

LAND CONSERVATION, RESTORATION, AND STORMWATER MANAGEMENT
PRIORITIES FOR THE SQUANNACOOK AND NISSITISSIT RIVER WATERSHEDS,
MASSACHUSETTS AND NEW HAMPSHIRE

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INTRODUCTION

This report summarizes the initial phase of mapping and modeling for the “Protecting the Source” project funded by the US EPA. It describes (1) the compilation of spatial data, (2) necessary modifications of coordinate and classification systems, (3) the GIS-based overlay process used to identify key areas for source water protection, and (4) preliminary findings.

THE WATERSHEDS

The Squannacook and Nissitissit Rivers flow in a southeasterly direction to join the Nashua River near the Massachusetts-New Hampshire border (Figure 1). The combined area of the watersheds is 340.9 km² (84,200 acres). The Nashua River flows north from Massachusetts to join the Merrimack River at Nashua, New Hampshire. Like most of southern New England, the region has undergone sweeping changes in settlement, land use, and water quality over the past 200 to 300 years. Beginning in the late-1600s, European settlers displaced Native Americans and cleared small, relatively isolated areas for subsistence farming. Forest conversion reached its peak in the early-1800s when 60 to 90 percent of the landscape was cleared for pasture, crops, and orchards. Western expansion, canals and railroads, the Civil War, immigration, and industrialization brought about sweeping changes in the region. The economy and environment of the region were rapidly transformed by water power derived from the Nashua, Merrimack, Blackstone, and other rivers. Mass production techniques, plentiful labor, and expanding markets for manufactured goods of all kinds led to rapid growth of urban areas and the abandonment of marginal farms.

By the late-1800s, most rivers were bordered with factories, towns, and cities and fouled by wastes and pollution of every description. In many cases, streams and rivers were essentially devoid of living things. Until federal and state environmental laws and regulations curbed the worst abuses, streams and rivers were written off as the “price of progress.” (Ironically or appropriately, depending upon your point of view, the New England Interstate Water Pollution Control Commission is located in a massive old mill complex in Lowell, Massachusetts.) Changing values and attitudes, diligent enforcement of environmental laws and regulations, educational programs by schools and NGOs, the shift from manufacturing to service industries initiated the process of ecological recovery. The rate of recovery in the well-watered temperate climate of southern New England has been nothing short of remarkable (see www.NashuaRiverWatershed.org). Old stone walls through second- and third-growth forests, farms and orchards in fertile valleys, mill buildings, and historic houses are quiet reminders of a transformed landscape.

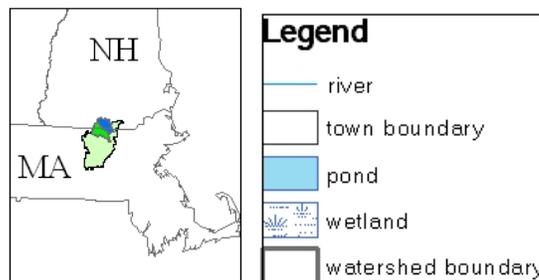
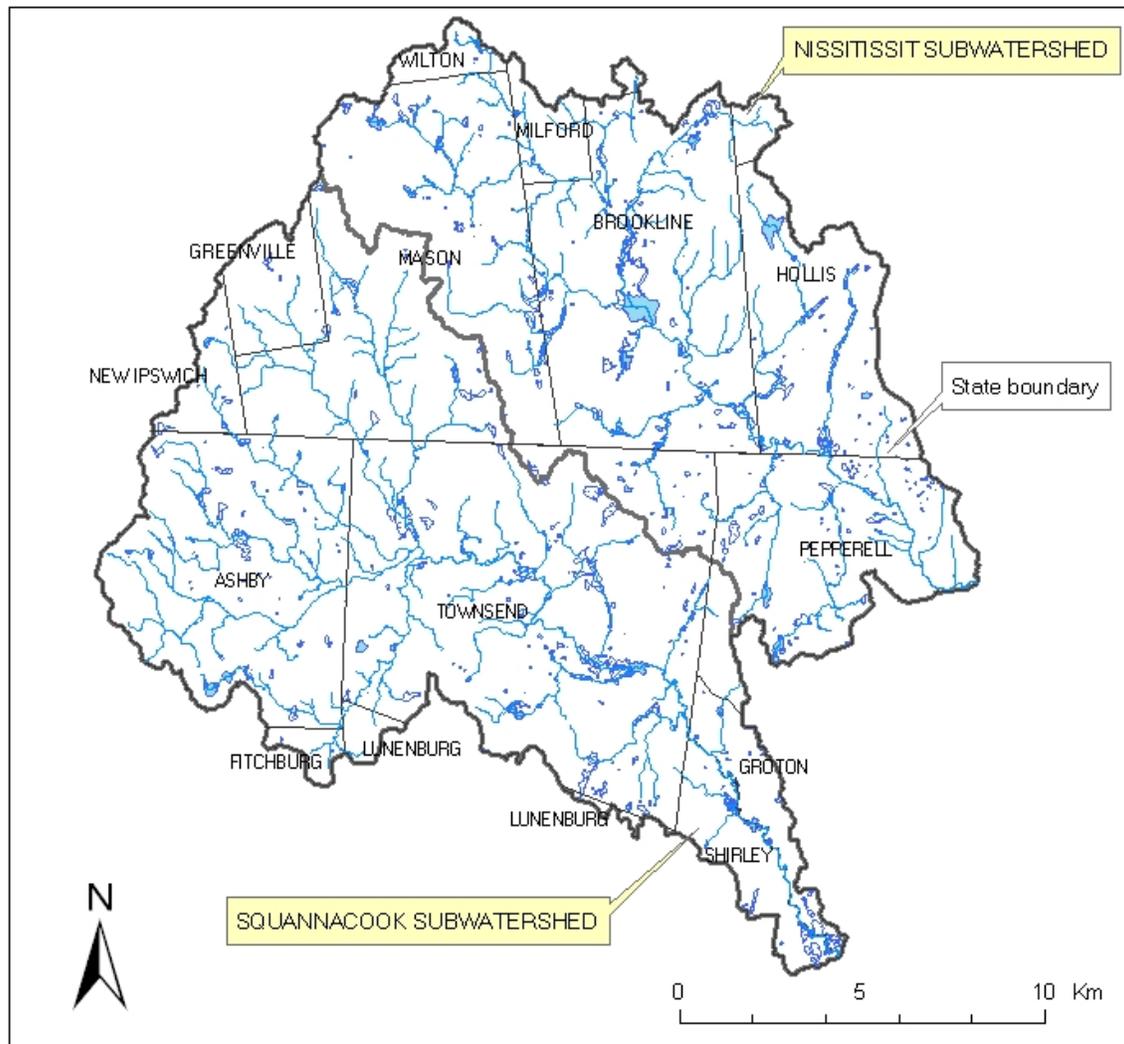


FIGURE 1 – The Squannacook and Nissitissit River watersheds, tributaries of the Nashua River in Massachusetts and New Hampshire. Data sources: MassGIS and NH GRANIT

Recent studies by the Massachusetts Audubon Society (Steele 1999) and the Society for the Protection of New Hampshire Forests (Sundquist and Stevens 1999; Thorne and Sundquist 2001) have documented the patterns and trends associated with contemporary changes in the region's economy, demographics, and environment. Their findings clearly show the pattern of suburban development that has become a ubiquitous feature of the U.S. landscape since the 1960s. As the metropolitan-Boston area has expanded towards the I-495 corridor, the rate of development in the study watersheds (as measured by the number of new homes, subdivision lots, and building permits) has increased dramatically beginning in the 1980s.

Unless growth is effectively managed, more people, more vehicles, and increased demand for commercial and municipal services will combine to steadily degrade water quality and ecosystem health. Unlike earlier agricultural settlement, subdivision (forest fragmentation and parcelization) into house lots is effectively a permanent change. Although patterns and trends are clear at the landscape-scale, at ground-level they are less dramatic, sometimes barely perceptible. The proximity of the watersheds to metropolitan Boston, Nashua, and other cities makes their current condition at once significant and vulnerable (Table 1). Forests, wetlands, and water comprise about 81% of the watersheds. Developed and cleared land totals about 13% of the study area. The cropland, pastures, hayfields, and orchards of the few remaining farms accounts for 6% of the watersheds. These summary statistics are especially noteworthy with respect to several generalized thresholds.

In a recent review of long-term paired watershed experiments, Hornbeck and others (1997) have shown that streamflow increases can be measured when forested area or total biomass is reduced to approximately 75% of a fully vegetated site. In other words, the effects of forest conversion can be clearly differentiated from inter-annual variation in climate and streamflow. Associated changes in water quality (e.g., increased concentrations of nutrients, trace metals, and sediment) begin with changes in water yield and pathways of flow (i.e., surface versus subsurface). Although the difference in spatial scale between small (30 to 75 acre) experimental watersheds and large, complex systems like the Squannacook and Nissitissit argues for a cautious interpretation of this threshold, the general mechanisms (reduced evapotranspiration leading to increased soil moisture and streamflow) and direction of changes are well supported by decades of hydrologic research. Other researchers have identified a total impervious area (roads, roofs, parking lots, etc.) of 10% of a watershed area as a threshold after which exponential increases in the volume of urban stormwater are plainly evident. Naturally, water quality suffers as result of increased overland flow and pollutant loading and associated decreases in residence time and assimilative capacity of soils, wetlands, streams, and rivers. Simply put, with increasing development a larger quantity of lower quality water is delivered more rapidly to wetlands, streams, and rivers.

The Squannacook-Nissitissit watershed system hovers right at both thresholds. Decades of research and operational experience have shown that NPS pollution from farms (only 6% of the watershed) can be effectively controlled with a combination of education and technical assistance, grants or cost-share programs, and public-private partnerships.

Hence, there is an ephemeral opportunity to protect and enhance water quality via forest conservation, stormwater management, and restoration of ecological function on farms.

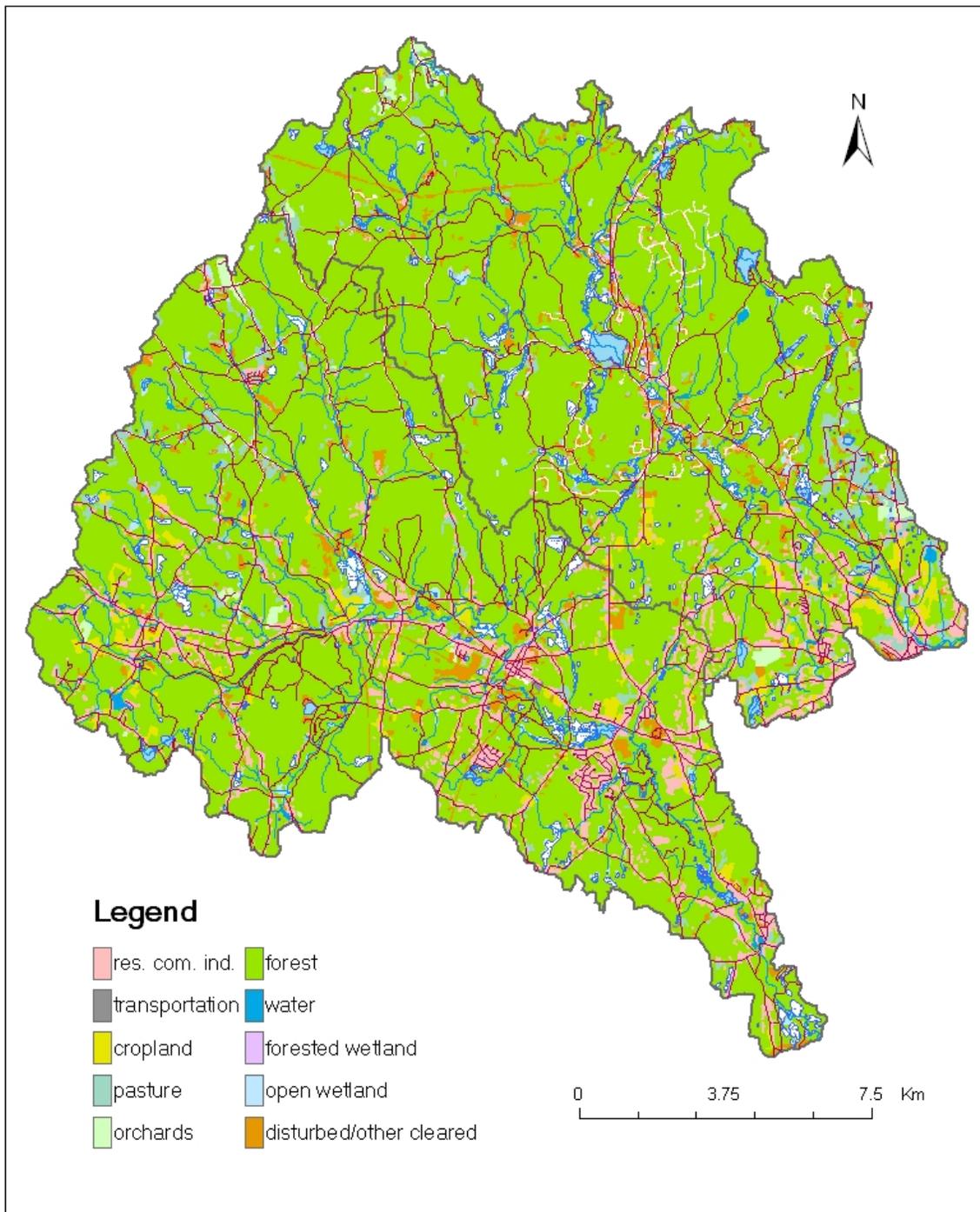


FIGURE 2 – Generalized land cover and land use for the Squannacook (south) and Nissitissit (north) River watersheds, Massachusetts and New Hampshire. Data sources: 1999 land cover/land use interpreted from aerial photography (MassGIS) merged with 200_ satellite imagery (NH GRANIT).

TABLE 1 – A summary of land cover and land use in the Squannacook and Nissitissit River watersheds, Massachusetts and New Hampshire. Data sources: 1999 land cover/land use interpreted from aerial photography (MassGIS) merged with 200_ satellite imagery (NH GRANIT).

Land Cover/Land Use	Area (km ²)	Proportion of Watershed (%)	MassGIS LU 37 code	NH GRANIT code
Residential Commercial Industrial	26.53	7.78	10, 11, 12, 13, 15, 16	100
Transportation	5.77	1.69	18, 32	140
Cropland	7.29	2.14	1	211
Pasture	10.28	3.02	2	212
Orchards	2.22	0.65	35, 36	221
Forest	265.19	77.78	3	412, 414, 419, 421, 422, 423, 430
Water	3.68	1.08	20	500
Forested wetland	0.42	0.12	37	610
Open wetland	7.12	2.09	4	620
Disturbed and other cleared*	12.46	3.65	5, 6, 7, 9, 17, 19, 24, 26, 31, 34	710, 790
Totals	340.96	100.00	26 classes	17 classes

* NH GRANIT: 710 = disturbed: gravel pits, quarries or other areas where the earth and vegetation have been altered or exposed; 790 = other cleared: clearcut forest, abandoned agricultural fields.
 MassGIS: 5 = sand, gravel and exposed rock; 6 = abandoned agriculture, power lines, areas of no vegetation; 7 = golf, tennis playgrounds, skiing; 9 = water based recreation; 17 = parks, cemeteries, public and institutional green space, vacant undeveloped land; 19 = landfills, sewage lagoons; 24 = powerlines; 26 = golf courses; 31 = urban public; 34 = cemeteries.

SPATIAL DATA AVAILABILITY

Our phase I results were generated with spatial data obtained from the US Geological Survey (digital elevation models, DEMs), MassGIS, and NH GRANIT. As expected, we needed to merge several data layers at the state boundary — most notably the land cover/land use layer — to seamlessly represent the watershed system. The coding systems were simplified into more general classes. By contrast to the other three study sites (Georgia, Maryland/Pennsylvania, and New Jersey), digital soils (SSURGO) data are not yet available for the Nashua River watershed. This is unfortunate because attributes such as the depth to seasonal water table and soil permeability profile yield valuable information about the potential for overland flow and NPS pollution.

PRIORITY INDICIES FOR SOURCE WATER PROTECTION

The watershed attributes used in the model include (1) proximity to streams, wetlands, lakes, and ponds, (2) land slope, (3) flow accumulation to identify ephemeral and intermittent streams, (4) surficial geology, (5) core habitat and supporting natural landscapes for rare plants and animals, (6) adjacency of forests to paved roads, (7) the zone of influence of municipal water supply wells, and (8) land cover/land use stratified into three categories. Every 30 x 30 meter grid cell in the 340.9 km² watershed system receives a score of 3, 2, or 1 to represent high, intermediate, or low potential influence on source water quality for each attribute (Tables 2, 3, and 4). Land cover/land use classes are stratified into one of the three indices. In other words, each class is only used for the calculation of one index—*either* conservation (Table 2), restoration (Table 3), *or* stormwater management (Table 4) priority. Both the modeling overview and the Powerpoint presentation used during the Kickoff Meeting can be found on the Trust for Public Land web site.² This site also has the Phase 1 reports and presentations for the Upper Little Tallapoosa River watershed in Georgia (October 2002) and the Prettyboy Reservoir watershed in Maryland and Pennsylvania (November 2002).

The layers were assembled into a computational model in ArcView (Figure 3). This flowchart details the sequence of vector to raster conversions (polygons to grid cells), assignment of 3-2-1 scores, and finally, the arithmetic overlay process that generates a priority index score for each of the more than 378,000 30 x 30 meter grid cells in the Squannacook and Nissitissit watersheds.

² www.tpl.org ...click on “Land & Water” ...click on “Demonstration Projects” ...click on Project Framework, Sites, and Tools.

TABLE 2 – Construction of the Conservation Priority Index (CPI) for the Squannacook and Nissitissit River watersheds, Massachusetts and New Hampshire.

	3	2	1	0
Land use	Forest Wetland Open land Forested wetland	-	-	-
Adjacency to water (lake, river, wetland)	≤ 30 meters	30-60 meters	60-90 meters	>90 meters
Slope (%)	□15	5-15	<5	-
Flow accumulation (# grid cells)	□200	150-200	<150	-
Surficial geology	Floodplain alluvium	Sand and gravel deposits	Till or bedrock	-
Public water supply	Well and IWPA	-	-	-
T&E Habitat	MassGIS Core area	-	-	-
Forests with road frontage	Within 30 meters of a road (road or street, primary route, secondary route, transition or non-standard road)	-	-	-

Public water supply wells data is dated 1995 (more recent data have been removed from web sites after September 11, 2001). The Massachusetts DEP Interim Wellhead Protection Area (IWPA) determines a radius with the following equation:

$$\text{Radius} = (32 * \text{pumping rate in gallons per minute}) + 400 \text{ feet}$$

The community water system wells in the study area have a mean pumping rate of 19.08 GPM, so the radius we used in our analysis is 1,010 feet (308 meters). (Reference: MassGIS metadata)

TABLE 3 – Construction of the Restoration Priority Index (RPI) for the Squannacook and Nissitissit River watersheds, Massachusetts and New Hampshire.

	3	2	1	0
Adjacency to water (lake, river, wetland)	≤ 30 meters	30-60 meters	60-90 meters	>90 meters
Slope (%)	□15	5-15	<5	-
Flow accumulation	□200	150-200	<150	-
Surficial geology	Floodplain alluvium	Sand and gravel deposits	Till or bedrock	-
Public water supply	Well and IWPA	-	-	-
T&E habitat	MassGIS Core areas	-	-	-
Land use	Cropland Pasture Mining Waste disposal Powerlines Orchard Nursery	Participant rec. Golf Urban public	Urban open	-

TABLE 4 – Construction of the Stormwater Management Priority Index (SMPI) for the Squannacook and Nissitissit River watersheds, Massachusetts and New Hampshire.

	3	2	1	0
Adjacency to water (lake, river, wetland)	≤ 30 meters	30-60 meters	60-90 meters	>90 meters
Slope (%)	□15	5-15	<5	-
Flow accumulation	□200	150-200	<150	-
Surficial geology	Floodplain alluvium	Sand and gravel deposits	Till or bedrock	-
Public water supply	Well and IWPA	-	-	-
T&E Habitat	MassGIS Core area	-	-	-
Land use	Residential (multi-family, high density) Commercial Industrial	Residential (medium density) Transportation Transportation facilities	Residential (low density)	-

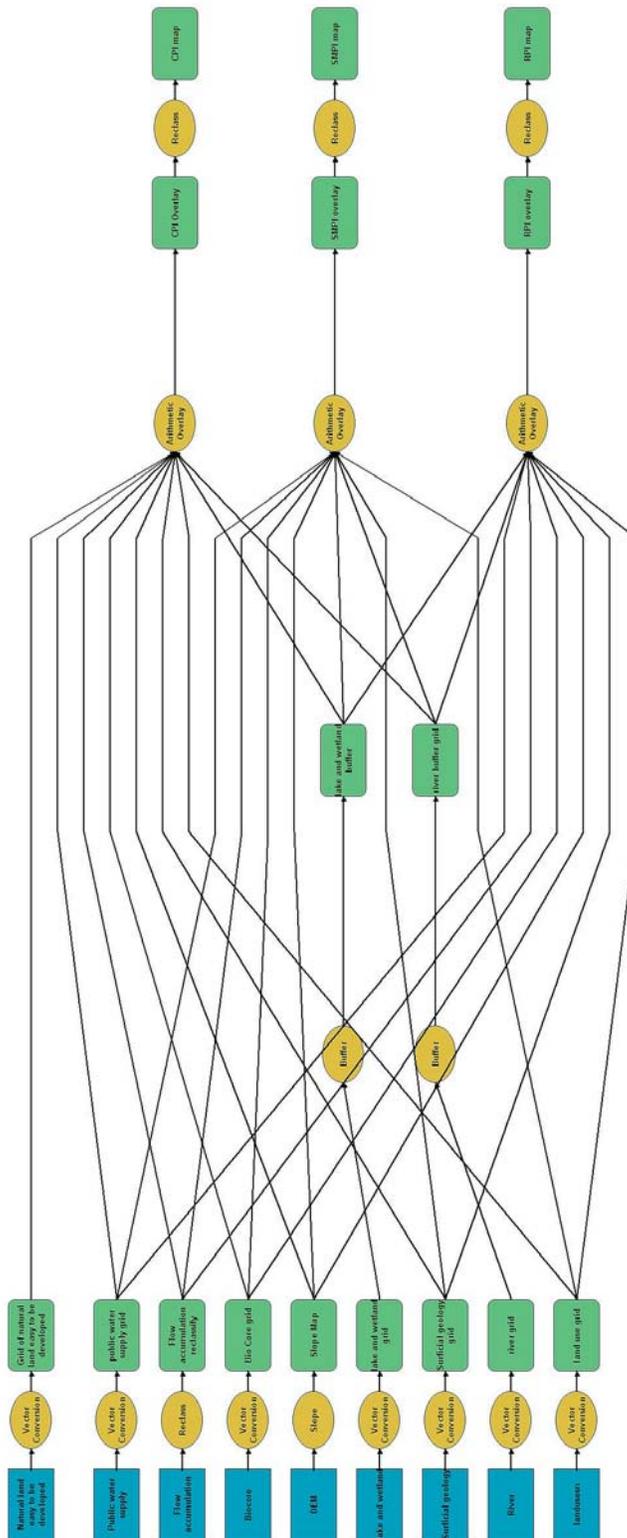


FIGURE 3 – Model schematic for Conservation (CPI), Restoration (RPI), and Stormwater Management (SMPI) Priority Indices for the Squannacook and Nissitissit River watersheds, Massachusetts and New Hampshire. The model structure may change as additional salient data become available.

PRIORITY INDICES AT THE WATERSHED SCALE

The overall extent, continuity, and importance of the forested land in the Squannacook and Nissitissit watersheds is clearly evident in the CPI overlay results (Figure 4). There are, however, gaps in the riparian forests bordering both rivers and many smaller tributaries that warrant attention. These correspond to areas and activities accounted for in the RPI and SMPI layers (Figures 5 and 6). The enlarged areas shown in Figures 7 through 10 also show the irregular width of riparian areas, as influenced by terrain features and soil properties. They also show patches with low CPI scores, typically well-drained soils on gentle slopes that are distant from streams and wetlands.

Since agricultural land uses only comprise about 6 percent of the study area, the RPI overlay process shows small scattered patches typical of southern New England (Figure 5). A notable exception is the large farm near the center of the Squannacook watershed (Figure 10). A review of aerial photographs and a site visit will be needed to determine whether the high RPI scores are consistent with field conditions and represent a threat to water quality. If riparian buffers are intact, livestock are excluded from water, and sediment and nutrients are carefully managed, then problems and opportunities lie elsewhere. If not, a "whole farm plan" and diligent implementation would help to minimize the effect of this parcel on water quality while maintaining an important part of the local community and landscape. The clusters of smaller patches with lower RPI scores in the downstream reaches of the Nissitissit and throughout the Squannacook may be small hayfields kept open by periodic mowing. Alternatively, they may be "hobby farms" with horses or other domestic livestock confined to small pastures. In some cases, soil compaction and year-round use lead to sediment, nutrient, and pathogen generation that can seriously impair water quality. In fact, a poorly managed hobby farms can substantially exceed the absolute impact of a large commercial operation (Fraser et al. 1998; Fraser 1999).

Because house lots require road frontage and reasonable access to secondary and primary roads for commuting, the road network often leads to adverse impacts on the quantity, timing, and quality of streamflow. In the Nashua subwatersheds—like most in rolling or mountainous terrain with human occupation dating from the Colonial period—roads follow, or at least parallel, streams. This brings 20th and 21st Century human activity in direct or proximate contact with receiving waters. The bright red areas scattered throughout the study area indicate parcels, subdivisions, or towns where stormwater management must meet very high performance standards in order to avoid contamination of source waters (Figure 6). The scattered spatial distribution may present an opportunity *or* a substantial challenge. It may be a cost-effective opportunity for water quality improvement if small-scale, low-tech Best Management Practices (BMPs) can prevent or mitigate urban stormwater impacts. Unfortunately, it may represent a substantial challenge if the space available for on-site mitigation (e.g., stormwater detention or diversion, created wetlands, etc.) does not permit enough time for settling and assimilation of suspended solids, nutrients, and other pollutants.

A composite map (Figure 7) is followed by a series four enlargements (Figures 8-11) that focus on key areas in the Squannacook and Nissitissit watersheds.

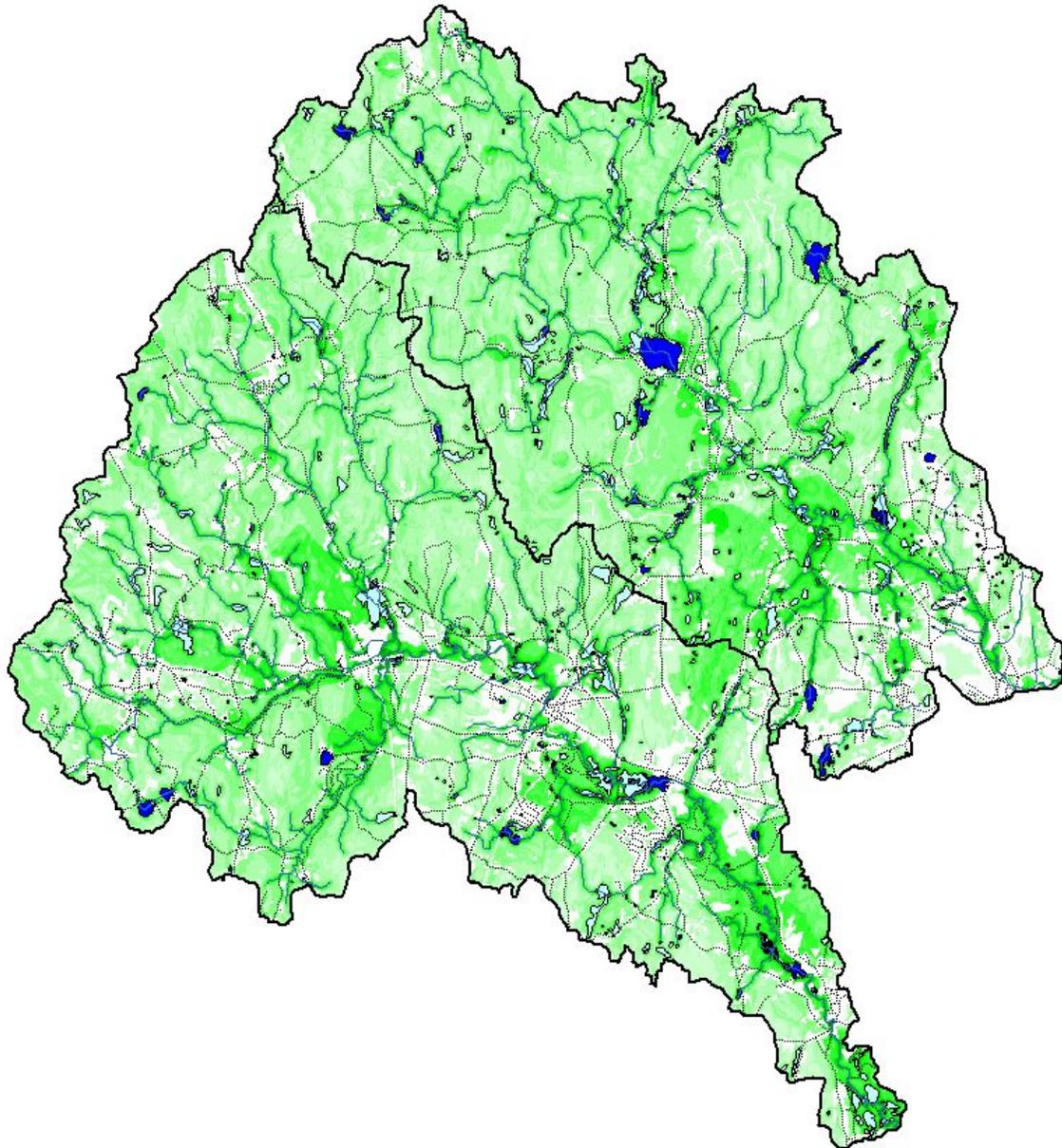


FIGURE 4 – Conservation Priority Index for forests and wetlands in the Squannacook and Nissitissit River watersheds, Massachusetts and New Hampshire. The darkest green hues have the greatest potential importance for the protection of source water quality and other ecological values. Dark blue represents water, light blue represents wetlands, dashed black lines are roads

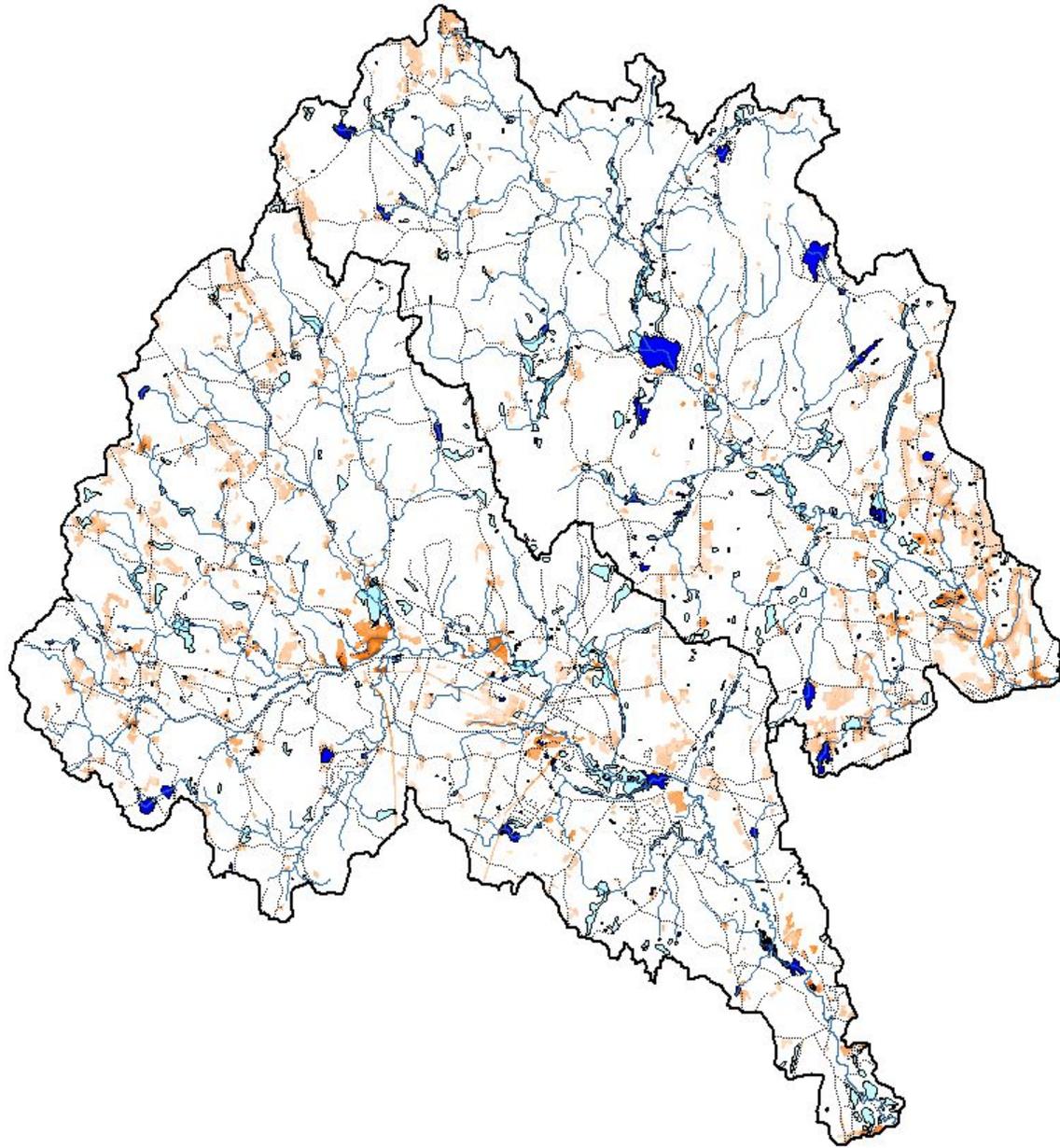


FIGURE 5 – Restoration Priority Index for agricultural and other open land in the Squannacook and Nissitissit River watersheds, Massachusetts and New Hampshire. The darkest orange hues have the greatest potential importance for the protection of source water quality and other ecological values. Dark blue represents water, light blue represents wetlands, dashed black lines are roads

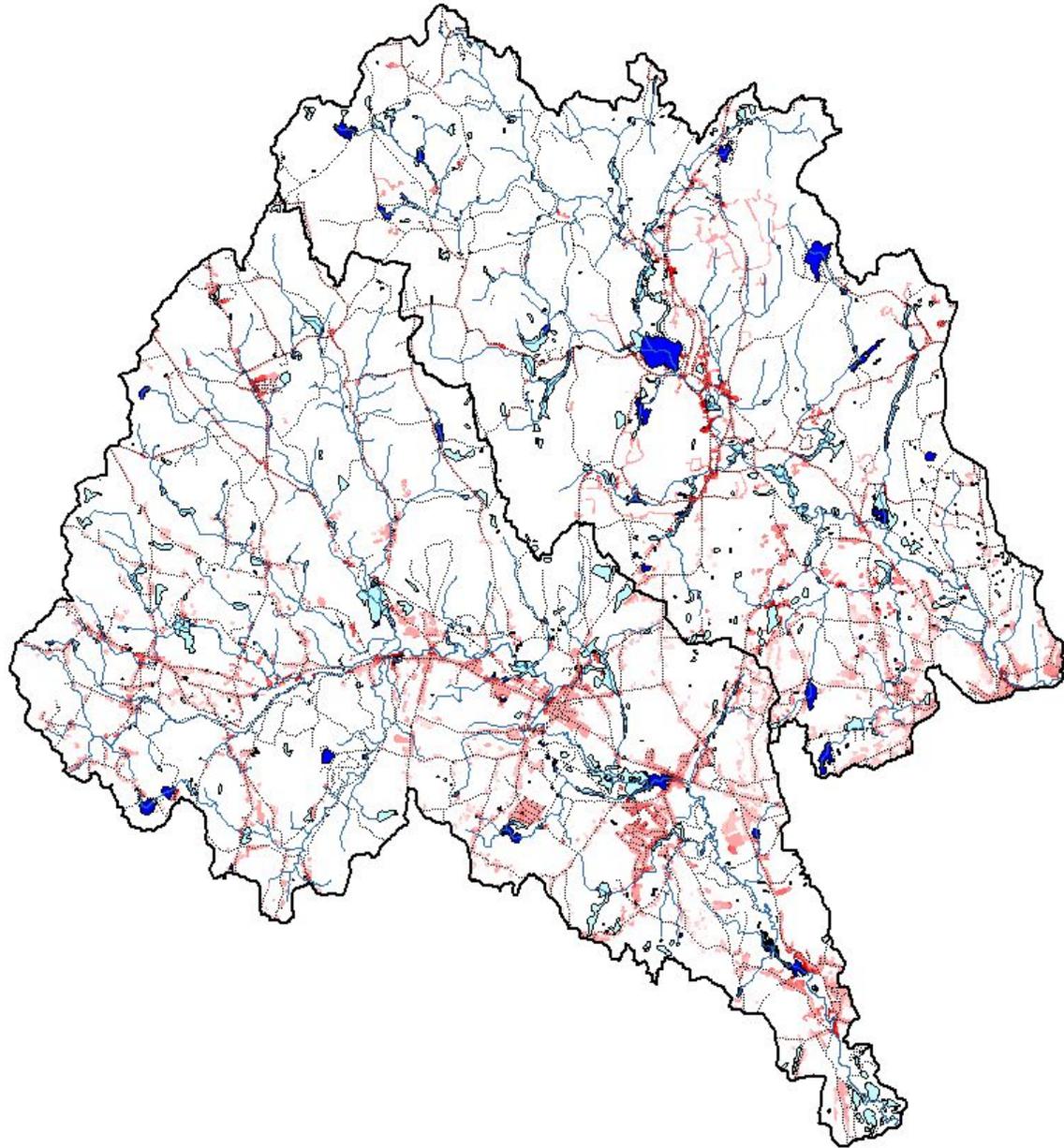


FIGURE 6 – Stormwater Management Priority Index for residential, commercial, and industrial land in the Squannacook and Nissitissit River watersheds, Massachusetts and New Hampshire. The darkest red hues have the greatest potential importance for the protection of source water quality and other ecological values. Dark blue represents water, light blue represents wetlands, dashed black lines are roads

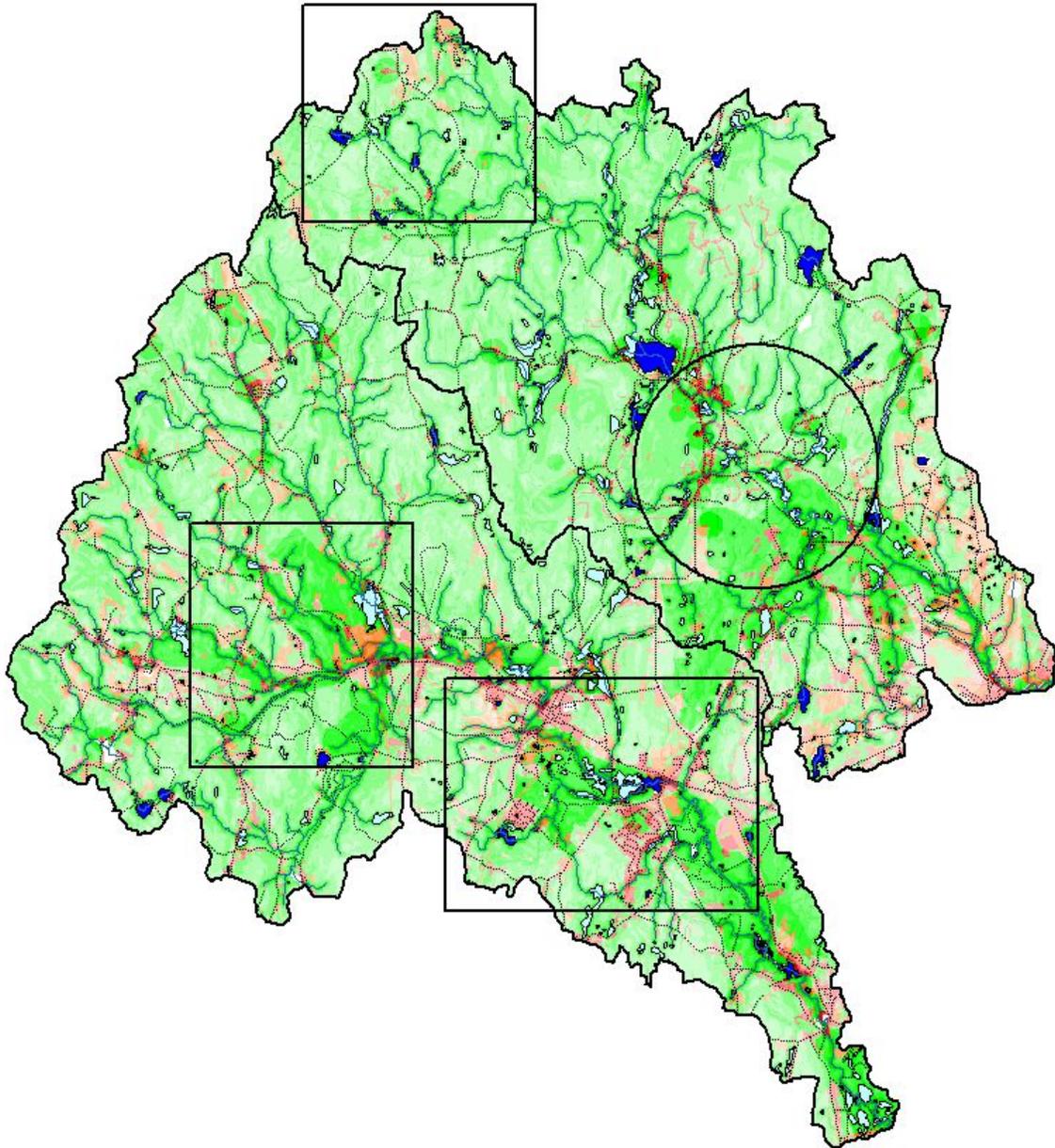


FIGURE 7 – A composite map of Conservation (green), Restoration (orange), and Stormwater Management (red) Priority Indices for the Squannacook and Nissitissit River watersheds, Massachusetts and New Hampshire. The darkest hues have the greatest potential importance for the protection of source water quality and other ecological values. The rectangles and circle show the areas enlarged in Figures 8-11 and 15-18. Dark blue represents water, light blue represents wetlands, dashed black lines are roads

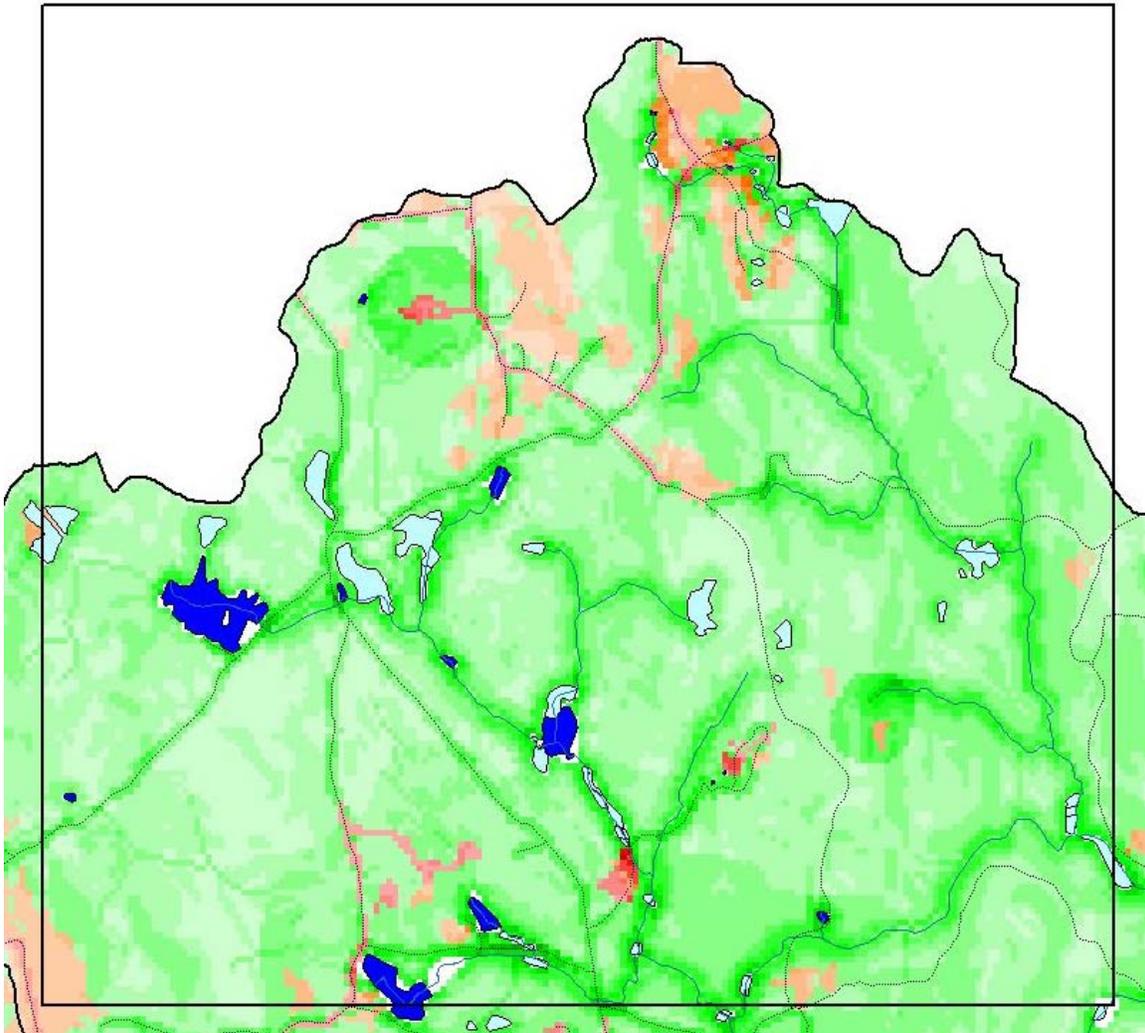


FIGURE 8 – A composite map of Conservation (green), Restoration (orange), and Stormwater Management (red) Priority Indices for an enlarged portion of the Nissitissit River watershed, New Hampshire. The darkest hues have the greatest potential importance for the protection of source water quality and other ecological values.

Cumulative effects on water quality begin at the watershed boundary. Small areas with high RPI scores appear along a headwater tributary of the Nissitissit at the northern edge of this enlargement. A patch of high SMPI values downstream from a group of small wetlands (light blue shading) in the south central part of the scene. The net effect of both areas will be determined by site-specific conditions and management practices *and* the assimilative capacity of many small wetlands and headwater stream reaches. In other words, in the best case, the influence of both areas would go undetected a few hundred meters downstream. In the worst case, NPS pollutants enter and begin to accumulate in the system within a few hundred meters of the watershed divide.

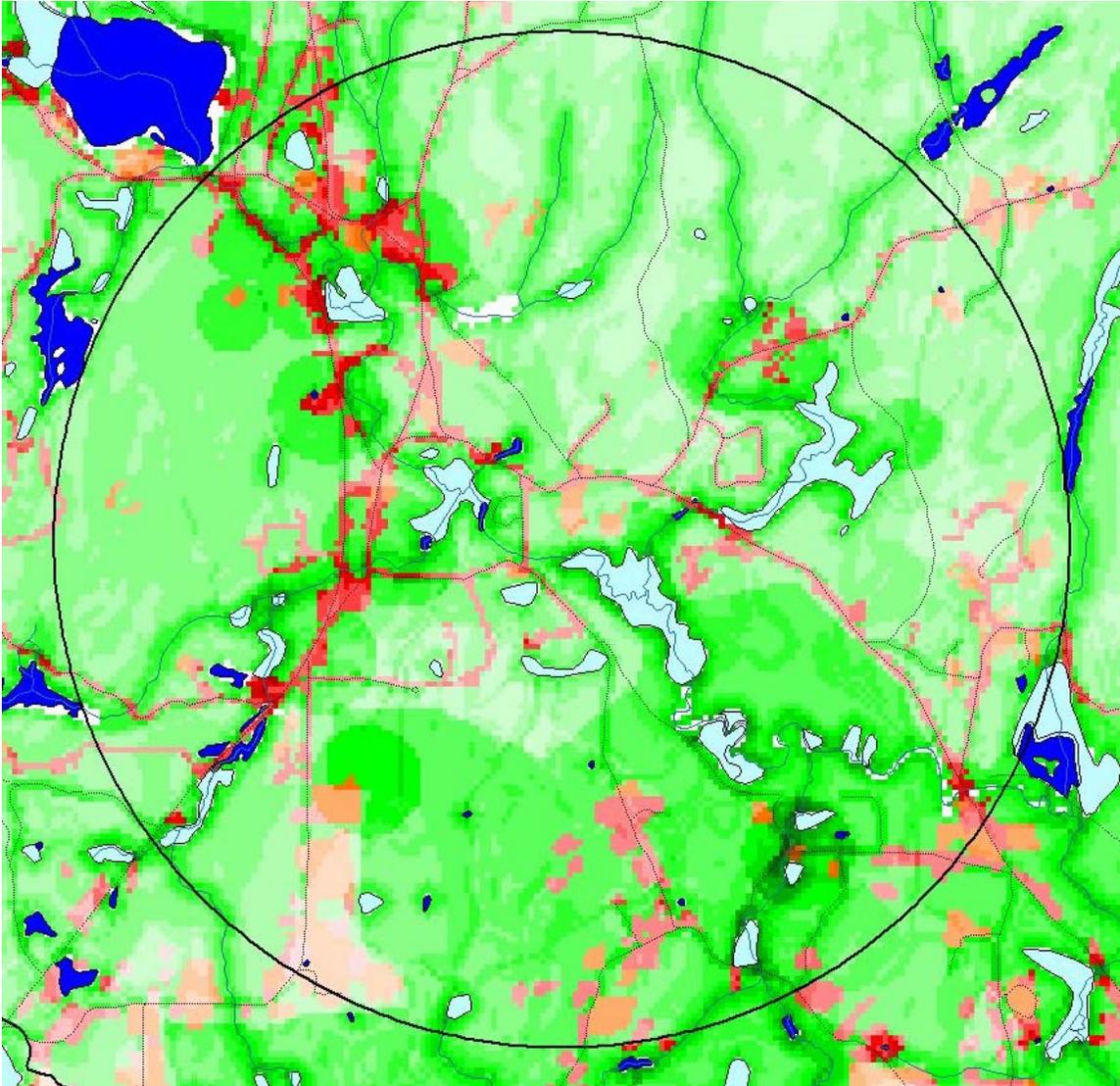


FIGURE 9 – A composite map of Conservation, Restoration, and Stormwater Management Priority Indices for an enlarged portion of the Nissitissit River watershed, New Hampshire. The darkest hues have the greatest potential importance for the protection of source water quality and other ecological values.

The large contiguous patches of high CPI scores reflect the core habitat areas used in the overlay process. The dark green circular areas indicate two features: (1) community water supply wells with a 300 meter radius protection zone and (2) 100 meter radius buffers around point locations of rare or threatened plants or animals identified by New Hampshire Natural Heritage. The high CPI scores in the southeast portion of the scene underscores the importance of wetland and intermediate stream reaches (2nd and 3rd order) for the maintenance of water quality. Another prominent feature of this enlarged area is this complex patchwork of agricultural and developed land and its relation to streams and wetlands. Development shown in the northwest portion of the figure is entangled with streams and wetlands over a significant area. Site-specific assessments, especially at road-stream crossings, will be needed to evaluate this problem.

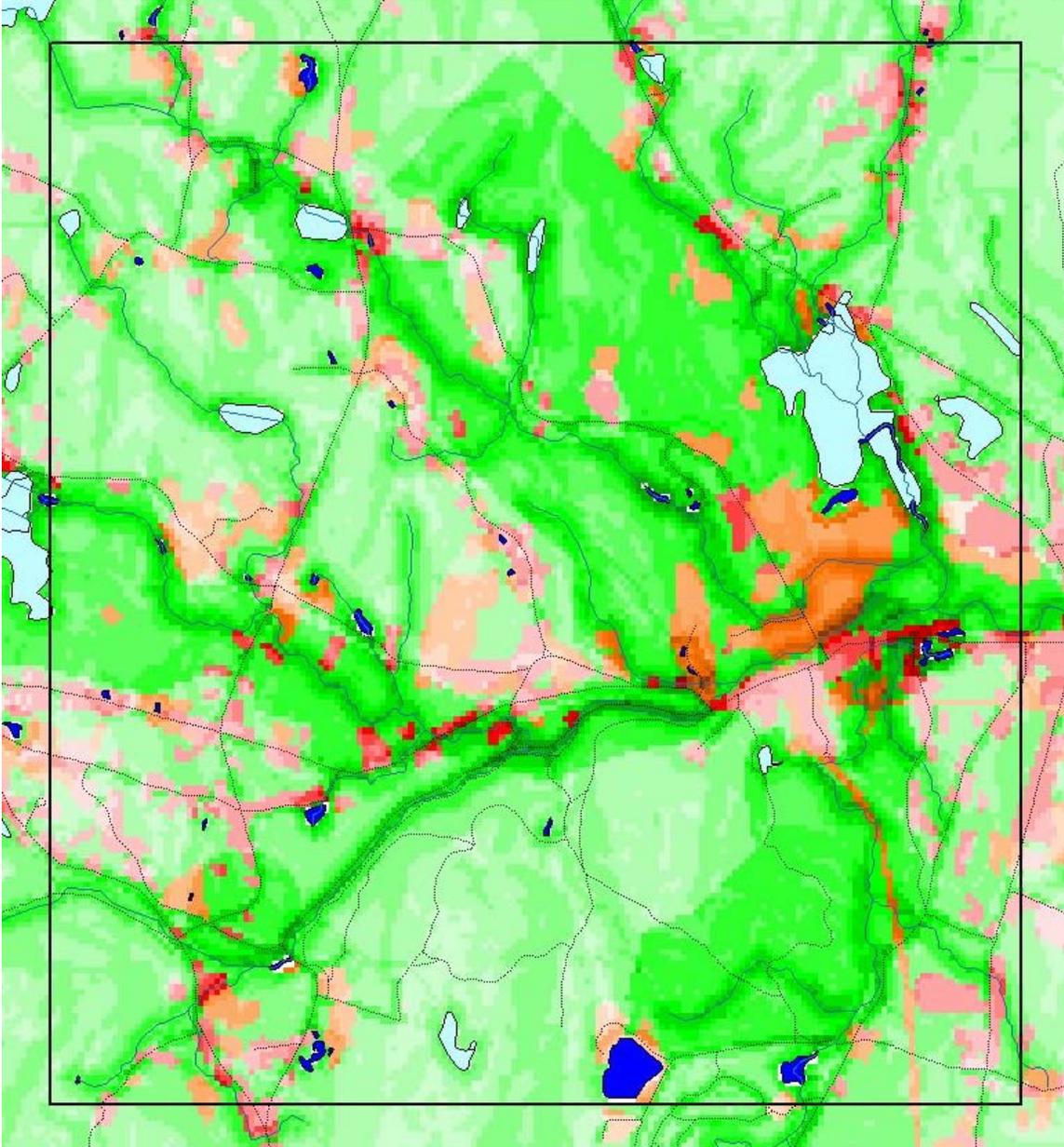


FIGURE 10 – A composite map of Conservation, Restoration, and Stormwater Management Priority Indices for an enlarged portion of the Squannacook River watershed, Massachusetts. The darkest hues have the greatest potential importance for the protection of source water quality and other ecological values.

As noted in the overview discussion of the RPI and SMPI layers, the farms (orange) and developed areas (red) in this scene warrant field assessments. These areas could have a disproportionately large adverse impact on water quality in the Squannacook River. Alternatively, a well managed farm can have a minimal impact and would be preferable to a large, high density residential subdivision on the same parcel.

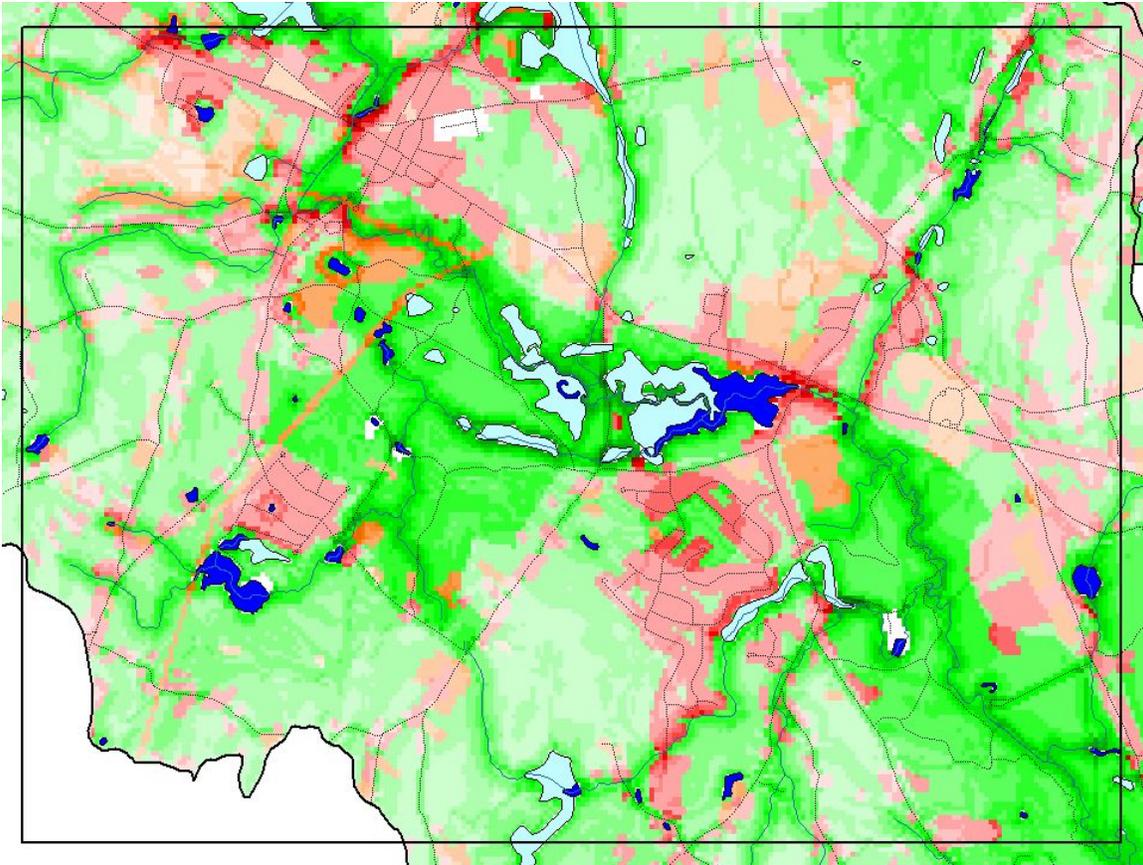


FIGURE 11 – A composite map of Conservation, Restoration, and Stormwater Management Priority Indices for an enlarged portion of the Squannacook River watershed, Massachusetts. The darkest hues have the greatest potential importance for the protection of source water quality and other ecological values.

This enlargement shows the potential influence of larger areas of development on water quality. The high SMPI scores immediately adjacent to streams and wetland are expected but may not indicate the full extent of impacts. The design and maintenance of storm drain systems in adjacent areas with lower SMPI values will be a key determinant of water quality impacts. If, for example, the developed areas in the northwest and southeast portions of the scene are connected directly, via drop inlets and pipes, to nearby streams and wetlands, some redesign and retrofit work will probably be needed. On-site infiltration of stormwater (e.g., dry wells for roof drainage), pre-treatment of overland flow from roads (e.g., filter media in catch basins changed at regular intervals), and periodic household hazardous waste collection could prevent a substantial amount of pollution without costly and disruptive re-construction of storm sewers.

In addition to the detailed review of GIS layers, CPI, RPI, and SMPI scores also can be evaluated with basic statistical methods (Figure 12). As expected, the frequency distributions for the priority indices are negatively skewed – many ordinary values, few exceptional values. By design, the GIS overlay process highlights the sites with combined characteristics that warrant special attention. For example, a forested grid cell that is within 30 meters of a stream, with a slope greater than 15%, et cetera (see Table 2) would yield a CPI score of 18; one of 154 grid cells out of 303,292 in the CPI calculation for the Squannacook and Nissitissit watersheds. By contrast, there are 100,782 cells with a score of 6.

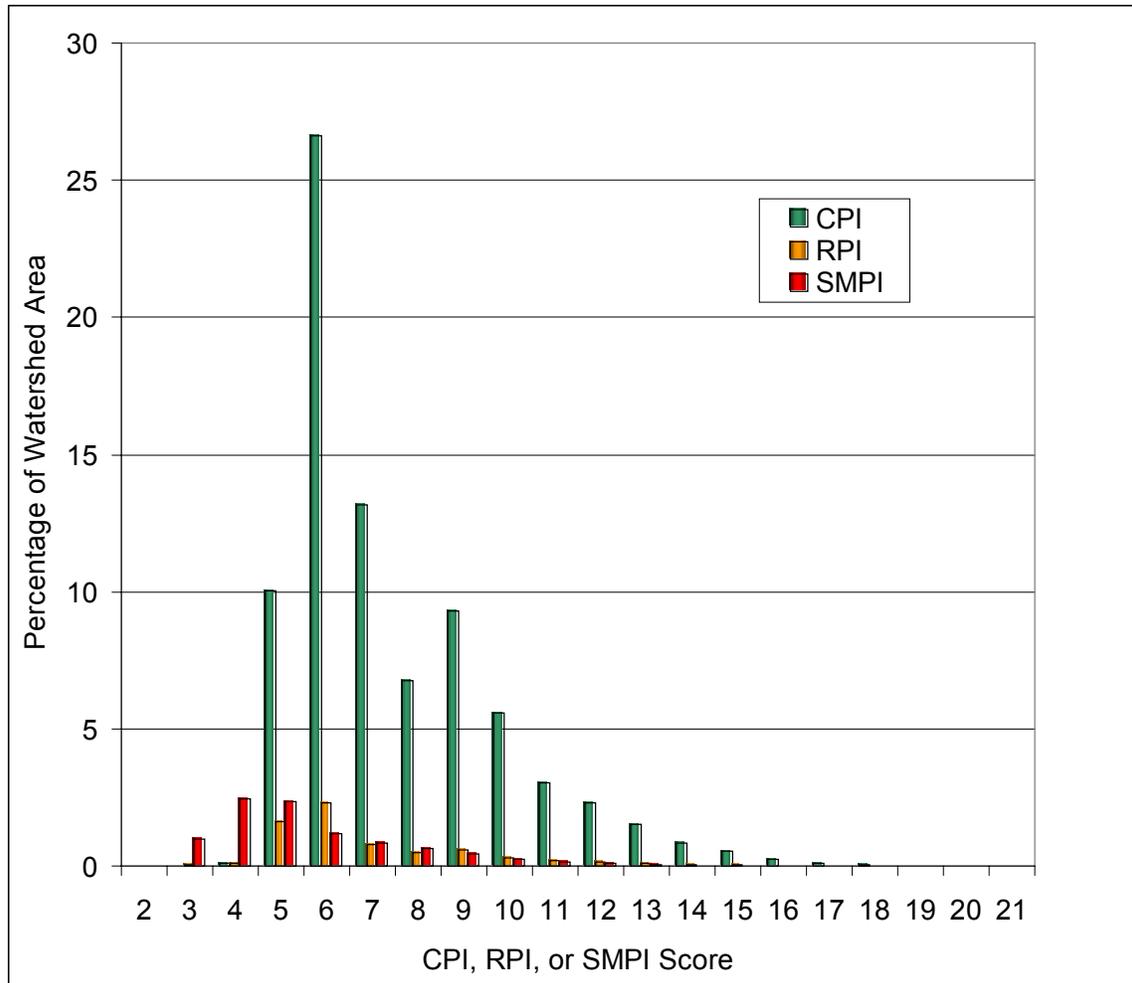


FIGURE 12 – Frequency distributions of Conservation (CPI, green), Restoration (RPI, orange), and Stormwater Management (SMPI, red) Priority Indices for the Squannacook and Nissitissit River watersheds, Massachusetts and New Hampshire.

When plotted as cumulative frequency distributions, percentile ranks can be readily determined for all three indices (Figure 13). A cumulative frequency distribution is developed by beginning with the lowest score and adding the total number of grid cells in each successive class until reaching the highest score and 100th percentile (e.g., 21 for

CPI). This is the same procedure used to report standardized test scores such as the SATs or as a reference for children's height and weight at annual physical examinations.

Interpreting and using both frequency distributions is directly analogous to the process by which teachers assign letter grades in relation to total numerical scores ...90% and higher, A, 80 to 90%, B, 70 to 80%, C ...and so forth. For example, the 90th percentile (the top 10% of CPI, RPI, and SMPI scores) can be used to focus land conservation, pollution prevention, and pollution mitigation efforts on areas that should generate the greatest return on investment. The GIS can be used to generate a customized map of the highest scores (e.g., 80th and 90th percentiles) in relation to streams, lakes, wetlands, and roads (Figures 14 through 18). This process can be incremented by different percentages and done separately or simultaneously for the three indices to enumerate and explore a range of management options.

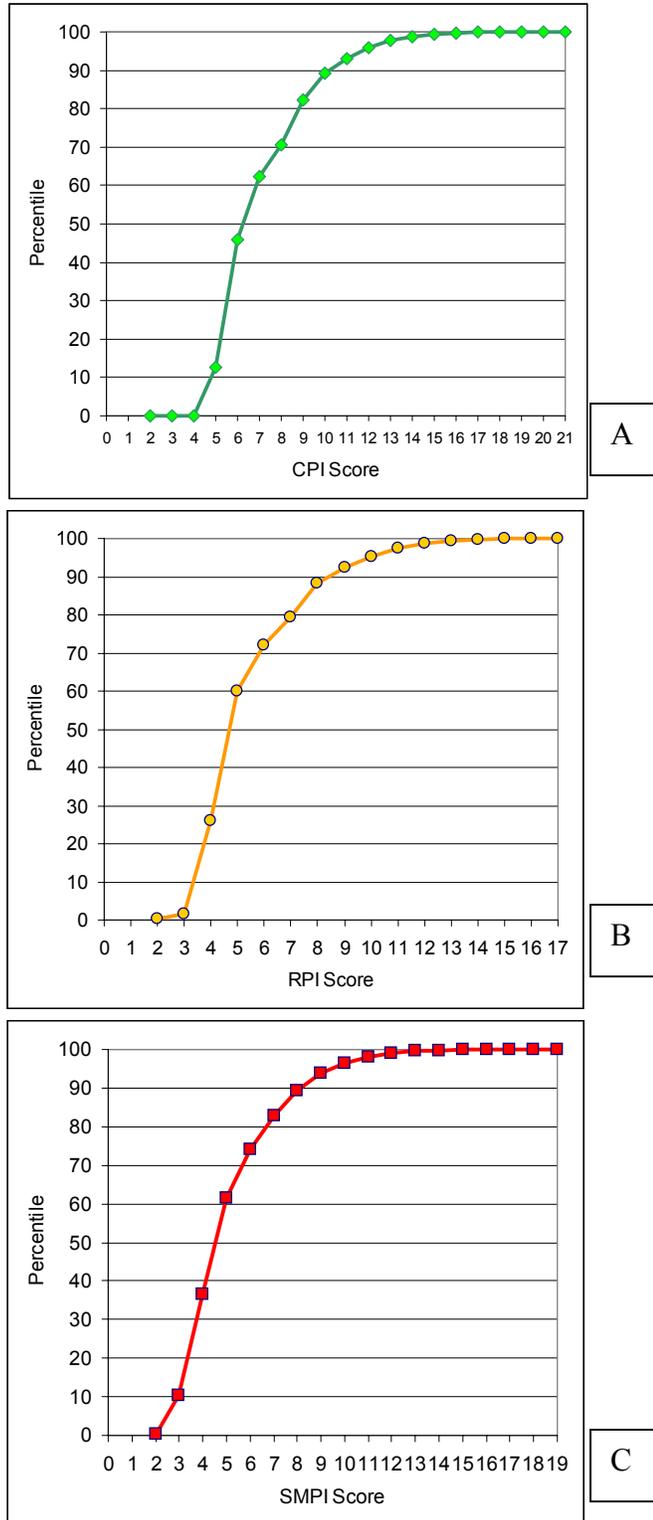


FIGURE 13 – Cumulative frequency distributions for Conservation (“A”), Restoration (“B”), and Stormwater Management (“C”) Priority Indices for the Squannacook and Nissitissit River watersheds, Massachusetts and New Hampshire.

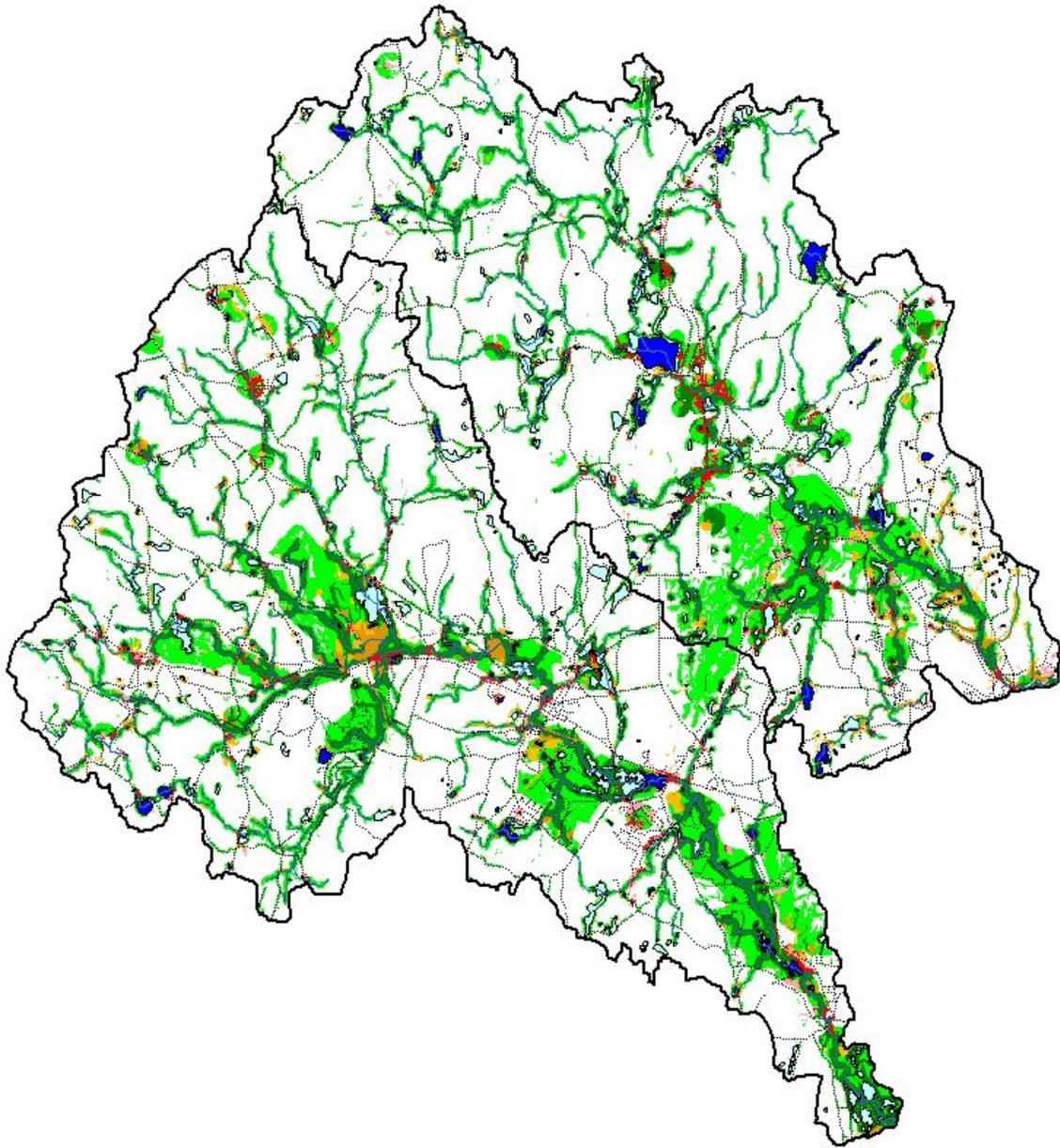


FIGURE 14 – Conservation, Restoration, and Stormwater Management Priority Indices (green, orange, and red, respectively) in the $\geq 80^{\text{th}}$ or $\geq 90^{\text{th}}$ percentile (light hues and dark hues, respectively) for the Squannacook and Nissitissit River watersheds, Massachusetts and New Hampshire. Also shown are roads, streams, lakes, ponds, and wetlands. Enlarged areas (demarcated in Figure 7) are shown in Figures 15-18.

This landscape-scale depiction of the 80th and 90th percentile CPI, RPI, and SMPI scores highlights (1) the importance of riparian forests throughout the watershed, (2) large contiguous patches of forests and wetlands, and (3) challenges associated with development in or around riparian and aquatic ecosystems.

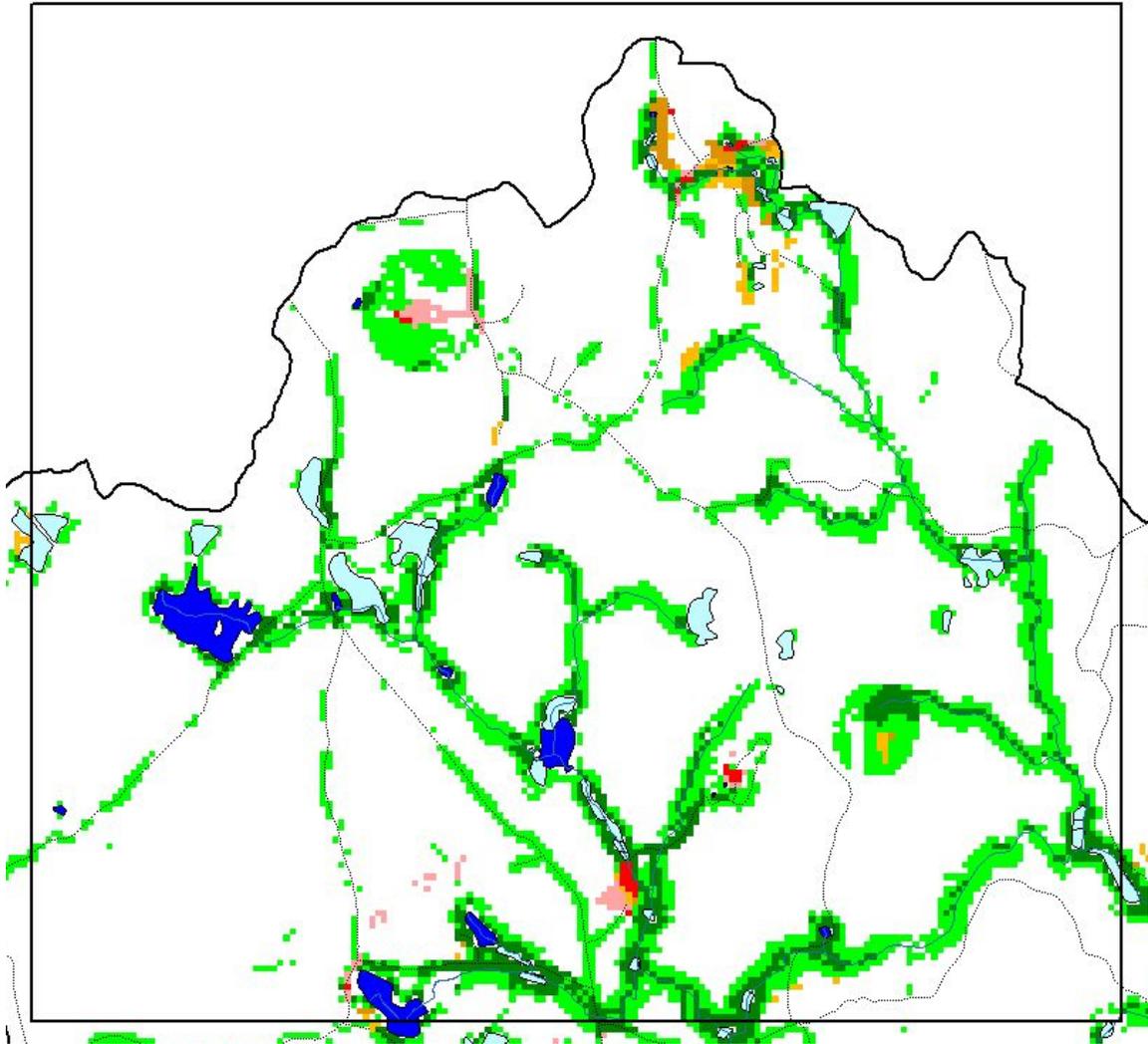


FIGURE 15 – Conservation, Restoration, and Stormwater Management Priority Indices (green, orange, and red, respectively) in the $\geq 80^{\text{th}}$ or $\geq 90^{\text{th}}$ percentile (light hues and dark hues, respectively) for the Nissitissit River watershed, New Hampshire. Also shown are roads (dashed lines), streams, lakes, ponds, and wetlands.

As noted on page 16, this headwater area has uninterrupted, high value riparian forests over most of the scene. It also has conspicuous, albeit small, patches of high RPI and SMPI scores that warrant attention. They may be benign or insignificant or mark the beginning of NPS pollutant loading high in the headwaters. Protecting ambient water quality in the headwaters augments the assimilative capacity of downstream reaches that may be subject to more pollutant loading. Dilution is at least part of the solution to pollution.

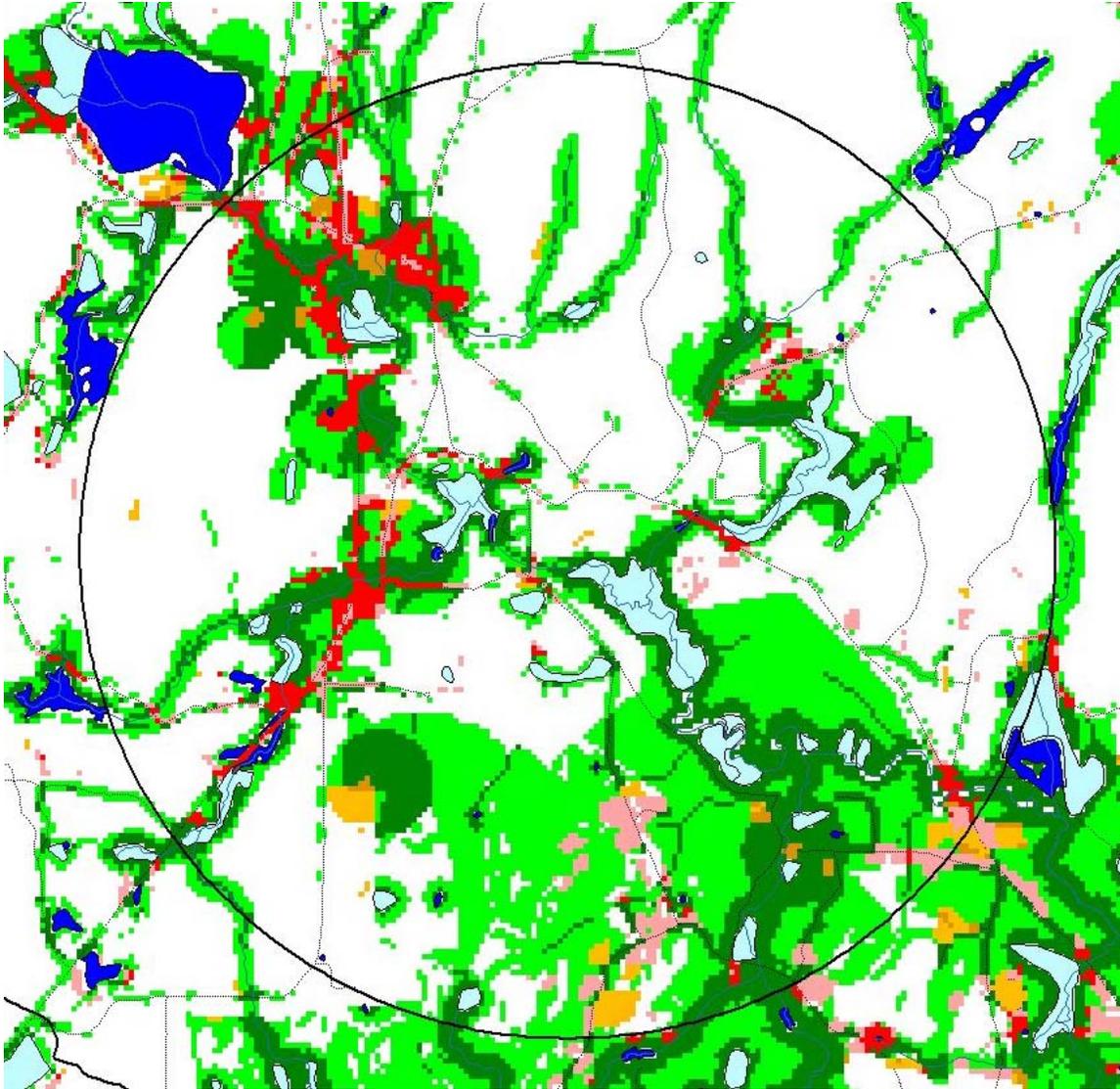


FIGURE 16 – Conservation, Restoration, and Stormwater Management Priority Indices (green, orange, and red, respectively) in the $\geq 80^{\text{th}}$ or $\geq 90^{\text{th}}$ percentile (light hues and dark hues, respectively) for the Nissitissit River watershed, New Hampshire. Also shown are roads (dashed line), streams, lakes, ponds, and wetlands.

This scene amplifies the patterns, trends, and challenges discussed on page 17. It could be particularly important to proactively manage this area so efforts to deliver clean water from upstream areas are not negated by what may be, in effect, a point source discharge of urban stormwater. The 1998 water quality assessment by the MA DEP noted "slight impairment" of water quality and "partial support" of aquatic life in the last 1.2 miles of the Nissitissit before its confluence with the Nashua River (MA DEM 2001:xi and 110-111). Their findings may be linked with land use in this area as well as the effect of small impoundments.

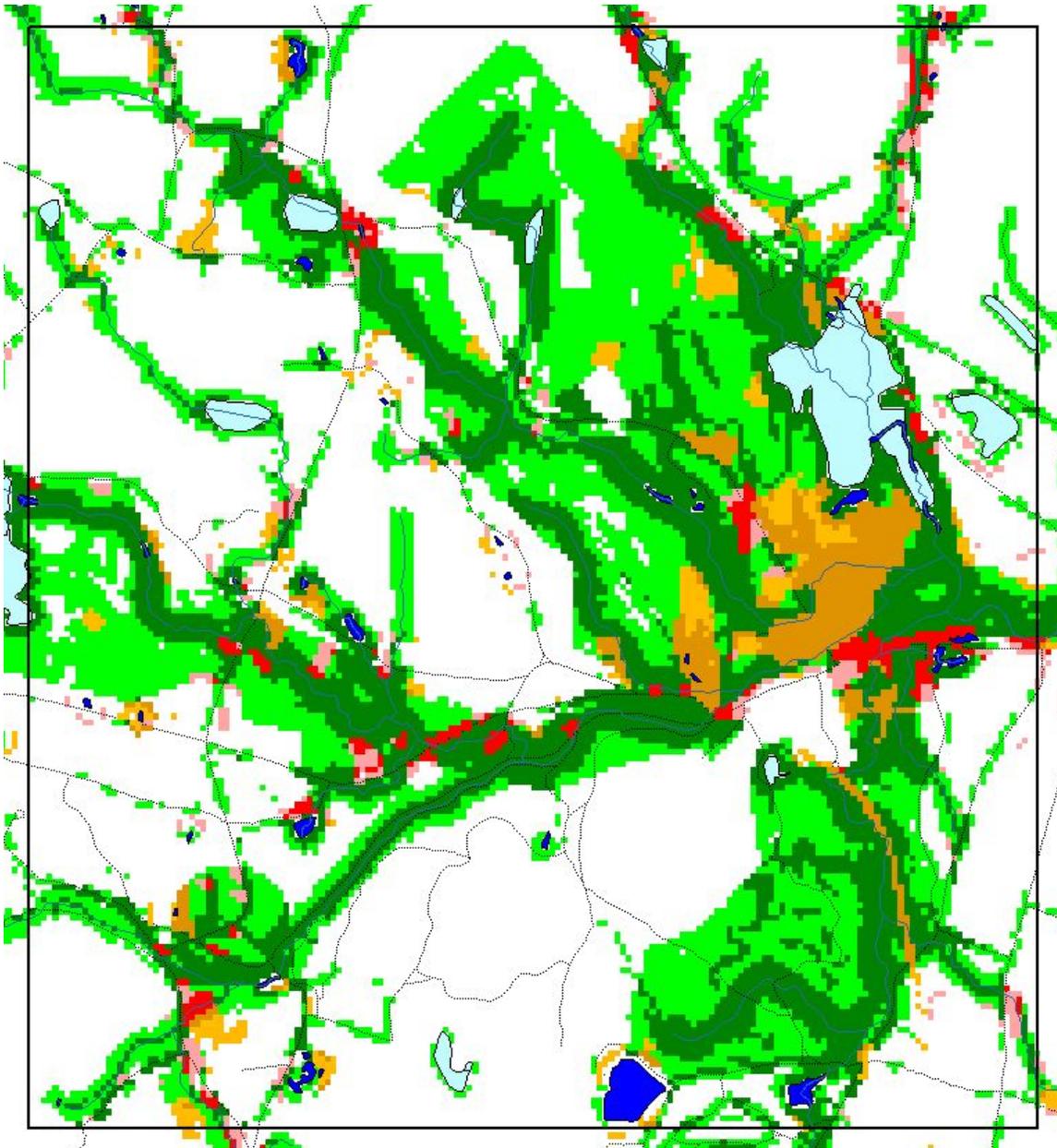


FIGURE 17 – Conservation, Restoration, and Stormwater Management Priority Indices (green, orange, and red, respectively) in the $\geq 80^{\text{th}}$ or $\geq 90^{\text{th}}$ percentile (light hues and dark hues, respectively) for the Squannacook River watershed, Massachusetts. Also shown are roads (dashed line), streams, lakes, ponds, and wetlands.

Most of the large farm near the center of the scene ranks in the 90th percentile of RPI scores. Along with several clusters of developed land with high SMPI scores, the farm(s) occupy a key landscape position near the confluence of several small tributaries. This is underscored by the extensive areas of high conservation value forest in the same area.

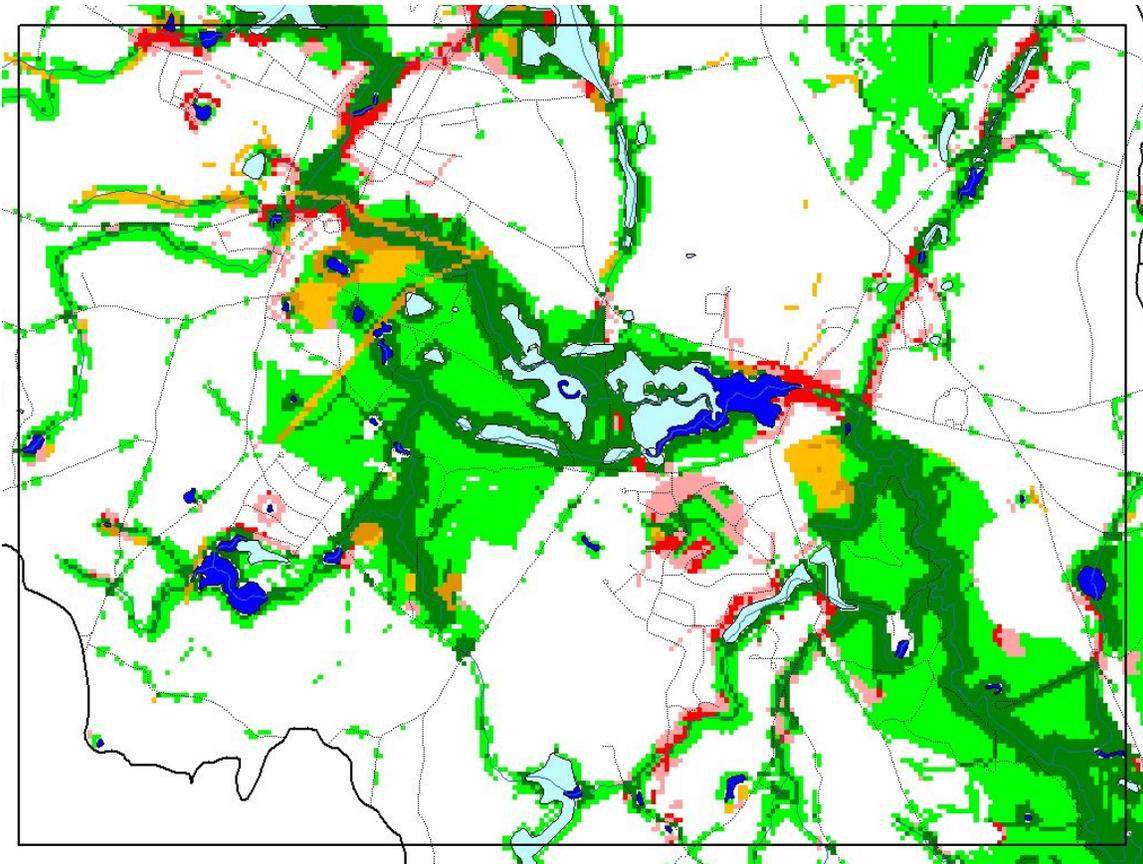


FIGURE 18 – Conservation, Restoration, and Stormwater Management Priority Indices (green, orange, and red, respectively) in the $\geq 80^{\text{th}}$ or $\geq 90^{\text{th}}$ percentile (light hues and dark hues, respectively) for the Squannacook River watershed, Massachusetts. Also shown are roads (dashed line), streams, lakes, ponds, and wetlands.

The high SMPI scores in two gaps in the riparian forest shows the potential for direct impacts. However, as noted on page 19, the overall influence of development depends upon the design and construction of storm sewers and roads. As-built plans for these features, along with field assessments, are needed to trace the path of stormwater and NPS pollutants to the Squannacook. The large areas of intact forest adjacent to developed areas may provide the opportunity for distributed treatment of stormwater (e.g., on-site detention basins, infiltration trenches, created wetlands, etc.). Like the lower reaches of the Nissitissit, the 1998 MA DEP assessment identifies slight impairment of water quality and partial support of aquatic life in the lower reaches (3.6 miles) of the Squannacook (MA DEM 2001: xi and 111). Elevated fecal coliform bacteria counts on some sampling dates indicate the contamination by pet waste common in residential areas.

WATERSHED MANAGEMENT IMPLICATIONS

At present the Squannacook and Nissitissit watersheds are largely forested and ambient water quality is high. However, land cover in the watersheds (81% forest and wetlands, 6% agricultural, and 13% developed land) is precariously close to two thresholds (~75% forest and ~10% impervious surfaces) after which rapid changes in streamflow and associated degradation of water quality begins to occur (Hornbeck et al. 1997; NRC 2000 and 2002). Ironically, the rural appearance of the landscape may make it more difficult to develop a sense of urgency needed to protect and conserve clean water. This will require sustained education and outreach efforts, something NGOs and the Nashua Watershed Team are uniquely positioned to do.

Local officials, business leaders, and the public at large need to understand that land conservation and source water protection are the best long-term investments in ecosystem and public health. Although preventive maintenance is less glamorous than ecosystem restoration, it usually costs pennies on the dollar to *avoid* rather than *repair* damage. Nevertheless, it can be more difficult to generate support for proactive conservation rather than reactive restoration work.

In the Upper Little Tallapoosa River watershed in Georgia (50% forest, 30% agricultural, and 20% developed) and the Prettyboy Reservoir watershed in Maryland and Pennsylvania (38% forest, 47% agricultural, and 15% developed), our preliminary management recommendations included the usual litany: restoring riparian forest buffers, fencing livestock from streams, soil erosion control and nutrient management on cropland, protecting wetlands, mitigating urban stormwater, guiding development to the least sensitive land, influencing the design of residential subdivisions, and educating landowners about a wide range of options. Because of the current character and condition of the Squannacook and Nissitissit watersheds, we can anticipate the need for all of the above ...just at a smaller scale.

In Georgia, residents of the city of Carrollton have endured a *Cryptosporidiosis* outbreak from fecal contamination of the Upper Little Tallapoosa. In Maryland, the Prettyboy Reservoir has frequent and persistent algal blooms, a reminder of nutrient loading problems and a precursor to carcinogenic disinfection by-products when the water is chlorinated. By contrast, the signs of change in the Squannacook and Nissitissit watersheds are more subtle and indirect — more traffic, more commercial development, higher land and housing prices.

In summary, the primary watershed management implication of our work to date is the need to develop broad-based support and a sense of urgency to maintain or enhance existing conditions in the face of pervasive and one-directional development pressure.

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