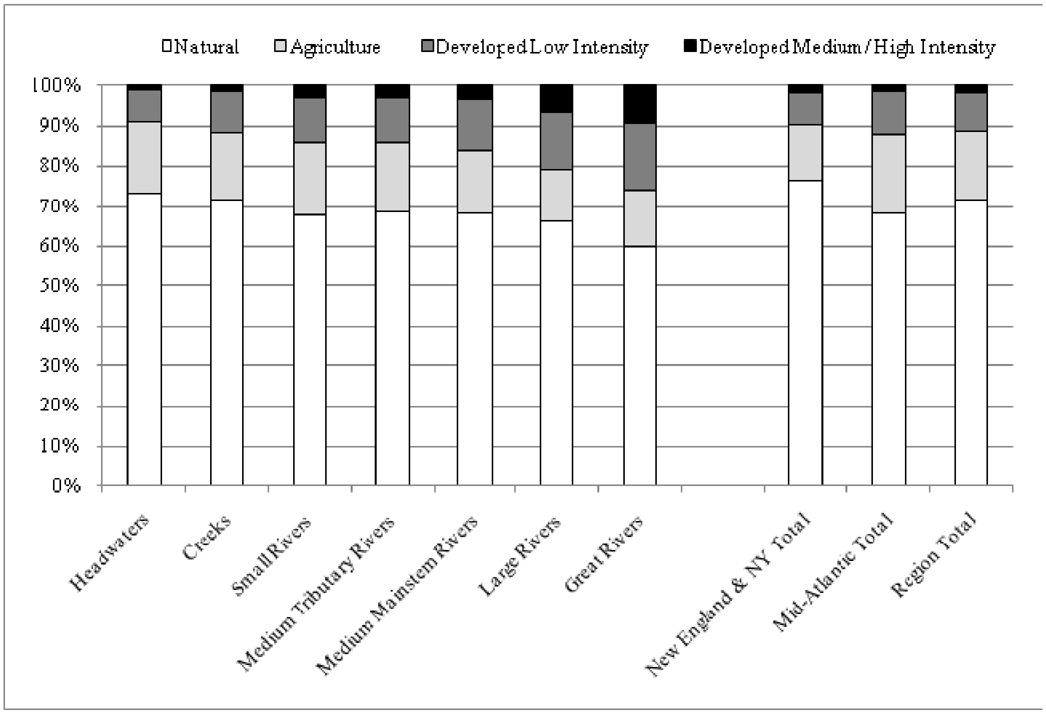


Figure 5. Percent of riparian buffer by land use type .



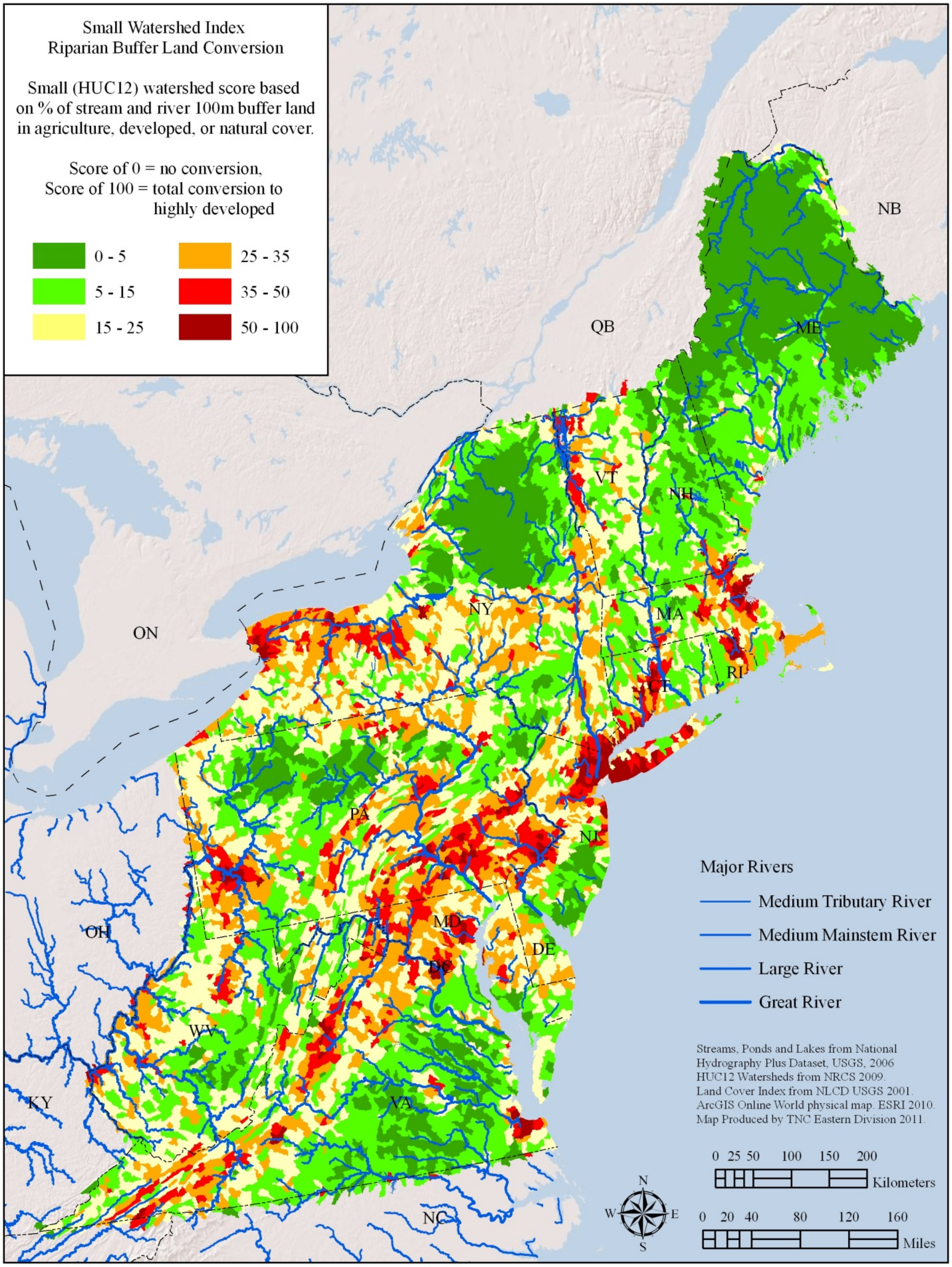
To see the spatial distribution of riparian buffer impacts, we developed a summary small watershed index. For each HUC12, we transformed the land cover information into a numeric impact index by summing the percent of development and agriculture in the buffer zone, and weighting the effect of high intensity development twice as much as of agriculture:

> *Impact = 0.5 * % agriculture + 0.75* % low intensity development+ 1.0* % high intensity development* (NLCD cover classes 81/82, 21/22, 23/24).

The impact index ranged from 100 for a watershed with its buffer zone totally developed to 0 where the buffer zone was completely within natural cover types. The results showed concentrations of highly impacted watersheds near the coast and in lower elevations where development and agriculture were more prevalent (Map 3).

<u>Conversion versus Securement:</u> To understand how the amount of conversion in the riparian buffer related to the amount of securement, we contrasted the amount of agriculture and developed land in this zone to the amount of land secured primarily for nature or secured for multiple uses. Across all streams and rivers, conversion exceeded securement 2:1, with 28 percent of the area converted and 14 percent secured (Figure 6, Table 2). This pattern was similar across all stream and river size classes, conversion always exceeding securement, and ranging from 1.8 times higher in headwater streams, to 2.6 times higher in medium mainstem rivers. Great rivers had the smallest discrepancies, but also had both the highest percent conversion (37 percent) and the largest proportion of their riparian buffers secured (18 percent). Small rivers, medium tributary rivers, and large rivers, ranged from 30-32 percent converted, with conversion averaging 2.4 times the amount of securement (Figure 6).

Map 3. Spatial distribution of riparian buffer impacts.



Conversion outweighed securement in both subregions, with New England and New York having smaller discrepancies (Figure 6). These ranged from almost equal percentages in great rivers, to conversion being almost four times greater than securement in large rivers, with an overall total ratio of conversion to securement of 1.3. Mid-Atlantic discrepancies ranged from 2:1 for large rivers to 3:1 for small rivers, with a slightly higher overall total ratio of conversion to securement of 2.5. Given that the two subregions had similar amounts of conversion in large river riparian buffers (29-32 percent), the Mid-Atlantic had much smaller discrepancies in the amounts of conversion and securement (2:1 vs. 4:1) indicating a better balance of conversion with securement on large rivers. For the smaller river and stream sizes, the Mid-Atlantic has both more conversion than New England and New York, (30-33 percent vs. 21-30 percent) and less securement (11-12 percent vs. 15-18 percent).

In all rivers and streams with catchments smaller than 1000 sq mi., conversion to agriculture was more prevalent than conversion to development. This pattern reversed in rivers with catchments over 3,861 (large and great rivers) which had more development than agriculture in their riparian buffers (Figure 6, Table 2).

Figure 6. Percent conversion to agriculture or development compared with the current securement status of riparian buffer. Based on a 100 m buffer area around each stream or river, each bar represents 100 percent of area assessed. Area to the left of the "0" axis indicates acreage of non secured land converted to development or agriculture, to the right is remaining natural area and secured land.

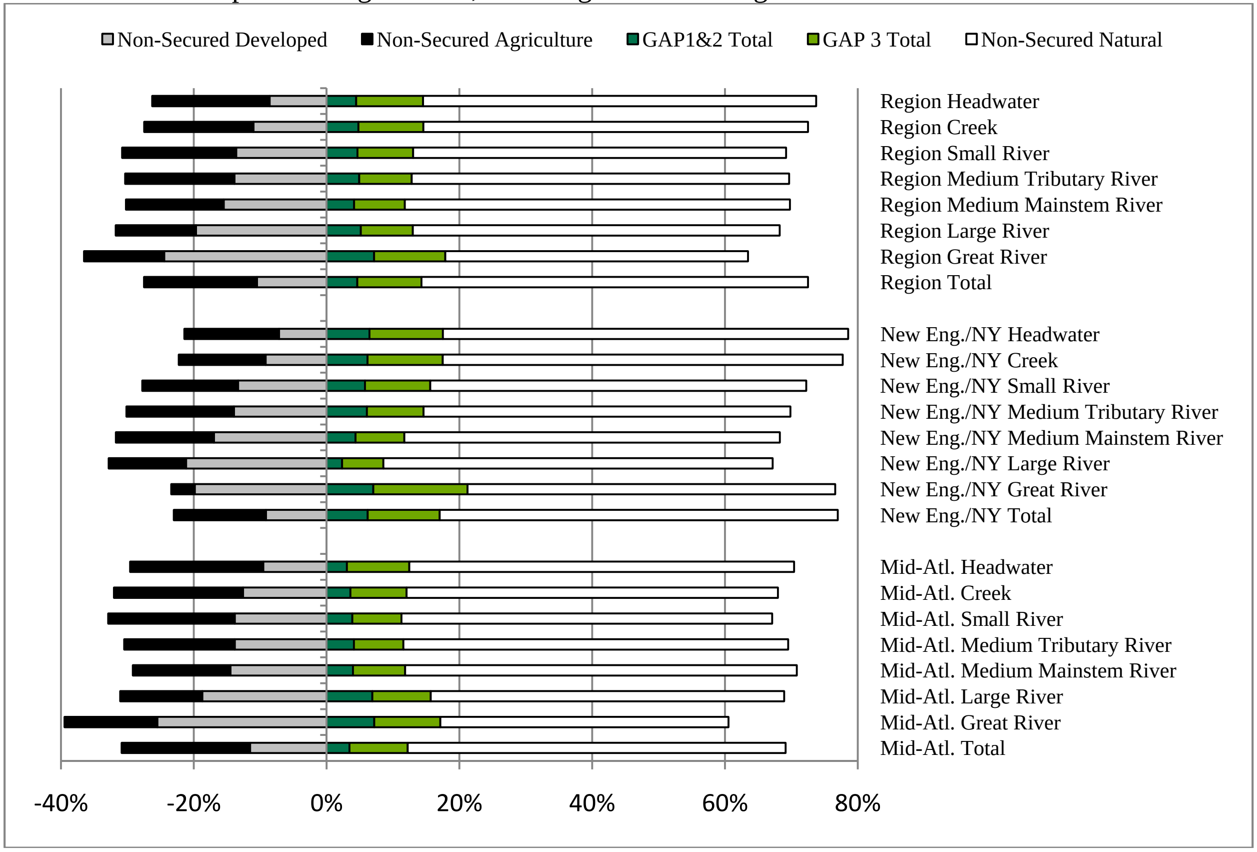


Table 2. Land use and conservation status of the riparian buffer area for all rivers and streams in the region. The units are acres in the 100 m riparian buffer. State by state details are in appendix 7-1.

		Acres Agriculture	%	Acres Developed	%	Acres GAP1&2	%	Acres GAP 3	%	Acres Non-Secured Natural	%	Total Acres	% converted	% secured	CRI-S ratio of converted / secured
Region	Headwater	1,458,379	18%	706,624	9%	366,924	4%	831,837	10%	4,881,868	59%	8,245,632	26%	15%	1.8
	Creek	1,052,323	16%	702,137	11%	306,585	5%	624,552	10%	3,699,379	58%	6,384,975	27%	15%	1.9
	Small River	295,925	17%	234,845	14%	80,334	5%	144,648	8%	968,222	56%	1,723,974	31%	13%	2.4
	Medium Tributary River	133,780	16%	112,794	14%	40,009	5%	64,187	8%	461,930	57%	812,701	30%	13%	2.4
	Medium Mainstem River	47,609	15%	50,104	15%	13,410	4%	24,700	8%	187,619	58%	323,443	30%	12%	2.6
	Large River	19,569	12%	31,801	20%	8,359	5%	12,664	8%	89,429	55%	161,822	32%	13%	2.4
	Great River	11,419	12%	23,132	24%	6,776	7%	10,153	11%	43,137	46%	94,616	37%	18%	2.0
Region Total		3,019,004	17%	1,861,437	10%	822,396	5%	1,712,740	10%	10,331,585	58%	17,747,162	27%	14%	1.9
Mid-Atlantic	Headwater	977,376	20%	465,611	10%	149,094	3%	458,919	9%	2,825,400	58%	4,876,401	30%	12%	2.4
	Creek	663,159	19%	429,377	13%	122,804	4%	288,053	8%	1,908,672	56%	3,412,064	32%	12%	2.7
	Small River	194,238	19%	141,008	14%	39,543	4%	75,392	7%	569,127	56%	1,019,308	33%	11%	2.9
	Medium Tributary River	79,424	17%	66,018	14%	19,641	4%	35,519	7%	276,583	58%	477,186	30%	12%	2.6
	Medium Mainstem River	28,168	15%	27,781	14%	7,655	4%	15,052	8%	113,171	59%	191,827	29%	12%	2.5
	Large River	12,401	12%	18,800	19%	6,921	7%	8,838	9%	53,420	53%	100,380	31%	16%	2.0
	Great River	10,804	14%	19,685	25%	5,554	7%	7,689	10%	33,524	43%	77,256	39%	17%	2.3
Mid-Atlantic Total		1,965,570	19%	1,168,279	12%	351,212	3%	889,463	9%	5,779,897	57%	10,154,421	31%	12%	2.5
New England & New York	Headwater	481,003	14%	241,014	7%	217,829	6%	372,917	11%	2,056,468	61%	3,369,231	21%	18%	1.2
	Creek	389,164	13%	272,760	9%	183,781	6%	336,499	11%	1,790,707	60%	2,972,911	22%	18%	1.3
	Small River	101,688	14%	93,837	13%	40,791	6%	69,255	10%	399,095	57%	704,666	28%	16%	1.8
	Medium Tributary River	54,356	16%	46,776	14%	20,368	6%	28,668	9%	185,348	55%	335,515	30%	15%	2.1
	Medium Mainstem River	19,442	15%	22,323	17%	5,755	4%	9,648	7%	74,448	57%	131,615	32%	12%	2.7
	Large River	7,168	12%	13,002	21%	1,438	2%	3,826	6%	36,009	59%	61,442	33%	9%	3.8
	Great River	615	4%	3,447	20%	1,222	7%	2,464	14%	9,613	55%	17,360	23%	21%	1.1
New England & New York Total		1,053,434	14%	693,158	9%	471,184	6%	823,277	11%	4,551,688	60%	7,592,741	23%	17%	1.3

Fragmentation and Flow

Impervious Surfaces: Impervious surfaces are substrates, like asphalt or concrete, incapable of being penetrated by water. Watersheds with reduced infiltration of rainwater tend to have more frequent and erosive flooding, and this contributes to increases in stream temperature, increases in sediment loads, and a reduction in structural habitat. Chemical pollution also tends to be higher in areas with an abundance of roads, parking lots, and houses.

All indicators of stream quality relative to biotic condition, hydrologic integrity, and water quality, decline with increasing watershed imperviousness. Current research suggests that aquatic systems become very seriously impacted when watershed impervious cover exceeds 10% (CWP 2003) and show significant declines in many stream taxa at much lower levels of impervious surface. For example, numerous declining species have been documented between 0.5 and 2% imperviousness, with 40-45% declines in regional stream biodiversity (invertebrates, fish, amphibians) at imperviousness greater than 2-3% (King and Baker 2010) based on the National Land Cover Impervious Dataset (Yang et al. 2002).

To examine impervious surface in the region, we summarized the amount of impervious cover for the upstream watershed of each stream reach using the National Land Cover Impervious Surface Dataset (Yang et al. 2002). We grouped each stream and river reach in the region into one of four impact categories guided by the thresholds found in King and Baker (2010). These categories match the categories used in the lake chapter:

- Class 1: Undisturbed: 0 < 0.5 percent impervious.
- Class 2: Low impacts: 0.5-2 percent impervious.
- Class 3: Moderately impacted: >=2-10 percent impervious.
- Class 4: Highly impacted: >=10 percent impervious.

The results revealed that 58 percent of stream and river miles in the region were undisturbed by impervious surface impacts, and 28 percent were in the low impact class. Conversely, 11 percent were in the moderately impacted class, and 4 percent were in the highly impacted class (Figure 7). The Mid-Atlantic and the New England and New York subregions both had 4 percent of their stream and river miles in the highly impacted class; however, the Mid-Atlantic had a lower percentage of streams and rivers in the undisturbed class.

The percent of undisturbed stream miles decreased with increasing stream size. This ranged from a high of 62 percent in headwater streams to a low of 0 percent in great rivers (Figure 7, Table 3). For rivers, the percent in the undisturbed class decreased with increasing river size: 45 percent for small rivers, 36 percent for medium rivers, 11 percent for large rivers, and 0 percent for great rivers. Conversely, the percent of streams in the highly impacted class was the same across headwaters, creeks, and small rivers (4 percent) and then decreased in larger rivers, probably due to the fact that their watersheds were so huge that the effects of impervious surfaces in one area may be offset by the presence of natural cover in another part of the huge drainage area.

Figure 7. Impervious surfaces classes by percent of stream miles.

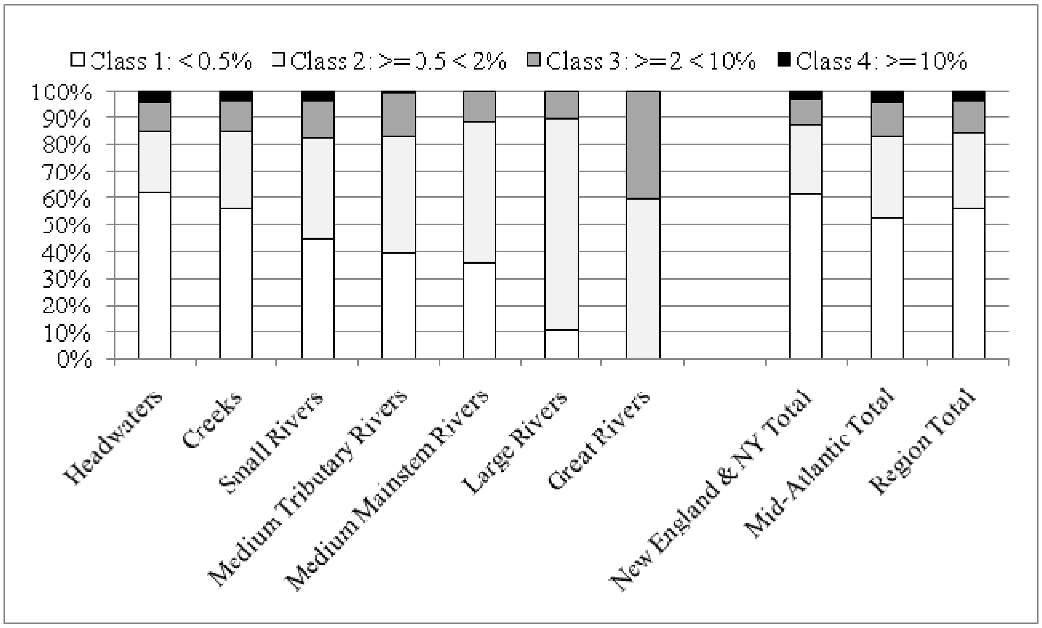


Table 3. Percent of stream miles by upstream impervious surface class.

Region	Size	Undisturbed: < 0.5%	Low: 0.5 < 2%	Moderate: 2 < 10%	High: >= 10%
	Headwaters	62%	23%	10%	4%
	Creeks	57%	28%	11%	4%
	Small Rivers	45%	37%	14%	4%
	Medium Tributary Rivers	40%	43%	16%	1%
	Medium Mainstem Rivers	36%	53%	11%	0%
	Large Rivers	11%	79%	10%	0%
	Great Rivers	0%	60%	40%	0%
Region Total		56%	28%	11%	4%
Mid-Atlantic	Headwaters	60%	24%	11%	5%
	Creeks	51%	31%	13%	5%
	Small Rivers	41%	38%	18%	3%
	Medium Tributary Rivers	36%	45%	18%	1%
	Medium Mainstem Rivers	24%	61%	15%	0%
	Large Rivers	1%	94%	5%	0%
	Great Rivers	0%	58%	42%	0%
M-A Total		53%	30%	13%	4%
NE & New York	Headwaters	65%	21%	9%	4%
	Creeks	63%	26%	9%	3%
	Small Rivers	51%	36%	10%	4%
	Medium Tributary Rivers	44%	41%	13%	2%
	Medium Mainstem Rivers	52%	41%	6%	0%
	Large Rivers	25%	57%	18%	0%
	Great Rivers	0%	70%	30%	0%
NE & NY Total		61%	26%	9%	4%
Grand Total		56%	28%	11%	4%

To see the spatial distribution of impervious impacts, we combined the impact classes into an index of impervious surfaces for watersheds. For each small watershed (HUC12), we calculated the miles of streams and rivers in each impact category and then summed them using the following weighting scheme:

Impact score = 1 (%Class 1) + 2* (%Class 2) + 3* (% Class 3) + 4* (%Class 4).*

This resulted in scores that ranged from 400 for a watershed where all stream and river miles were in the high impact class to a low of 100 where all streams and river miles were in the undisturbed class (Map 4). Results showed concentrations of highly impacted watersheds near the coast and within the urban and suburban fringe of existing cities.

Stream Barriers: Dams and improperly designed culverts alter the structure and function of a river as it is transformed from a continuous free-flowing system into segments separated by barriers and impoundments. In addition to creating migration barriers, dams cause a series of changes downstream and upstream from the impoundment. These include changes in: flow velocity and timing, oxygen levels, temperature, water clarity, and physical habitat.

The size, purpose, and operation of dams influence their impact on river systems. Hydroelectric dams store large quantities of water and replace a stream’s natural hydrology with artificial flow regimes designed to meet daily and seasonal energy demands. Flood control dams collect and store water during floods and gradually release it after storm events. Water supply dams maintain large stores of water in a reservoir with a variety of release management practices. Recreational dams create impoundments within a river or maintain a constant high water level within a natural lake. Tailings dams hold the materials left over from the mining process. Low stature “run-of-the-river” dams are less disruptive of natural flow regimes because they release water at the same rate as it enters the impoundment. In general, the storage capacity of dams is highly correlated with measures of hydrologic alteration, and dams that retain larger amounts of water are thus agents of greater hydrologic alteration in the system.

To assess the extent and distribution of dams, we used a new regional dataset compiled by The Nature Conservancy for the Northeast Regional Aquatic Connectivity Assessment Project. This dataset combines the National Inventory of Dams barriers (dams over 6 ft high or storing 50 acre-feet) with state-based inventories of smaller dams. In all, this region (and this dataset) contains 28,103 dams, with 14,034 of those on streams with drainage areas greater than 1 square mile. Surprisingly, then, half the dams in the region were found on very small headwater creeks and pond systems, many of which are not perennial water bodies consistently mapped at the 1:100,000 scale.

We focused our analysis only on the 14,034 dams on streams with drainage areas over 1 square mile, and ignored the dams on smaller streams. The focal dams had a variety of primary purposes, the most common types being recreational dams followed by water supply, hydroelectric, and flood control dams. The northern subregion had a higher percentage of hydroelectric and fish and wildlife dams than the Mid-Atlantic, which had a higher percentage of tailings dams. Otherwise, the two subregions were relatively similar (Figure 8). The highest dams in the region were flood control, followed by water supply, hydroelectric, and recreational. Hydroelectric dams had the highest normal and maximum storage capacity and recreational dams the lowest, while flood control dams have a large difference between normal and maximum storage, with their maximum storage being almost three times their normal storage (Figure 9).

Map 4. Index of impervious surfaces for small watersheds.

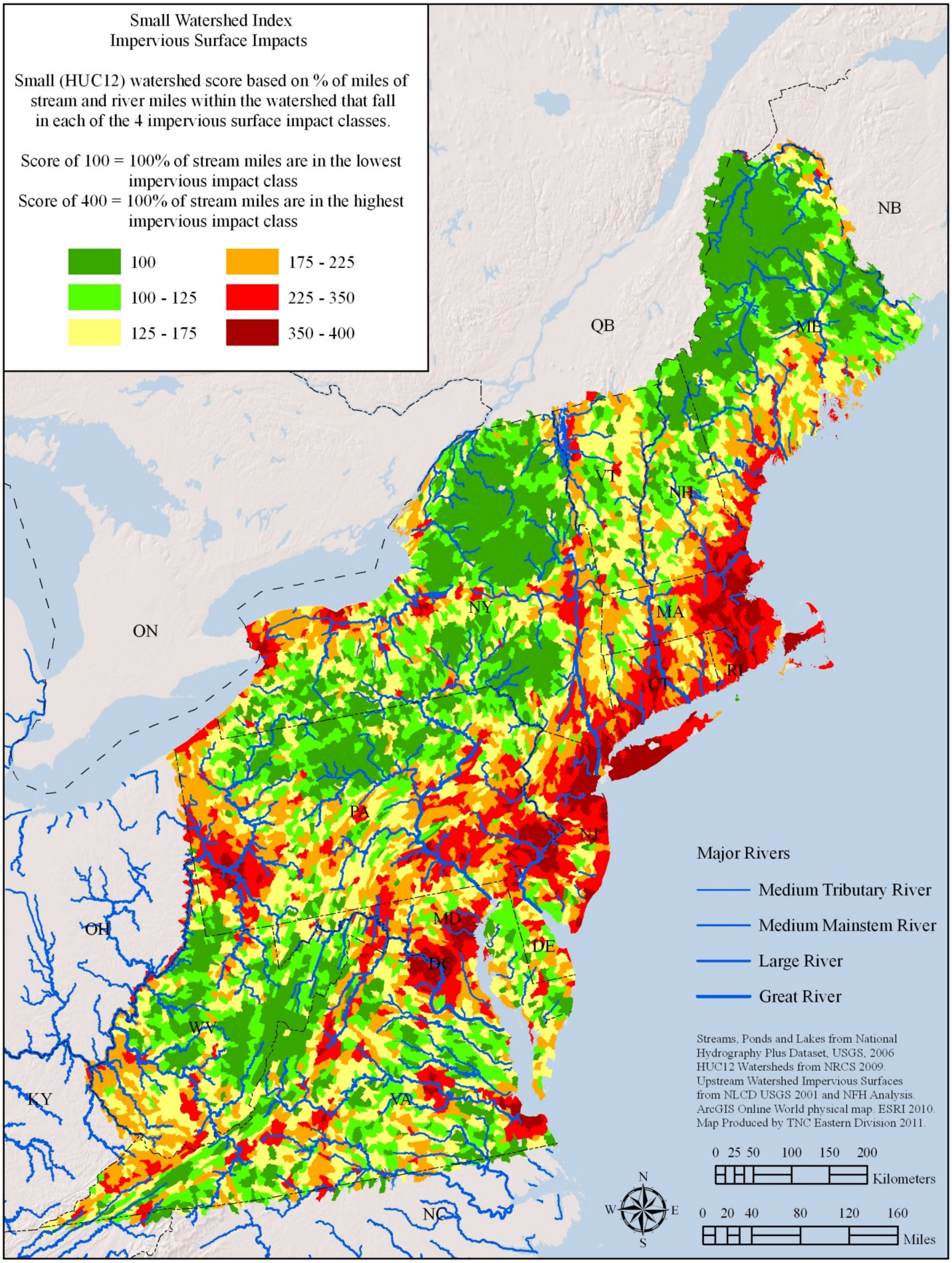
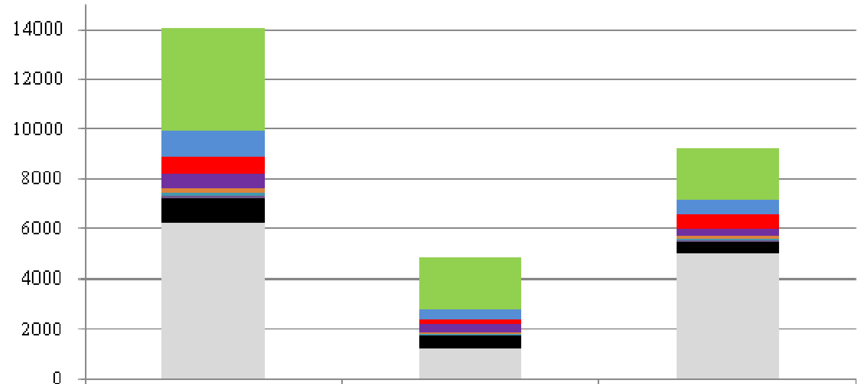
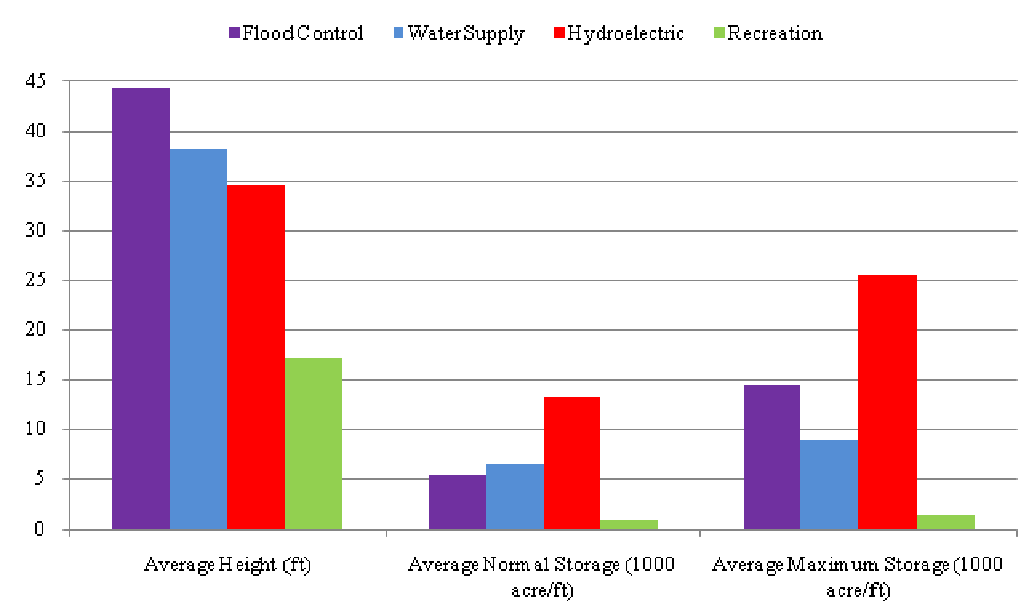


Figure 8. Number and type of dams on streams with a drainage area over 1 square mile.



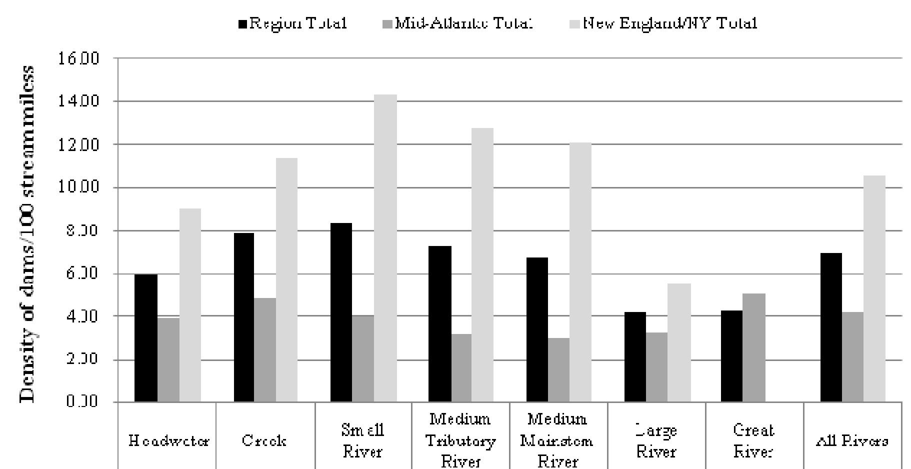
	Region	Mid-Atlantic	New England
Total	14034	4837	9197
Recreation	4105	2102	2003
Water Supply	1034	401	633
Hydroelectric	668	110	558
Flood Control	636	341	295
Irrigation	172	91	81
Navigation	85	34	51
Fish and wildlife pond	75	8	67
Tailings	44	42	2
Other	994	504	490
Unknown	6221	1204	5017

Figure 9. Average height and storage characteristics of dams sorted by primary purpose.



On average, there were 7 dams for every 100 miles of streams and rivers in the region. The density of dams in the northern subregion was 2.5 times the density in the Mid-Atlantic (Figure 10). The density of dams was highest on small rivers, 8 per 100 stream miles, and was even higher in the New England and New York subregion with 14 per 100 stream miles. In the Mid-Atlantic, the dam density was highest on the small creeks and great rivers (5 per 100 stream miles). Hydroelectric dams had their highest density on medium and large rivers, while the density of recreational dams was highest in the headwaters and creeks (Figure 11). The small watersheds (HUC 12) with the highest dam density are in Rhode Island, Connecticut, Massachusetts, New Jersey, and southern New York; these watersheds have over 25 dams per 100 stream-miles (Map 5).

Figure 10. The density of dams on streams and rivers. The chart shows the number of dams per 100 stream-miles and arranged by stream size class.



	Headwater	Creek	Small River	Medium Tributary River	Medium Mainstem River	Large River	Great River	All Rivers
Region Total	5.96	7.84	8.33	7.25	6.74	4.20	4.21	6.94
Mid-Atlantic Total	3.88	4.84	3.97	3.23	2.93	3.27	5.08	4.18
New England/NY Total	8.99	11.36	14.23	12.74	12.13	5.54	0.00	10.62

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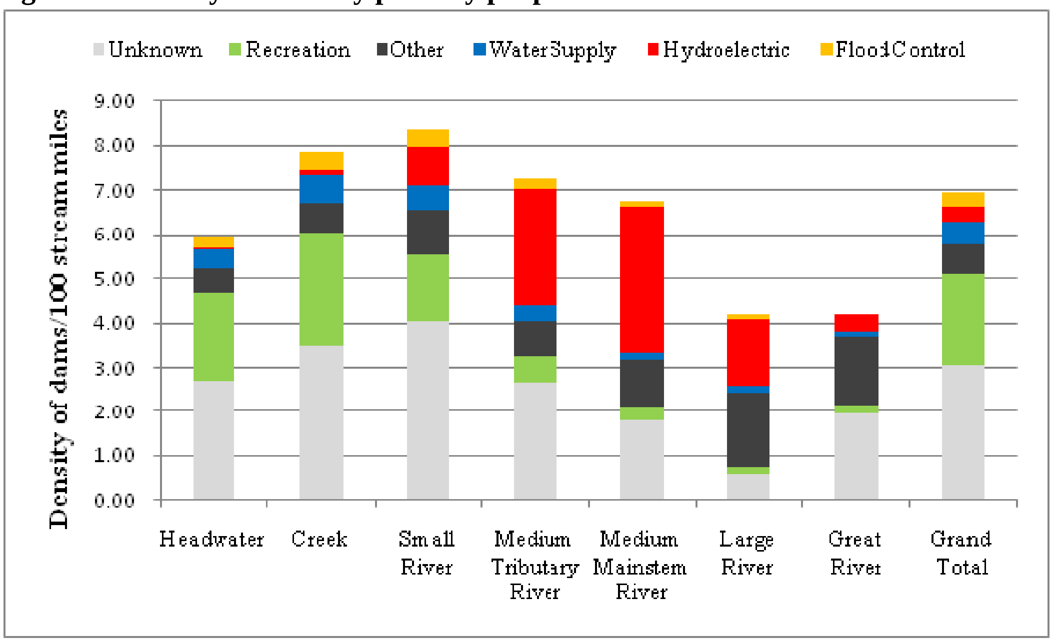
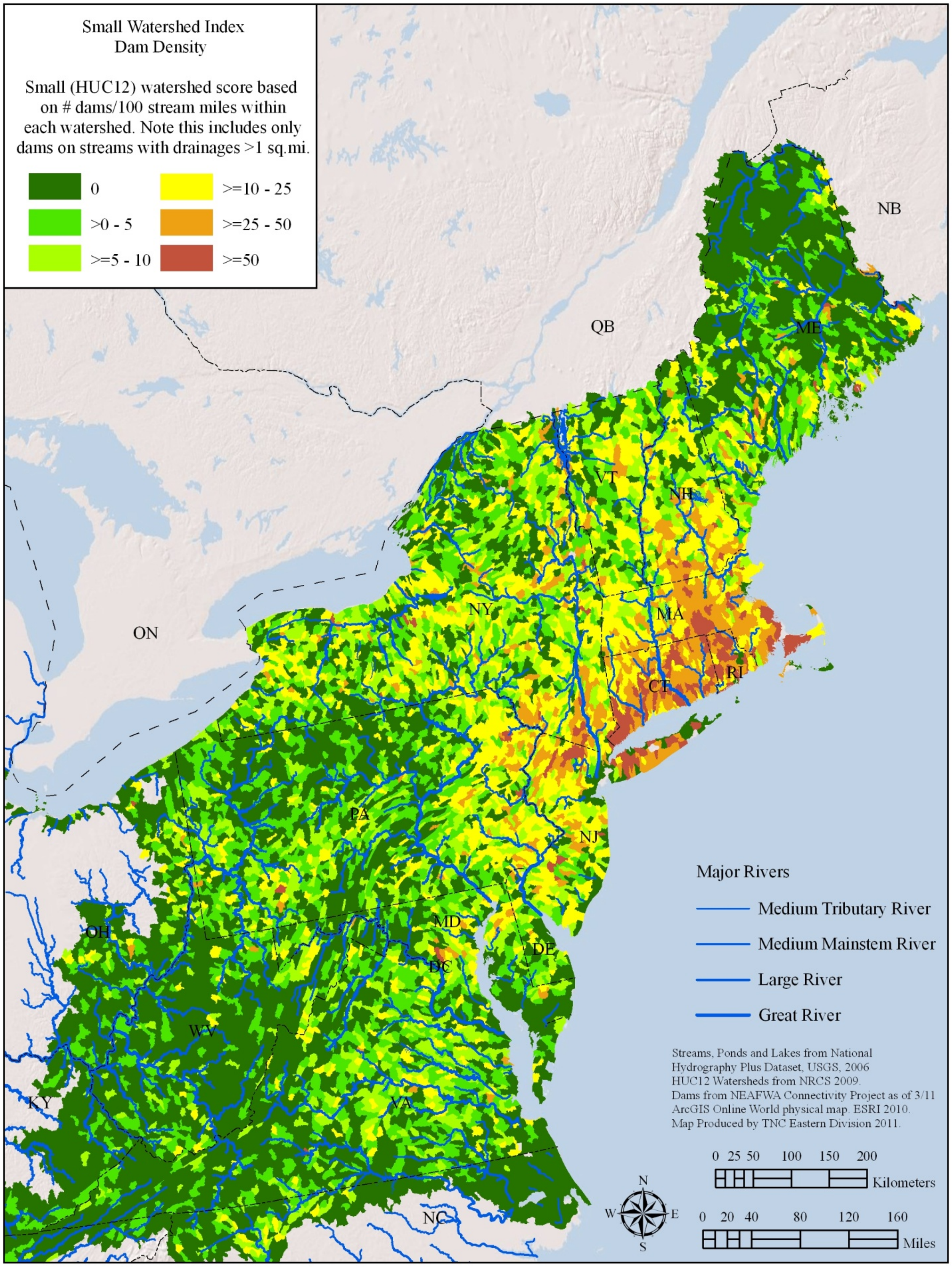
Figure 11. Density of dams by primary purpose and river size class.



Map 5. Dam density in small watersheds.



The region's streams are also fragmented by impassable culverts at thousands of road-stream crossings. On larger streams, road crossings are usually facilitated by bridges and are less obstructive to fish passage, but many culverts installed at small stream crossings act as partial to total barriers at certain times of the year. A simple count of the number of road-stream crossings on headwaters and creeks amounted to 177,801 (not including crossings at 4-wheel drive trails and other trails), although it was not possible to determine how many of these had impassable culverts. This translates to an overall density of 106 crossing per 100 miles of headwaters and creeks (Table 4.). Road crossing density ranged from a low of 89 crossings per 100 creek miles in New England and New York to a high of 118 crossing per 100 headwater miles in the Mid-Atlantic. When combined with the 7 dams per 100 stream miles, these numbers are sobering. Further work is necessary to determine which of these culverts are currently acting as full or partial barriers, and which could be retrofitted to improve passage.

<u>Connected Stream Networks:</u> The length of connected stream and river networks in the region has been profoundly changed by dams and impassable culverts. Stream barriers impact both resident species that move within the freshwater network, and diadromous species that move between freshwater streams and the ocean. Diadromous species in the northeast that have suffered from reduced access to spawning and nursery habitats include Atlantic salmon, American shad, alewife, blueback herring, Atlantic sturgeon, shortnose sturgeon, rainbow smelt, and American eel.

Resident fishes also move extensively throughout the freshwater network, to access seasonal habitats for feeding and spawning, to find refuge during times of stress, and to colonize new areas. Some species of trout and sucker, for example, regularly move 1 to 10 km within a stream network to spawn. Barriers to upstream re-colonization after a catastrophic event can fragment and isolate populations resulting in local extinctions. These impacts disproportionally affect rare species and they may have a cascading effect on other species. For instance, barriers have been implicated in the decline of freshwater mussels because the parasitic larval stage of most freshwater mussels requires a fish as a host. Thus, the blockages that fragment the host fish populations end up isolating the freshwater mussel populations also, leading to local extinctions. The distribution of the federally endangered dwarf wedgemussel (*Alasmidonta heterodon*) in certain streams is confined to stream reaches below blockages, suggesting that impediments to the upstream movement of host fishes restrict the mussels to downstream habitats.

To evaluate change in the length and distribution of the region's functionally connected stream networks in the region, a connected stream network data layer was created in GIS. One version –historic connectivity – was built by linking all existing streams that connect to each other, using only major waterfalls to split the network; a theoretically dam-free system (Map 6). A second version – current connectivity – was created using dams in addition to waterfalls to split the network (Map 7). In both cases, the emergent connected networks were bounded by fragmenting features (falls or dams) and/or the topmost extent of headwater streams (Figure 12). This allowed us to measure the length of every network between fragmenting features. Our intent was to quantify the distance that a fish or aquatic animal could

Table 4. Number and density of road-stream crossings on headwaters and creeks.

	# Road Crossings on Headwaters	# Road Crossings on Creeks	Total # of Road Crossings on Headwaters and Creeks	Density of Road Crossings on Headwaters/100 stream miles	Density of Road Crossings on Creeks/100 stream miles	Density of Road Crossings on Headwaters and Creeks/100 stream miles
Mid-Atlantic	64,802	44,252	109,054	118	109	114
New England & New York	37,778	30,969	68,747	100	89	95
Region Total	102,580	75,221	177,801	111	100	106

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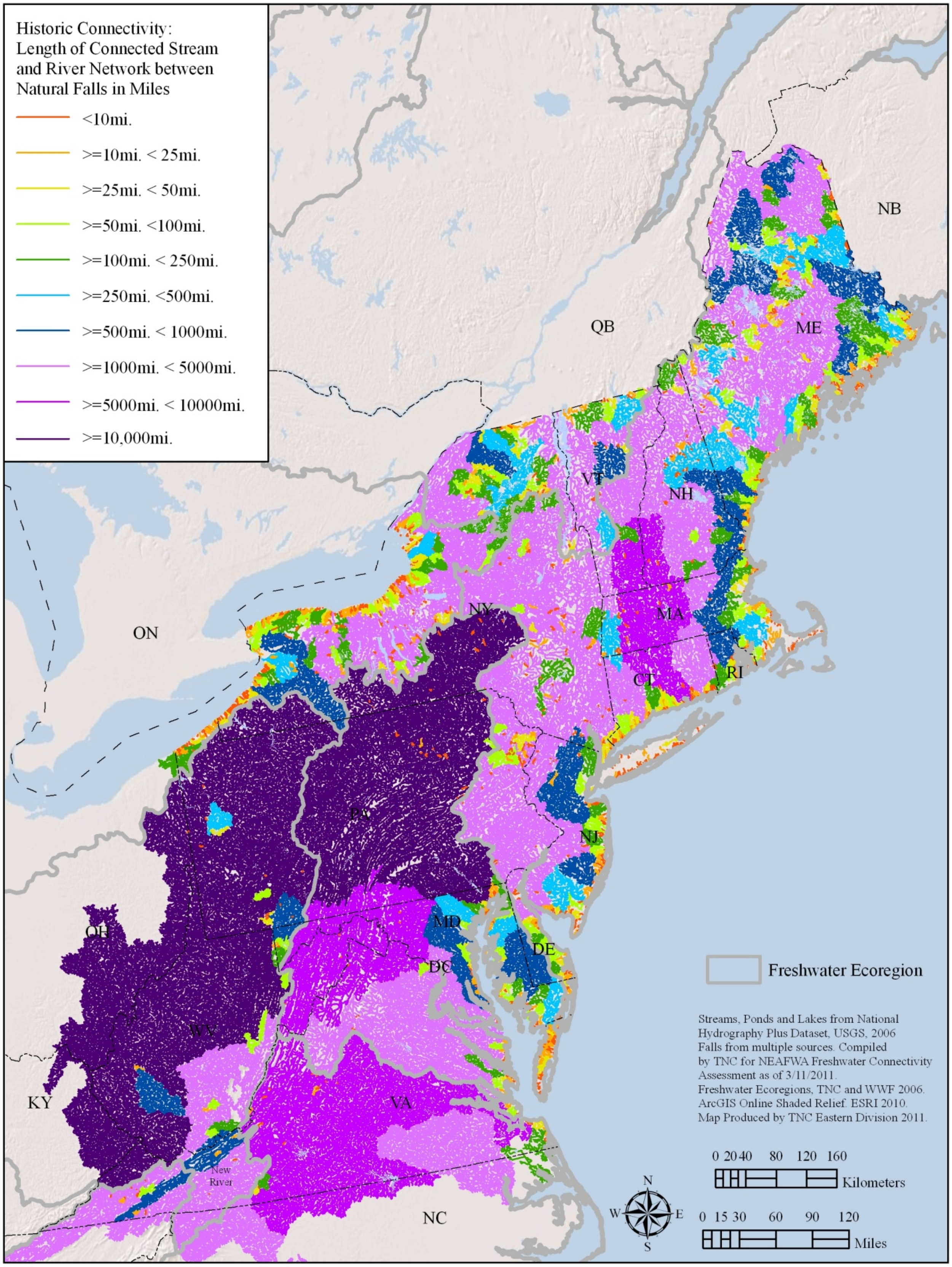
Map 6. Historic connectivity.



Map7. Current connectivity.

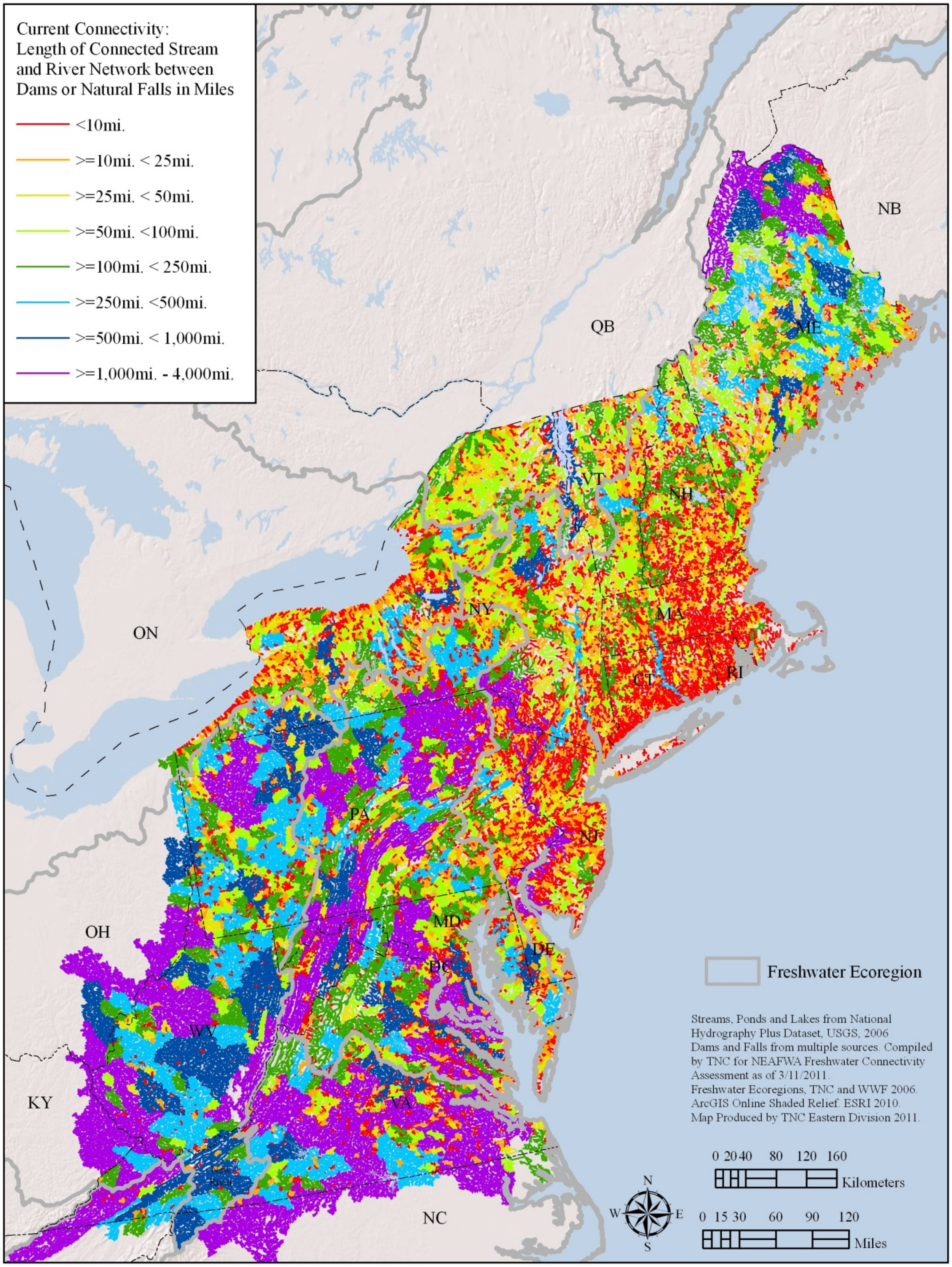
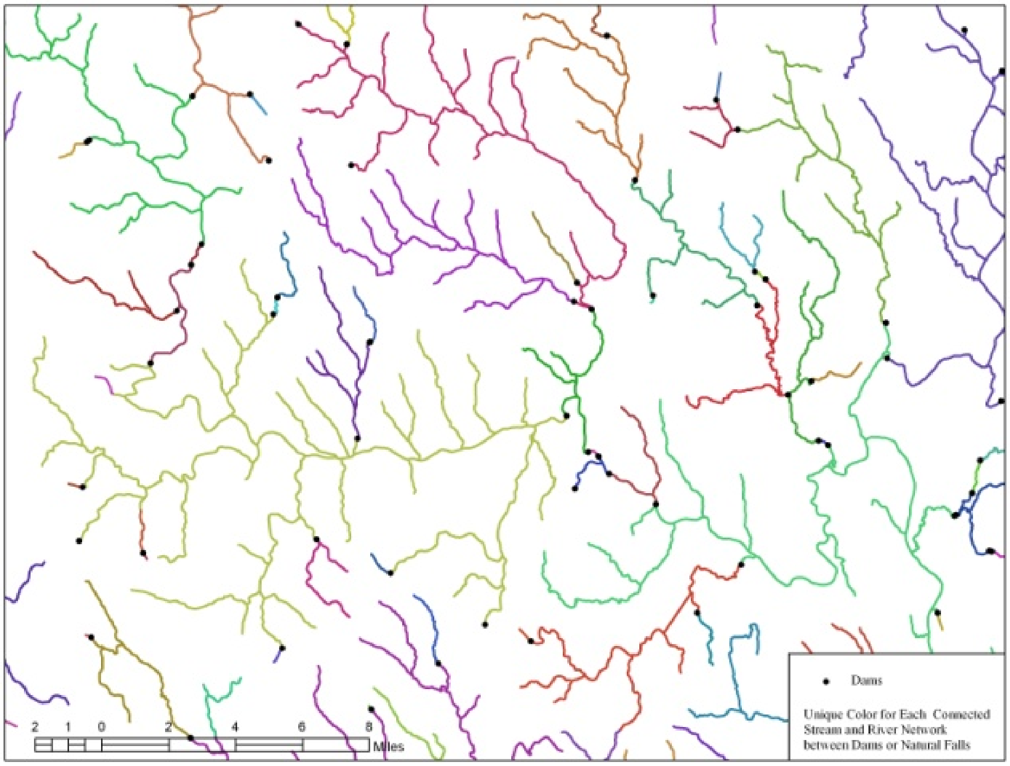
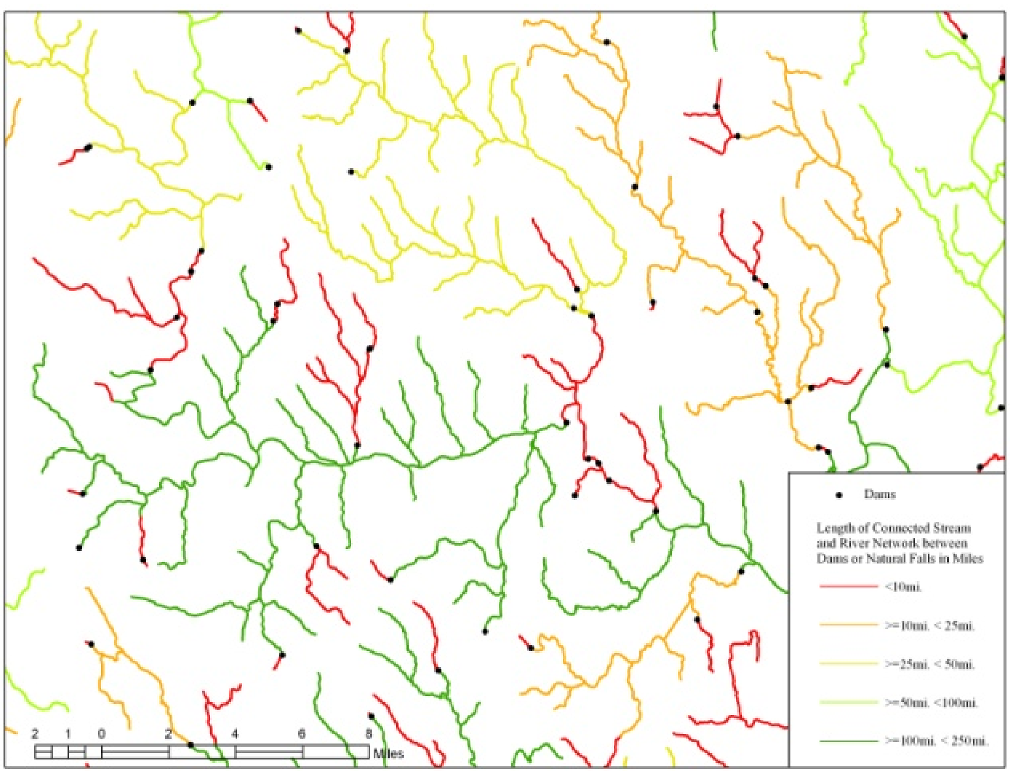


Figure 12 (a, b). Example of functionally connected stream networks. Each network is bounded by dams and/or the topmost extent of headwater streams.

a: Unique color for each connected network



b: Each connected network symbolized by its total connected length class.



move within until reaching one of these bounding features (Figure 12). Please remember that dams on small streams with less than a 1 square mile drainage area were omitted from this analysis due to the lack of consistency in their mapping, see detailed methods for more information.

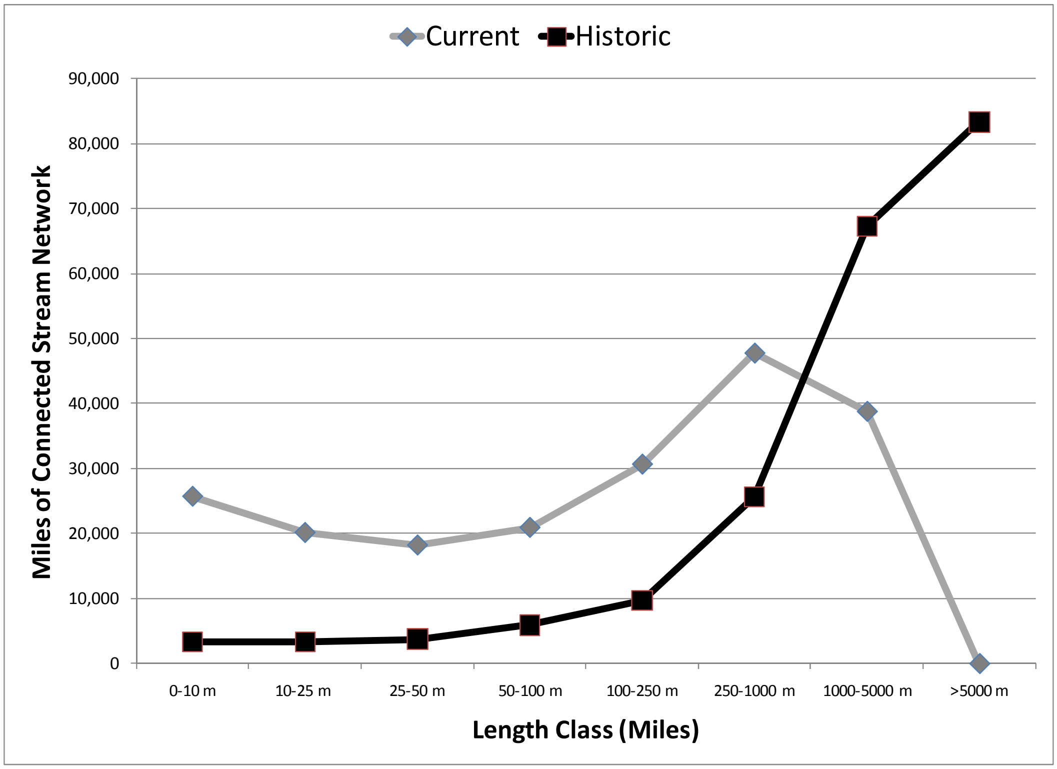
Comparing the current to the historic connected networks revealed a striking loss of large networks and a corresponding gain of smaller networks (Table 5, Figure 13, Map 6 and 7). Historically 83 percent of stream miles were part of connected networks over 500 miles in length; currently only 29 percent of stream miles are in these large networks. Moreover, there are no longer any networks in the region larger than 5,000 miles, while historically 41 percent of all stream miles were in these very large networks. At the other end of the scale, historically only 3 percent of stream miles were in short networks of less than 25 miles, but currently these account for 23 percent of all stream miles in the region. The largest remaining connected network in the region, nearly 4,000 miles long, extends through much of the Upper Susquehanna and up into the West Branch Susquehanna drainages.

Results by subregion showed a similar pattern of network loss and gain, however the loss of large networks and gain of smaller networks was exaggerated in New England and New York region that now had 63 percent of its stream miles in networks under 100 miles and 10 percent in connected networks over 500 miles in length. In the Mid-Atlantic, 27 percent were in networks less than 100 miles long and 44 percent in larger connected networks over 500 miles long.

Table.: Length of stream miles within each functionally connected network size class

	Region		Mid-Atlantic		New England/New York	
Network Length Class	Current Miles	Historic Miles	Current Miles	Historic Miles	Current Miles	Historic Miles
1. <10mi.	25,715	3,375	9,469	1,074	16,246	2,301
2. >=10mi. <25mi.	20,151	3,278	7,339	1,220	12,811	2,057
3. >=25mi. <50mi.	18,217	3,762	6,169	866	12,048	2,896
4. >=50mi. <100mi.	20,992	5,915	8,083	2,293	12,909	3,623
5. >=100mi. <250mi.	30,657	9,680	15,862	2,384	14,795	7,297
6. >=250mi. <500mi.	27,106	8,424	18,220	2,049	8,886	6,374
7. >=500mi. <1000mi.	20,611	17,242	15,644	7,836	4,966	9,406
8. >=1,000mi. < 5,000mi.	38,759	67,221	34,823	27,198	3,936	40,024
9. >=5,000mi. <10,000mi.		28,644		23,257		5,387
10. >=10,000mi.		54,665		47,432		7,233
Grand Total	202,207	202,207	115,609	115,609	86,598	86,598

Figure 13. Distribution of stream miles within each connected network size class. The current and historical number of stream miles falling within each connected network size class is plotted by increasing network size. The chart shows a smooth increase in network sizes in the historic condition compared to the increase in small networks, and the loss of large network, in the current condition.



Flow Alteration: Flow is the essence of a stream, the "master variable" that structures the physical habitat both in the channel and on the adjacent floodplain. The natural timing, magnitude, and frequency of stream flow influences the evolutionary adaptations of river biota, and controls many physical and chemical processes. High flows shape the stream channel, move sediment, and deposit silt-laden floodwaters on adjacent floodplains, replenishing the soil, and creating feeding and nursery grounds for fish. Low flows define the smallest habitat area available to stream biota during the year, and many riparian and stream species have evolved to complete their life histories during periods when water is available.

Changes in flow can be caused by dams, water withdrawals, ground water pumping, changes in land cover, and changes in climate. Altered flow magnitudes are frequently linked to ecological impairment, and are the primary predictor of biological integrity for fish and macro-invertebrate communities. Diminished maximum flows are associated with significant changes in riverine ecosystem structure and have been implicated in the decline of many floodplain and riparian communities.

Only recently have data become available to assess alteration to stream flows across large geographic areas. In 2010, the USGS employed 2,888 stream gages throughout the coterminous U.S. to apply standardized indicators of alteration to minimum and maximum flows (Carlisle et al. 2010). Their methods utilized 27 years of data (1980-2007) to calculate mean annual minimum flows (7-day moving average) and mean annual maximum flows (daily average), and compare them to reference conditions. They used the ratio of observed conditions to expected conditions (O/E) as a standard metric to report on relative alterations. For this metric, gages were grouped into three categories: 1) *Inflated* = the O/E value was greater than 90 percent of those from reference sites (O/E value >=9), 2) *diminished* = O/E values were less than 90 percent of those from reference sites (O/E value <= 0.1), or 3) *unaltered* = the O/E value was within the above limits (O/E value 0.1 to 9.0). This analysis is conservative in terms of reporting only very large alterations to maximum or minimum flows, and does not attempt to detect other alteration to flow such as timing.

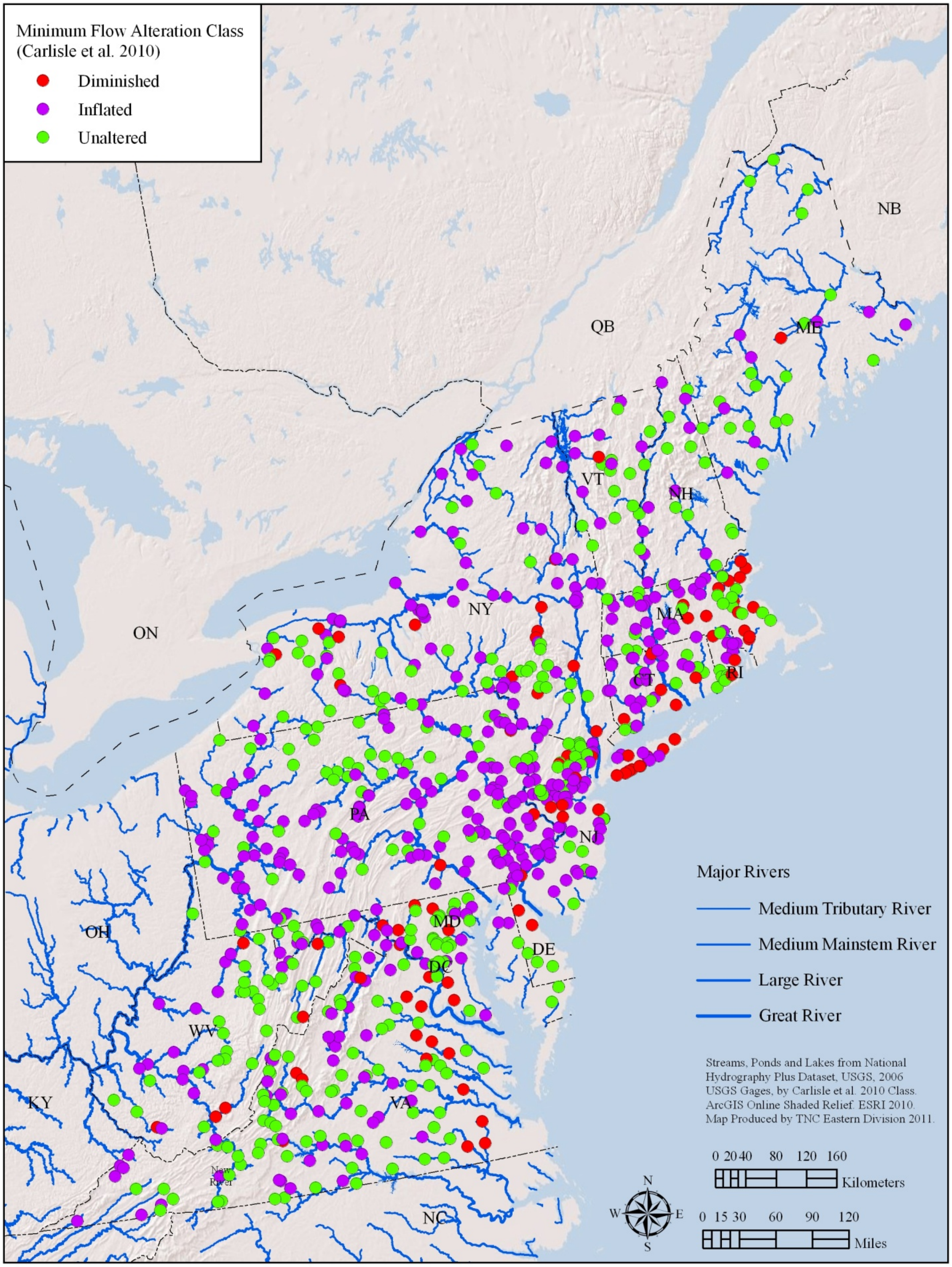
Results for the 807 gages in our region showed that 66 percent of the sites had either altered minimum flows, altered maximum flows, or both; 34 percent were unaltered (Table 6). Minimum flows were the most effected: 49 percent had inflated minimum flows, 11 percent had diminished minimums and 40 percent were unaltered (Map 8). The results for maximum flows indicated: 70 percent were unaltered, 24 percent had diminished maximums, and 6 percent had inflated maximums (Map 9). These overall patterns were similar between the two sub-regions; however, New England and New York had a higher percentage of diminished maximum flows (33 percent vs. 19 percent) and of diminished minimum flows (16 percent vs. 9 percent) than the Mid-Atlantic.

As streams increased in size, a smaller proportion of them were affected by diminished minimum flows and a larger percentage were affected by diminished maximum flows (Table 6, Figure 15). This suggest that diminished flows are more of a problem for our headwaters, creeks and small rivers, while diminished maximum flows are more of a problem in our medium to great rivers. Medium sized mainstem rivers were particularly affected by diminished maximum flows with over half of the samples showing diminished flows (56 percent), and 77 percent of the large and great rivers also showing diminished maximum flows.

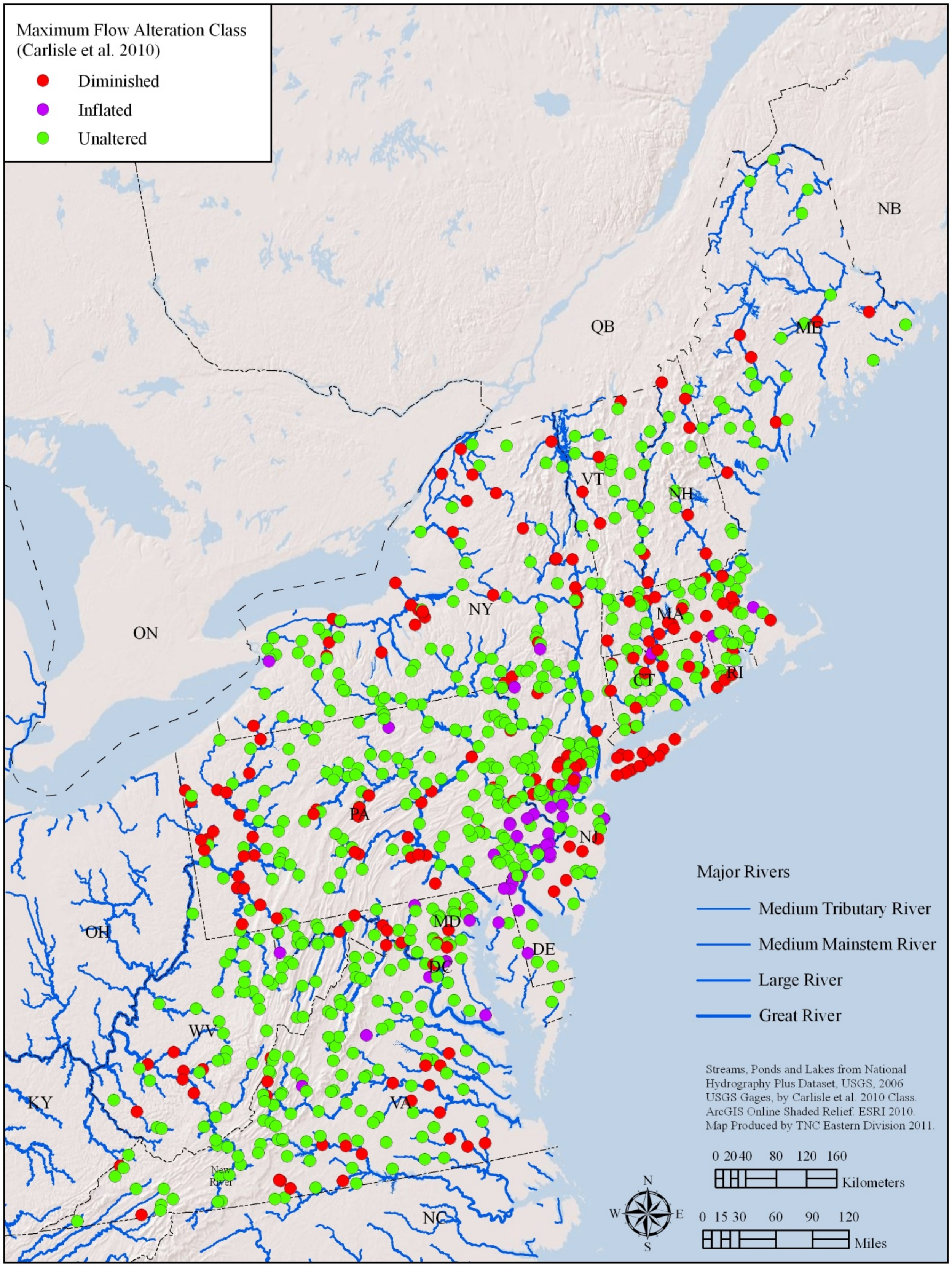
Table 6. Streams and rivers by size class, region or subregion, and flow alteration class.

		Minimum Flows			Maximum Flows		
	Number of Gages	%Diminished	%Inflated	%Unaltered	%Diminished	%Inflated	%Unaltered
Mid-Atl. Headwater	6	33%	17%	50%	17%	33%	50%
Mid-Atl. Creek	81	14%	46%	41%	10%	30%	60%
Mid-Atl. Small River	193	9%	41%	50%	10%	7%	83%
Mid-Atl. Medium Tributary River	154	6%	53%	41%	18%	1%	81%
Mid-Atl. Medium Mainstem River	45	7%	76%	18%	47%	0%	53%
Mid-Atl. Large River	20	0%	95%	5%	60%	0%	40%
Mid-Atl. Great River	6	0%	83%	17%	100%	0%	0%
MID-ATL. TOTAL	505	9%	51%	41%	19%	8%	73%
New Eng./NY Creek	67	34%	28%	37%	28%	6%	66%
New Eng./NY Small River	109	14%	39%	47%	22%	1%	77%
New Eng./NY Medium Tributary River	86	9%	58%	33%	40%	2%	58%
New Eng./NY Medium Mainstem River	31	3%	61%	35%	45%	0%	55%
New Eng./NY Large River	9	0%	100%	0%	100%	0%	0%
NEW ENG./NY TOTAL	302	16%	46%	38%	33%	2%	65%
Headwater	6	33%	17%	50%	17%	33%	50%
Creek	148	23%	38%	39%	18%	19%	63%
Small River	302	11%	40%	49%	14%	5%	81%
Medium Tributary River	240	8%	55%	38%	26%	2%	73%
Medium Mainstem River	76	5%	70%	25%	46%	0%	54%
Large River	29	0%	97%	3%	72%	0%	28%
Great River	6	0%	83%	17%	100%	0%	0%
REGION TOTAL	807	11%	49%	40%	24%	6%	70%

Map 8. Minimum flow alteration class.



Map 9. Maximum flow alteration class.



Impairment to fish communities has been found most prominently at sites with 1) diminished maximum flows, 2) diminished minimum flows, or 3) inflated minimum flows but unaltered maximum flows (Carlisle et al. 2010). Applying these categories to our region (Table 7) suggests likely impacts to fish communities in 61 percent of the region (67 percent of northern sub-region and 58 percent of Mid-Atlantic).

Table 7. Gages by their minimum flow alteration class and maximum flow alteration class.

			Region		New England/New York		Mid-Atlantic	
	Minimum Flow Class	Maximum Flow Class	# of gages	% of gages	# of gages	% of gages	# of gages	% of gages
*	Diminished	Diminished	27	3%	19	6%	8	2%
*	Diminished	Inflated	12	1%	3	1%	9	2%
*	Diminished	Unaltered	52	6%	25	8%	27	5%
*	Inflated	Diminished	136	17%	65	22%	71	14%
	Inflated	Inflated	27	3%	2	1%	25	5%
*	Inflated	Unaltered	233	29%	73	24%	160	32%
*	Unaltered	Diminished	32	4%	16	5%	16	3%
	Unaltered	Inflated	10	1%	2	1%	8	2%
	Unaltered	Unaltered	278	34%	97	32%	181	36%
		Totals	807	100%	302	100%	505	100%

* Combinations most likely to result in impaired fish communities (Carlisle et al. 2010)

Figure 14. Maximum Flow: percentage of altered maximum flows for streams by size class, and region.

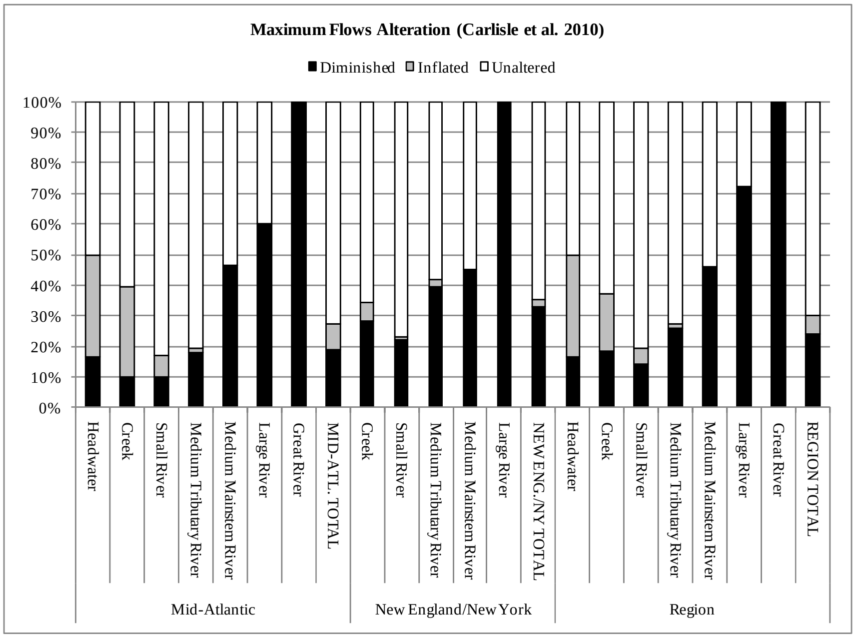
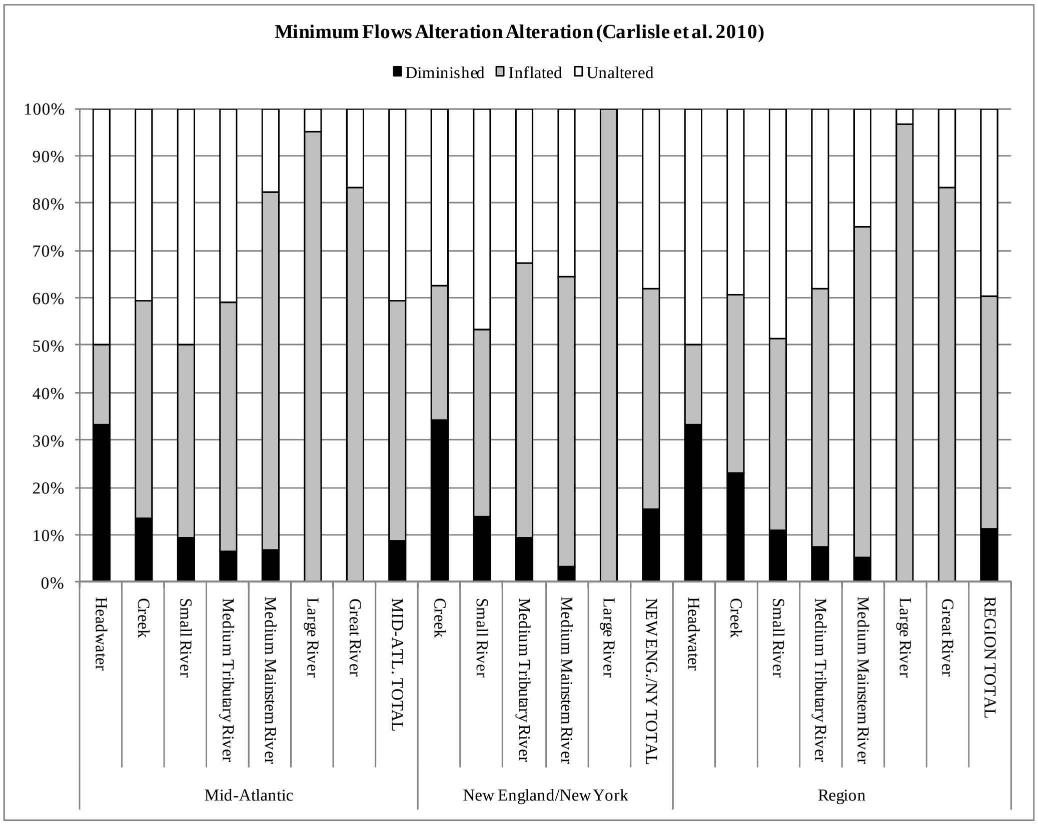


Figure 15. Minimum Flows: percent of altered minimum flows in streams by size class, and region.



Biotic Patterns and Trends

Distribution and Population Status of Native Eastern Brook Trout: Many species of fishes, amphibians, crayfishes, freshwater mussels, and insects have been severely affected by human activities, but few northeastern species have gained as much attention as the native eastern brook trout, a species with strong public appeal. Brook trout is a useful indicator of condition because it integrates water quality and habitat condition, and is typically found where both of these factors are of high quality. Thus, loss of eastern brook trout from streams and watersheds may represent a loss of ecosystem integrity.

Data on the distribution and status of brook trout within the region has been collected by the Eastern Brook Trout Joint Venture (EBTJV) for all watersheds in the region. In small watersheds, where there was no information, the Joint Venture used a GIS model to predict the status of brook trout based on watershed characteristics. Although more data is needed to verify the predicted status of brook trout in these watersheds, we report below the pattern of brook trout distribution and status in the region as in found by the EBTJV model (Hudy et al. 2008, Theiling, 2006).

Results show that brook trout are thought to be extirpated in 26 percent of their historic regional range (Figure 16, Map 10) and reduced in 42 percent of their historic range. There have been higher levels of extirpation in the Mid-Atlantic (44 percent) than in New England and New York (14%). The amount of intact range is a mirror image of that: 14 percent in Mid-Atlantic and 45 percent in New England and New York. The majority of the intact watersheds are found in Maine, New Hampshire, New York, Vermont, and Virginia.

Map 10. Eastern brook trout status.

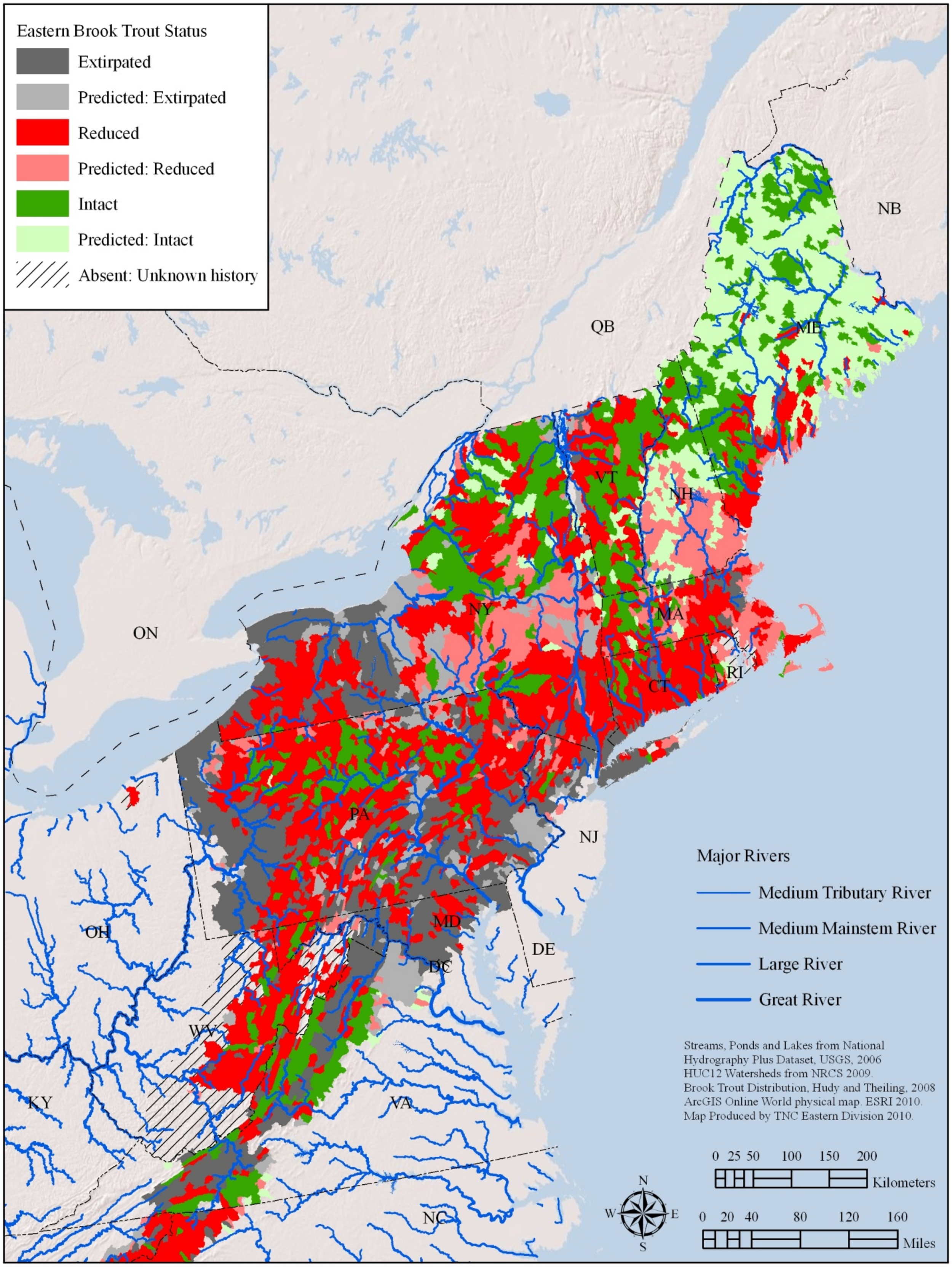
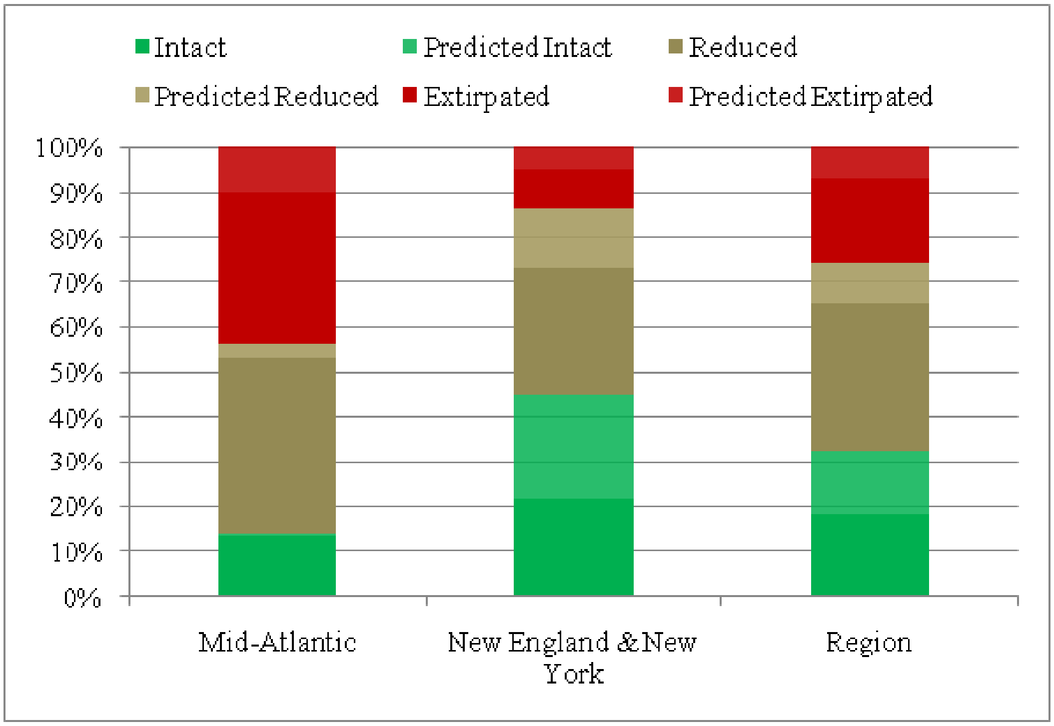


Figure 16. The Percent of the historic brook trout range by current status.

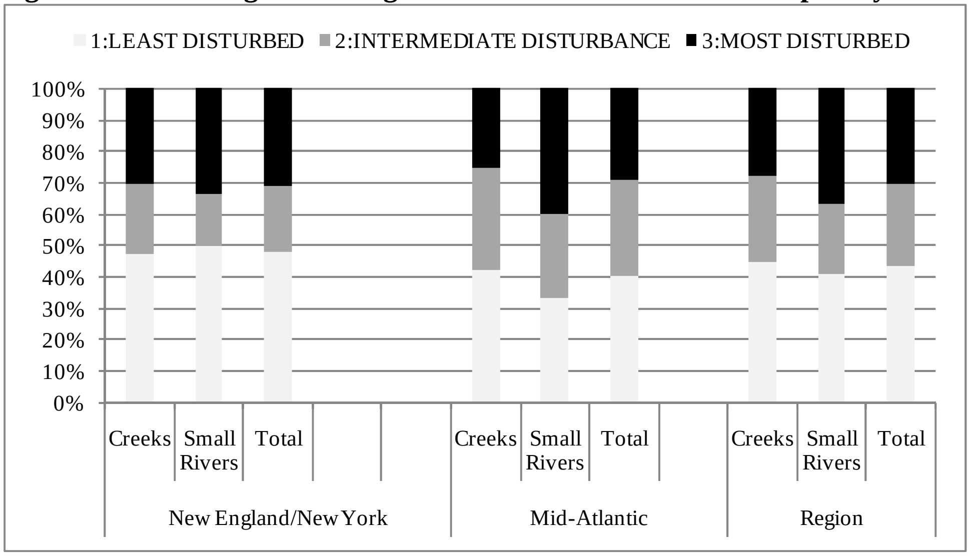


Index of Biotic Integrity: The biological condition of water resources can be assessed by analyzing the characteristics of the benthic organism communities. These characteristics include the composition and relative abundance of key macro-invertebrates that reflect the quality of their environment and respond to human disturbance in predictable ways. The EPA's Index of Biotic Integrity (IBI) based on benthic macro-invertebrates is a multi-metric measure that integrates across many indices describing the benthic community including: taxonomic richness, taxonomic composition, taxonomic diversity, feeding groups, habits, and pollution tolerance. The index is widely used by state and federal agencies to assess the ecological quality of streams, and it has been incorporated into the water quality criteria regulations of some state agencies.

Here we summarize IBI data obtained from the EPA Wadeable Stream Assessment (EPA 2006) for 103 stream sites in our region. This is the only consistently applied and sampled IBI dataset in the region, but it was only dependably collected for wadeable streams, the equivalent of creeks and small rivers in our size classification. An IBI is created by first identifying and counting all benthic macro-invertebrates found from a stream sampling event. Each metric is then tabulated using these raw data. After the metrics are calculated, they are then converted to three categorical scores: A value of "5 -least disturbed" is assigned for the range of expected results (i.e., the score for each metric) in undisturbed sites. A value of "3 -intermediate disturbance" is designated for results expected from a somewhat degraded sites, and a value of "1-most disturbed" is assigned for values expected in severely degraded sites. Several states have developed state specific benthic macro-invertebrate IBI indices, and these can helpful in assessing the state specific conditions.

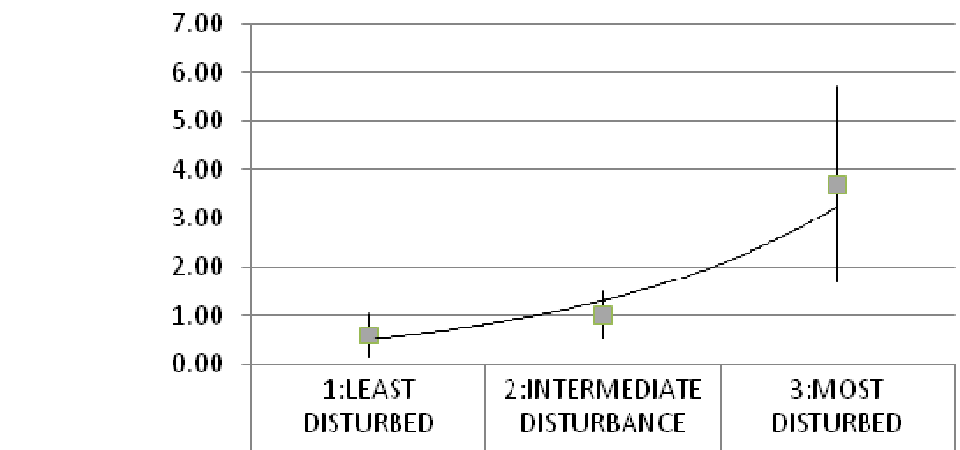
For this region, the EPA results indicated that 44 percent of creeks and small rivers were in the undisturbed class, 26 percent in the intermediate disturbance class and 30 percent in the most disturbed class. Creeks appear to be slightly less disturbed than small rivers (Figure 17). In New England and New York wadeable streams appeared slightly more intact than those of the Mid-Atlantic.

Figure 17. Percentage of the region's EPA wadeable stream samples by benthic IBI class.



Relationship of IBI to Imperviousness Surfaces: We tested whether the IBI score for the sampled streams correlated with the amount of impervious surfaces in the watershed by calculating the mean and standard deviation of impervious surfaces for samples in each of the three disturbance classes (Figure 18). Average impervious surface levels were 0.06 percent for undisturbed, 1.0 percent for the somewhat degraded and 3.7 percent for the severely degraded sites, suggesting a fairly direct relationship described by a slightly exponential relationship (Figure 18). These results support recent research showing impacts to stream biodiversity at very low levels of upstream impervious surfaces.

Figure 18. IBA and impervious surfaces: Mean and confidence interval for the percent of upstream imperviousness surfaces calculated for samples in each IBI disturbance class. Line is an exponential trend line fit to the three points.



	1:LEAST DISTURBED	2:INTERMEDIATE DISTURBANCE	3:MOST DISTURBED
Upper 95% Mean	1.05	1.50	5.73
Lower 95% Mean	0.15	0.53	1.67
Mean	0.60	1.01	3.70

Non-Indigenous Aquatic Species: Non-indigenous aquatic species (NAS) are individuals or populations of a species that enters an aquatic ecosystem outside of its historic or native range. They may be vertebrates, invertebrates, plants, or diseases. Invasive NAS may alter ecosystems by preying on natives, competing with natives, hybridizing with natives, or spreading diseases to native species. NAS may be more likely to become established when stream and watershed conditions are degraded.

The most comprehensive survey of NAS is the USGS Non-indigenous Aquatic Species program that maintains a useful website of information (http://nas.er.usgs.gov/queries/). This site was established as a central repository for accurate and spatially referenced biogeographic accounts of NAS, obtained from a variety of sources such as researchers, field biologists, and fishermen. Because the reports are opportunistic, rather than based on comprehensive surveying, some states have better reporting than others. The reports are also influenced by publications, or lack thereof, and by news coverage, or the news-worthiness, of the species (Fuller, per. com). Data from NAS was extracted and summarized for the region and subregions by Pam Fuller, USGS Nonindigenous Aquatic Species Program, Gainesville, FL as of 1/2011, and we are grateful to her for the charts and summaries in the following section.

Over 300 non-indigenous aquatic species occur in the region and two-thirds of them are fish. The next most common taxa group is mollusks, followed by crustaceans, reptiles, amphibians, annelids, bryozoans, coelenterates, and mammals. This pattern is similar between the two sub-regions (Figure 19). Mapping the results by watershed revealed that there were few areas of the region with less than 5 NAS species (Map 11). These areas include northern Maine, major tributaries of the St. Lawrence and Northeastern Lake Ontario, major tributaries of the Mid-Upper Connecticut River, eastern Chesapeake Bay major rivers, major tributaries of the Allegheny, the Upper Ohio-Beaver, Upper Monongahela, and Lower Kanawha and its major tributaries. In contrast, areas with high number of NAS species include the middle and lower Connecticut River, Housatonic, middle Hudson, lower Susquehanna, mid to lower Potomac, upper Roanoke, New River, and Kanawha. It is important to remember that these patterns partly reflect survey effort.

In addition to the individual species, the NAS program tracks the method of introduction for each species and its location. Summaries of this data show that the most common introduction pathways in the region are stocking, bait release, and shipping, followed by hitch-hiker, aquarium release, canal, pet release, and food release. Stocking and bait release account for over half of the major pathways (Figure 20).

When a species shows up in a new area (state, county, or HUC) and is reported within a year of discovery, it is tracked as an alert by the NAS program. Figure 23 depicts all alerts for each state during the last five years, but does not distinguish the level of that alert. The species may have been found in the state previously but was moved to a new drainage or county, or a species may be totally new to a state. A total of 137 alerts were tracked by NAS over the last five years for the Northeast and Mid-Atlantic area. New York had the highest number of alerts, followed by Maryland and Pennsylvania (Figure 21).

Map 11. Number of Non-indigenous aquatic species per drainage.

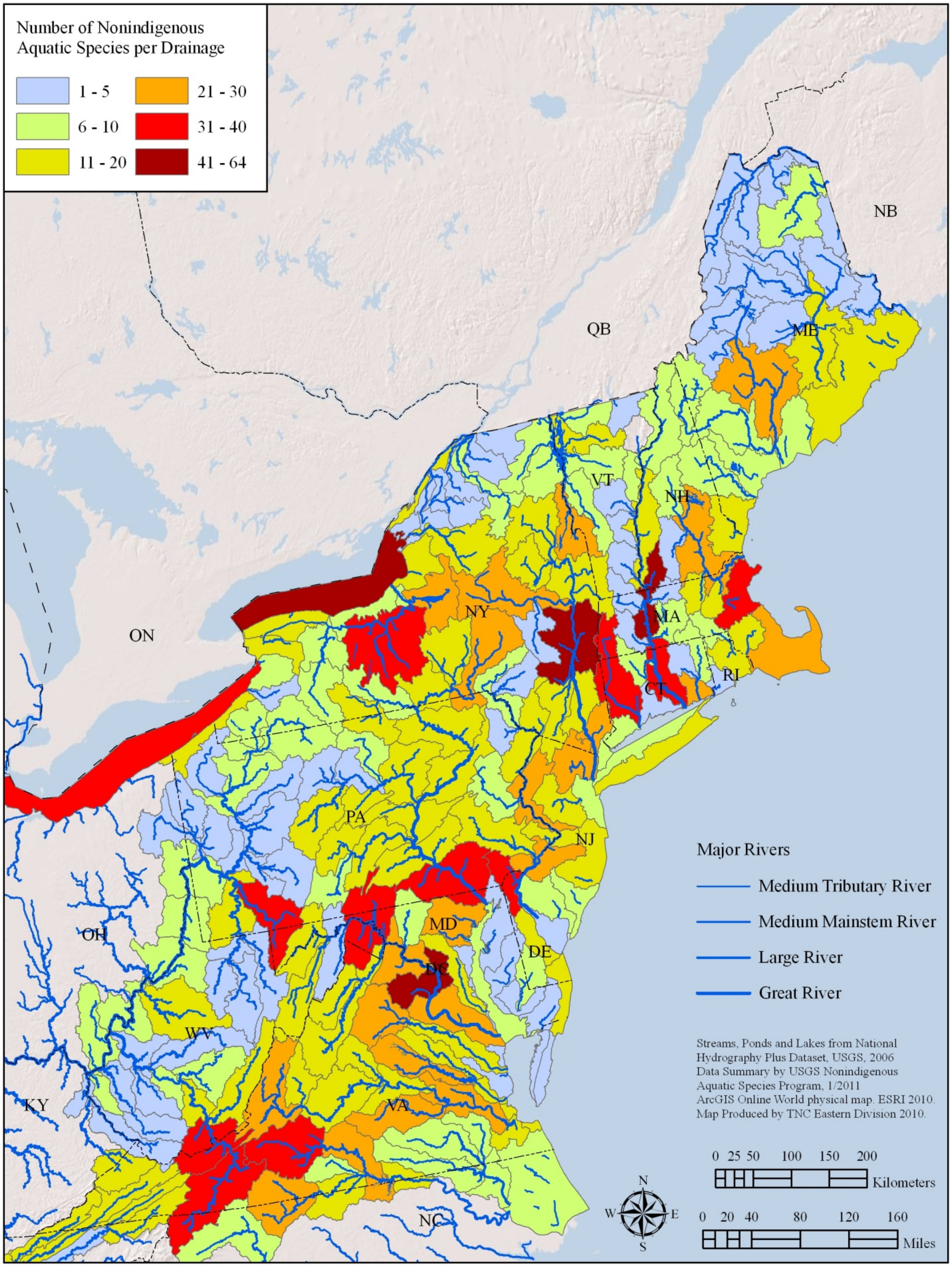


Figure 19. Non-indigenous Aquatic Species. The charts show the major taxonomic groups for the full region and both sub-regions.

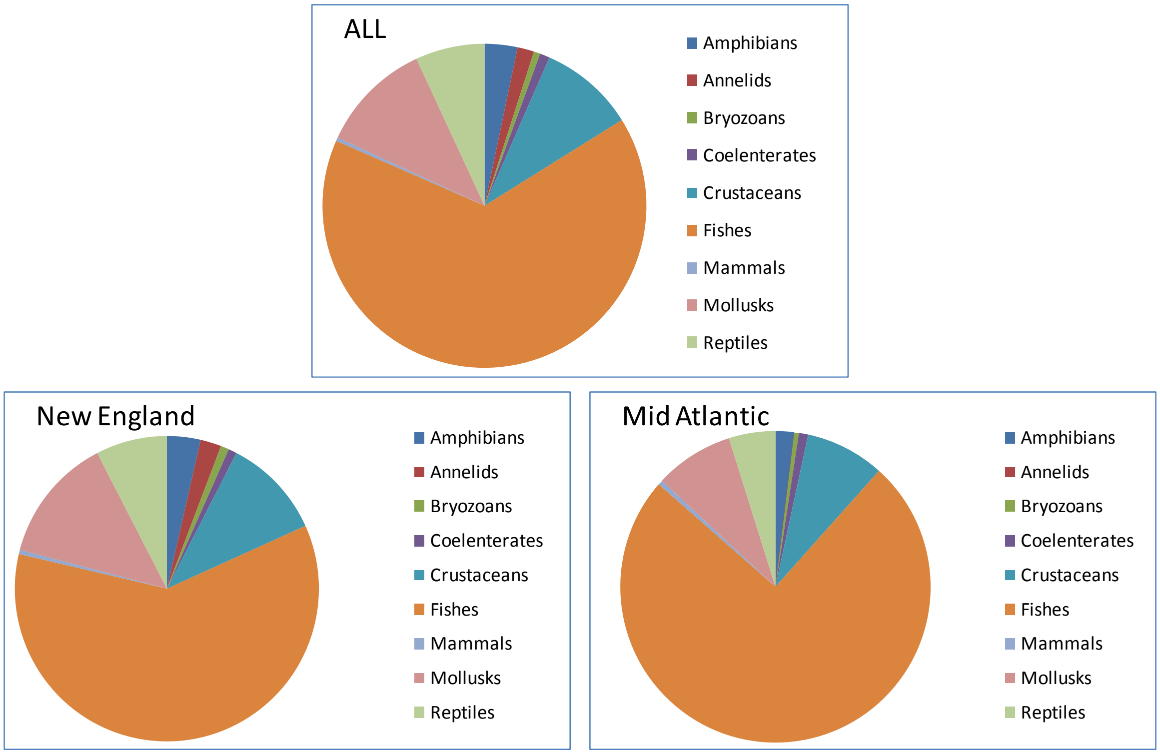


Figure 20: Major pathways of non-indigenous aquatic species introductions.

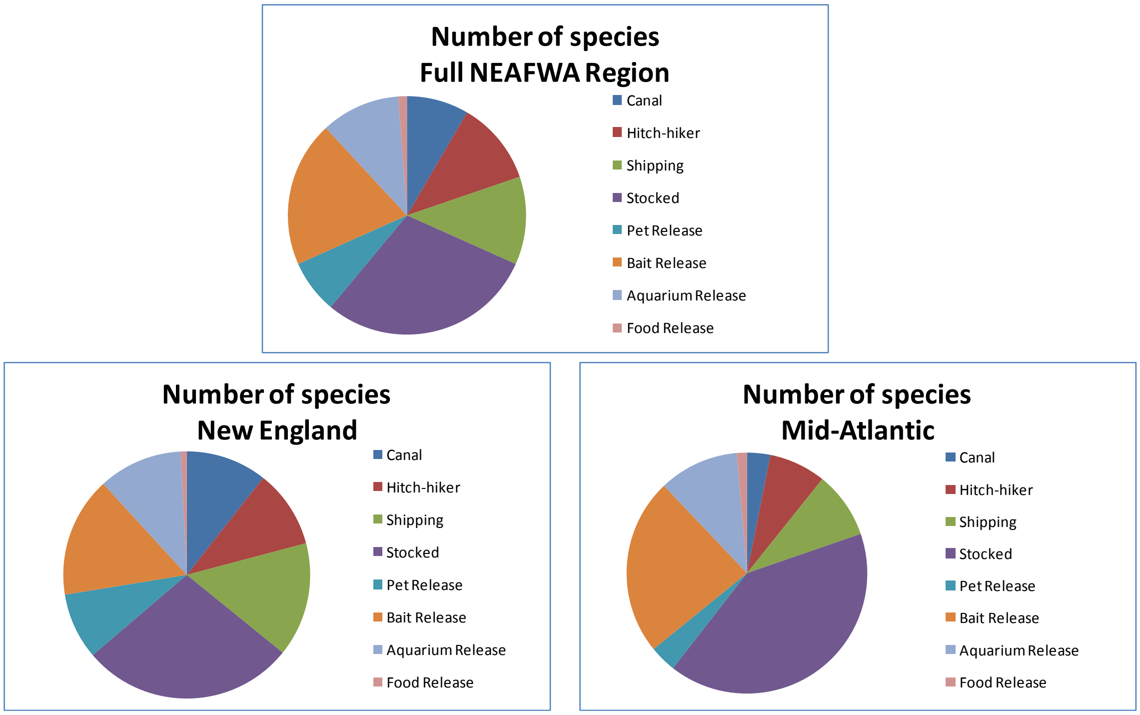
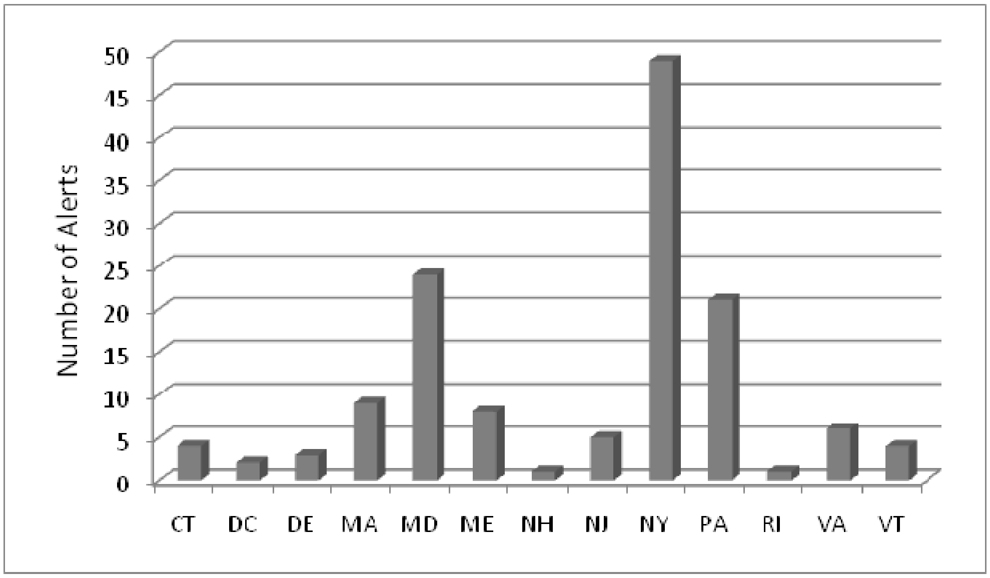


Figure 21. Number of non-indigenous aquatic species alerts by state in alphabetical order.



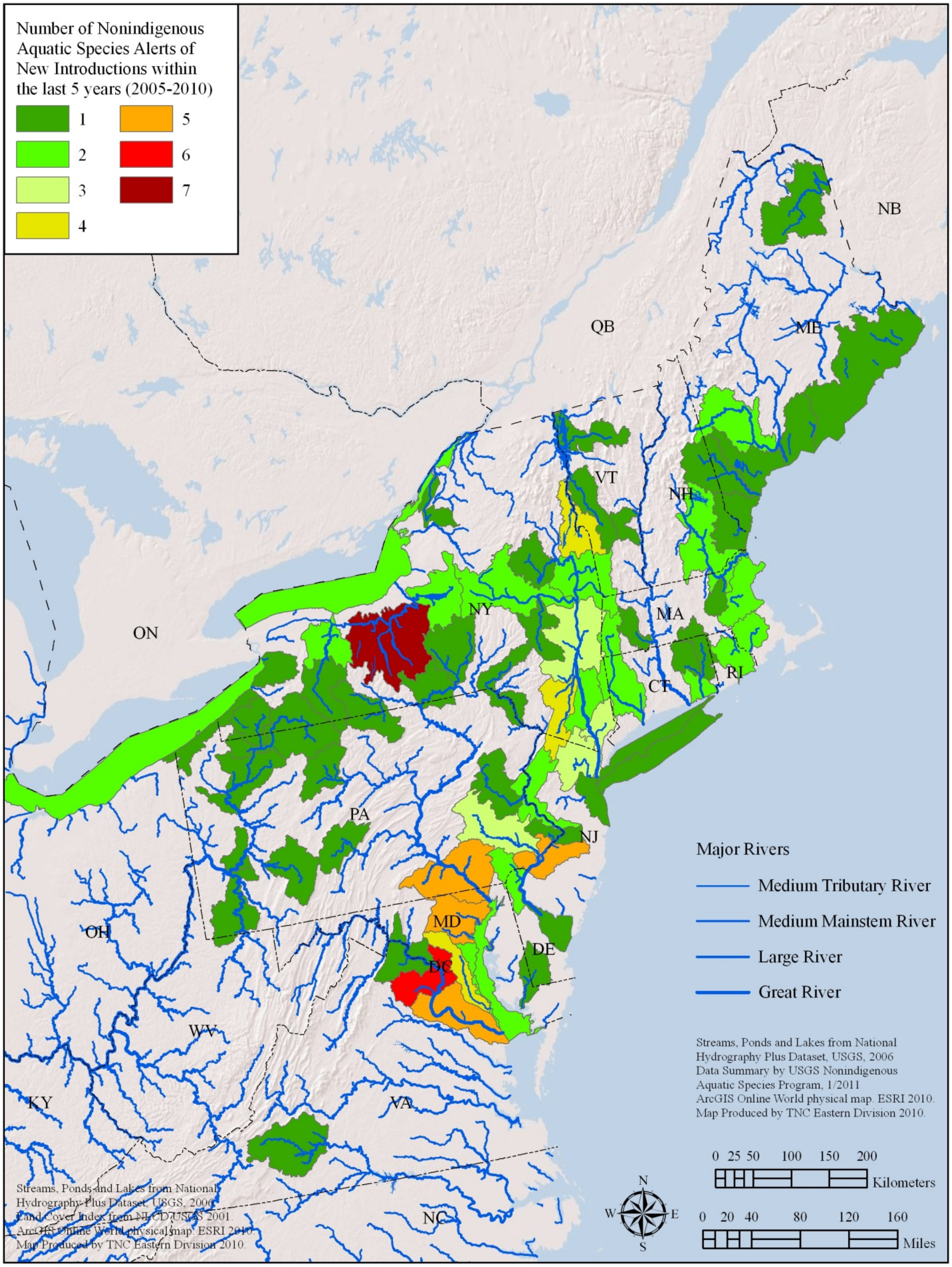
The spatial distribution of alerts by HUC8 watershed (Map 12), shows that watersheds with more than three alerts seem to be associated with the lower mainstems watersheds of large rivers such as the Potomac, Susquehanna, Delaware, and Hudson and in the watersheds of the Finger Lakes and Southern Lake Champlain. Coastal watersheds from Maine through Long Island Sound and along the Great Lakes coast also show a higher proportion of watersheds with low levels of 1-2 alerts. The remaining watersheds have had no alerts reported in the last 5 years. Further work is needed to determine whether areas with reports of more recent invasions share similar characteristics that make them more susceptible to invasion.

Reduction in Native Fish Diversity: The EPA indicator of Fish Faunal Intactness, tracks the completeness of the native freshwater fish fauna in each of the nation's major watersheds by comparing the current faunal composition of those watersheds with their historical composition. We applied this indicator in the Northeast and Mid-Atlantic by looking at the reduction in native species diversity in each major watershed (HUC 8: USGE 8-digit hydrologic cataloging unit). Intactness is expressed as a percent based on the formula:

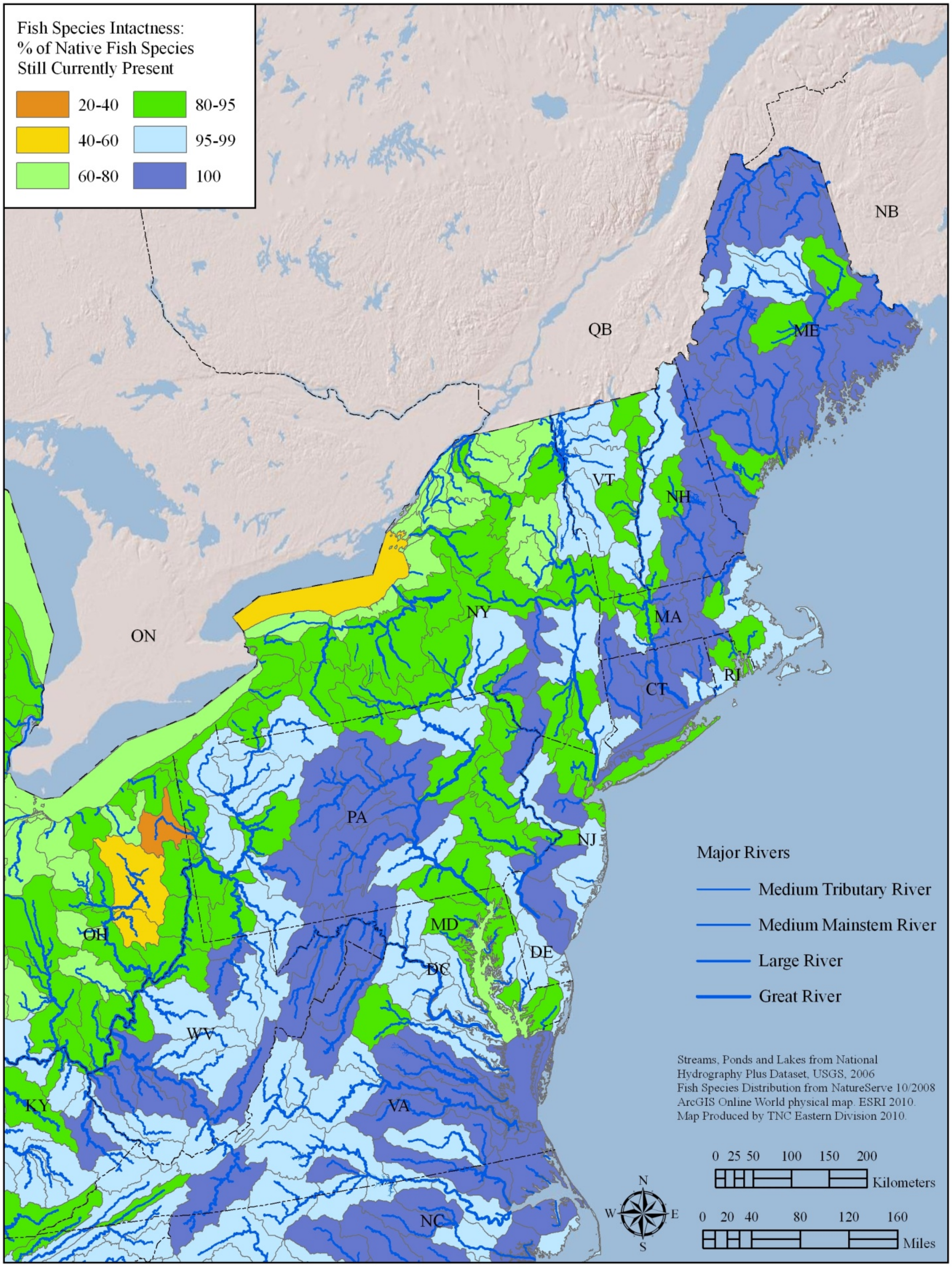
*Fish Faunal Intactness = (# of current native species / # of historic native species * 100)*

Results for this region indicated that the majority of the northeast watersheds still had 95-100% of their native fish species present (Map 13). Areas of less intactness were concentrated in parts of New York State, the Lower Delaware watershed, and the Lower Susquehanna watershed. Although the region appears quite intact, particularly in comparison to other areas of the United States, it is important to note that this indicator does not reflect declines in the populations of native species; it can only highlight where there has been a total extirpation of a species from a watershed. Further work could be done to investigate which watershed characteristics were associated with reductions in fish faunal intactness.

Map 12. Number of non-indigenous aquatic species alerts of new introductions.



Map 13. Fish species intactness.



References

Please see the data sources (appendix A) and detailed methods (appendix B) sections of the main report for more information on the data sources and analysis methods used in this chapter.

Center for Watershed Protection (CWP). 2003. Impacts of Impervious Cover on Aquatic Systems. Watershed Protection Research monograph No. 1.

Carlisle, D. M., Wolock, D.M., and Meador, M.R. 2010. Alteration of stream flow magnitudes and potential ecological consequences: a multiregional assessment. Frontiers in Ecology and the Environment. Doi: 10.1890/100053

Fuller, P. 2011. Nonindigenous Aquatic Species Northeast Summary. USGS Nonindigenous Aquatic Species Program, Gainesville, FL

Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan, 2004. Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing.

Hudy, M., T.M. Thieling, N. Gillespie and E.P. Smith. 2008. Distribution, status, and land use characteristics of subwatersheds within the native range of brook trout in the eastern United States. North American Journal of Fisheries Management **28**(4)**:**1069-1085.

King, R.S. and M.W. Baker. 2010. Considerations for analyzing ecological community thresholds in response to anthropogenic environmental gradients. Journal of the North American Benthological Society. **29**(4)**:**998.

Langdon, R., J. Andrews, K.Cox, Fiske, S., Kamman, and N., Warren, S 1998. A Classification of The Aquatic Communities of Vermont. Prepared by The Aquatic Classification Workgroup for The Nature Conservancy and the Vermont Biodiversity Project.

NatureServe. 2008. Watershed Distribution Maps of Freshwater Fishes in the Conterminous United States. Version 2. Arlington, VA. U.S.A.

Olivero, A. P. and M.G. Anderson. 2008. Northeast Aquatic Habitat Classification System. The Nature Conservancy, in Collaboration with the Northeast Asssociation of Fish and Wildlife Agencies. 88p.

Palone, R. and Todd, A. 1997. Chesapeake Bay Riparian Handbook: A Guide for Establishing and Maintaining Riparian Forest Buffers. Chesapeake Bay Program 1997.

Stuart, C. et al. 2003. Living Waters Technical Report. Natural Heritage and Endangered Species Program. 103p.

The Nature Conservancy. 2011. Northeast Regional Dam Dataset Version 3/1/2011. The Nature Conservancy Eastern Conservation Science Office. Boston, MA.

The Nature Conservancy. 2009. Eastern U.S. Secured Lands. Various scales.

Thieling, T.M. 2006. Assessment and predictive model for brook trout (*Salvelinus fontinalis*) population status in the eastern United States. Masters Thesis. James Madison University

USDA/NRCS - National Cartography & Geospatial Center. 1994. (Data Access from NRCS 3/31/2009) 8-Digit HUC Hydrologic Units 1:250,000. Fort Worth, TXOnline http://datagateway.nrcs.usda.gov/

USDA/NRCS, National Cartography & Geospatial Center. 1999-2009 (Data Access from NRCS Data 3/31/2009) 12-Digit Watershed Boundary Data 1:24,000. Fort Worth, TX.

USEPA. 2006. Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams. EPA 841-B-06-002 U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, D.C.

USGS and USEPA. 2006. National Hydrography Dataset Plus (NHD-Plus). 100,000.

USGS. 2009. Geographic Names Information System (GNIS) 1.2009.

Vannote, RL,G. W. Minshall, K. W. Cummins, J.R. Sedell, and E. Gushing 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37: 130-137.

Walsh, M., Deeds, J. and Nightengale, N. 2007. User's Manual and Data Guide to the Pennsylvania Aquatic Community Classification. Pennsylvania Natural Heritage Program and Western Pennysylvania Conservancy.

Welsch, D.J. 1991. Riparian Forest Buffers. U.S. Forest Service Northeastern Area State & Private Forestry. Radnor, PA. NA-PR-07-91. 20 pages.

Yang, L, C. Huang, C. Homer, B. Wylie, and M. Coan, 2002. An approach for mapping large-area impervious surfaces: Synergistic use of Landsat 7 ETM+ and high spatial resolution imagery. Canadian Journal of Remote Sensing, 29: 2, 230-240.

Appendix 7-1

Acres of Land within 100m buffer of Streams and Rivers

	Non-Secured Agriculture	Non-Secured Developed	Non-Secured Natural	GAP1&2 Total	GAP 3 Total	Total
CT						
Headwater	12,691	32,466	98,530	6,941	17,149	167,778
Creek	11,348	33,634	68,429	7,197	14,156	134,765
Small River	2,158	6,951	12,532	2,205	3,199	27,044
Medium Tributary River	1,476	3,442	7,271	772	2,010	14,971
Medium Mainstem River	145	2,138	2,348	216	308	5,155
Large River	7	83	143		18	251
Great River	311	1,137	4,575	850	947	7,820
CT Total	**28,135**	**79,851**	**193,829**	**18,182**	**37,787**	**357,784**
DC						
Headwater	8	261	53		223	545
Creek	1	94	10	0	168	274
Small River	8	403	147		1,130	1,688
Great River	7	140	109	0	480	736
DC Total	**24**	**898**	**320**	**1**	**2,002**	**3,244**
DE						
Headwater	38,416	3,849	36,225	2,548	7,866	88,904
Creek	14,116	3,559	25,915	2,363	5,886	51,839
Small River	1,083	975	7,724	902	2,303	12,986
Medium Tributary River	180	780	1,020	75	469	2,524
Great River	218	409	2,443	1,417	1,742	6,230
Total	**54,014**	**9,572**	**73,327**	**7,305**	**18,265**	**162,483**
MA						
Headwater	16,733	40,029	129,203	7,123	46,130	239,218
Creek	14,157	35,924	90,310	6,057	36,532	182,980
Small River	4,279	12,823	22,509	2,181	9,960	51,753
Medium Tributary River	2,408	6,194	11,232	906	2,574	23,313
Large River	1,575	3,469	4,983	165	1,031	11,223
MA Total	**39,153**	**98,438**	**258,237**	**16,432**	**96,227**	**508,486**
MD						
Headwater	124,498	34,934	181,365	11,836	34,710	387,343
Creek	67,347	20,954	130,085	11,116	25,259	254,762
Small River	25,326	10,580	55,584	8,729	16,683	116,902
Medium Tributary River	12,289	6,995	25,563	5,273	9,264	59,384
Medium Mainstem River	13	5	366	1,159	522	2,066
Large River	71	75	973	2,994	184	4,297
Great River	2,629	830	6,015	1,692	1,443	12,608
MD Total	**232,173**	**74,373**	**399,951**	**42,800**	**88,065**	**837,362**
ME						
Headwater	26,208	25,364	667,134	31,318	87,284	837,309
Creek	21,574	25,802	628,849	25,284	106,525	808,034
Small River	7,468	8,971	133,569	7,896	22,928	180,833
Medium Tributary River	4,455	5,447	52,177	8,331	11,613	82,023
Medium Mainstem River	4,394	5,328	31,887	3,957	3,657	49,223
Large River	1,789	3,846	16,663	203	898	23,400
ME Total	**65,888**	**74,759**	**1,530,280**	**76,990**	**232,905**	**1,980,822**

	Non-Secured Agriculture	Non-Secured Developed	Non-Secured Natural	GAP1&2 Total	GAP 3 Total	Total
NH						
Headwater	11,847	20,112	176,731	19,809	56,973	285,471
Creek	11,380	21,731	130,752	17,178	50,014	231,055
Small River	4,331	10,158	29,964	1,589	10,973	57,015
Medium Tributary River	3,028	4,678	11,363	767	3,638	23,474
Medium Mainstem River	2,436	3,050	6,222	362	2,725	14,794
Large River	662	638	2,271	113	404	4,088
NH Total	**33,684**	**60,366**	**357,302**	**39,817**	**124,728**	**615,898**
NJ						
Headwater	40,002	38,538	114,884	52,140	6,167	251,729
Creek	23,107	32,563	92,562	43,278	6,087	197,597
Small River	6,659	12,835	28,035	14,551	3,107	65,187
Medium Tributary River	678	4,399	6,703	3,925	877	16,582
Medium Mainstem River	85	293	747	2,116		3,241
Large River	379	1,623	2,825	1,554	91	6,472
Great River	418	1,148	1,383	1,896		4,845
NJ Total	**71,327**	**91,399**	**247,139**	**119,460**	**16,329**	**545,654**
NY						
Headwater	387,598	102,951	834,985	143,408	135,447	1,604,388
Creek	283,157	120,559	710,909	116,707	92,276	1,323,608
Small River	64,718	41,135	169,043	25,168	17,730	317,794
Medium Tributary River	33,342	18,676	88,452	8,176	7,779	156,424
Medium Mainstem River	10,409	10,654	31,202	1,137	2,794	56,196
Large River	2,159	4,230	10,174	709	1,400	18,672
Great River	304	2,310	5,038	372	1,517	9,540
NY Total	**781,687**	**300,514**	**1,849,803**	**295,677**	**258,943**	**3,486,623**
PA						
Headwater	396,715	183,735	908,563	40,536	234,414	1,763,962
Creek	250,149	170,118	622,399	30,390	146,305	1,219,361
Small River	64,236	49,880	179,585	8,766	19,867	322,335
Medium Tributary River	19,206	21,029	79,239	8,237	9,569	137,281
Medium Mainstem River	3,742	11,355	31,401	3,220	4,144	53,862
Large River	5,334	10,246	22,867	1,881	801	41,128
Great River	1,597	9,027	11,779	163	1,312	23,877
PA Total	**740,979**	**455,390**	**1,855,832**	**93,193**	**416,413**	**3,561,806**
RI						
Headwater	1,947	6,248	20,744	1,739	4,817	35,496
Creek	1,223	5,372	10,116	1,305	5,061	23,077
Small River	312	2,103	2,437	135	718	5,705
Medium Tributary River	167	2,550	1,689	422	227	5,054
RI Total	**3,650**	**16,273**	**34,986**	**3,601**	**10,823**	**69,332**
VA						
Headwater	286,251	98,235	921,715	34,445	96,551	1,437,197
Creek	225,546	91,485	655,851	29,664	56,777	1,059,323
Small River	67,698	29,400	194,184	5,829	10,909	308,019
Medium Tributary River	30,700	11,577	100,651	1,617	6,962	151,507
Medium Mainstem River	18,642	6,571	57,072	1,154	7,141	90,579
Large River	5,890	3,130	20,094	486	3,712	33,312
Great River	2,252	1,245	5,053	385	951	9,886
VA Total	**636,980**	**241,641**	**1,954,620**	**73,579**	**183,003**	**3,089,823**

		Non-Secured Agriculture	Non-Secured Developed	Non-Secured Natural	GAP1&2 Total	GAP 3 Total	Total
VA							
	Headwater	286,251	98,235	921,715	34,445	96,551	1,437,197
	Creek	225,546	91,485	655,851	29,664	56,777	1,059,323
	Small River	67,698	29,400	194,184	5,829	10,909	308,019
	Medium Tributary River	30,700	11,577	100,651	1,617	6,962	151,507
	Medium Mainstem River	18,642	6,571	57,072	1,154	7,141	90,579
	Large River	5,890	3,130	20,094	486	3,712	33,312
	Great River	2,252	1,245	5,053	385	951	9,886
	VA Total	**636,980**	**241,641**	**1,954,620**	**73,579**	**183,003**	**3,089,823**
VT							
	Headwater	23,978	13,844	129,142	7,491	25,117	199,571
	Creek	46,325	29,739	151,341	10,052	31,935	269,392
	Small River	18,420	11,697	29,041	1,617	3,747	64,522
	Medium Tributary River	9,480	5,789	13,164	996	828	30,256
	Medium Mainstem River	2,058	1,154	2,788	82	164	6,246
	Large River	976	735	1,775	248	74	3,808
	VT Total	**101,237**	**62,957**	**327,251**	**20,486**	**61,865**	**573,795**
WV							
	Headwater	91,485	106,060	662,596	7,590	78,989	946,720
	Creek	82,892	110,604	381,849	5,992	47,570	628,908
	Small River	29,228	36,935	103,869	765	21,393	192,191
	Medium Tributary River	16,371	21,238	63,406	515	8,378	109,907
	Medium Mainstem River	5,685	9,557	23,586	6	3,245	42,080
	Large River	728	3,726	6,661	7	4,049	15,171
	Great River	3,684	6,887	6,742		1,762	19,074
	WV Total	**230,073**	**295,007**	**1,248,708**	**14,875**	**165,387**	**1,954,050**
Region Total		**3,019,004**	**1,861,437**	**10,331,585**	**822,396**	**1,712,740**	**17,747,162**