

7.0 MONITORING THE STATUS AND IMPACTS OF FOREST FRAGMENTATION AND URBANIZATION

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The geographic expansion of urban and suburban development and the influx of residential and recreational development into previously forested areas are growing concerns for natural resource managers. This project sought to:

- Identify and characterize urbanization and forest fragmentation over large areas with the detail and accuracy required for studies of wildlife habitat, plant composition, and water quality
- Identify potential effects of urbanization and fragmentation on water quality
- Develop appropriate methods for achieving the first two objectives, with a focus on:
 - o Identifying ways of describing and quantifying urbanization and forest fragmentation that are scale- and issue-appropriate, reasonably accurate, consistent over time, and relevant to management.
 - o Identifying measures of and standards for accuracy assessment

7.1 Background

Development intrusion has been shown to increase edge conditions and reduce forest interior habitat, which can change the habitability of the forest for particular wildlife or plant species. Enough development may even create isolated islands of this previously continuous forest habitat, affecting the long-term survivability of such species and biodiversity of the system as a whole. Contributing to the effects of forest fragmentation, urbanization increases the proximity of forest land to human disturbances and land uses such as roads, industrial sites, and residential areas, and changes the landscape context in which a forest or stream occurs. This frequently increases contact between humans and forests and streams, changes the local hydrology, alters the types of forest management that can be used, facilitates the invasion of exotic species and increases exposure to chemical pollutants. Changes in the type, density, and distribution of developed land uses within the surrounding area have the potential to change the physical and biochemical characteristics of terrestrial and aquatic ecosystems and to alter many of the ecological processes at work.

7.2 Measurement of Urbanization and Fragmentation

Urbanization is the process of increasing urban (vs. agricultural) development and includes the loss of forest land to developed land uses. Forest fragmentation in this study was considered to be the spatial breakup of forest land by developed land uses and is described by its distribution and configuration with respect to other land uses. Context, another important descriptive factor, is defined as the land use composition and pattern of the area surrounding a point, stream, or patch of forest of interest. Proximity is a measure of the distance between forest or stream to the nearest developed land use of any type. Together, these types of measures describe landscape characteristics of interest for their potential impact on forest and hydrologic systems.

A number of methods and indicators have been used for assessing urbanization and forest fragmentation. These include, but are not limited to, quantification of patch size and shape, edge, interior area, land use composition, forest isolation, human use, landscape pattern, and parameters describing landscape texture and the degree of connectivity. Different

parameters of landscape structure have more or less relevance to specific issues of interest because of their correlation with observed changes in those areas. For example, parameters of fragmentation, proximity, and context that have been shown to be important to forest management are the size of the forested patch and its distance to the nearest road, residential, or urban area—factors that affect both treatment constraints and the economic viability of forest industry on that patch (e.g., Barlow et al. 1998, Cooksey 2000, Wear et al. 1999). On the other hand, parameters of fragmentation observed to be important to water quality are land use composition of the watershed; length of stream bounded by agriculture, forest, and residential; and percent of impervious surfaces in the watershed—factors that affect flow and flow variability, biogeochemical cycles, macroinvertebrates, and sedimentation (e.g., Hunsaker et al. 1992, McMahon and Cuffney 2000, Richards and Host 1994, Wear et al. 1998). Parameters observed to be important to changes in forest composition are total size of forest patch, amount of edge, distance from edge, distance to nearest road or developed land use, an index of human development or human use, or a measure of human, deer, or road density in the area—all factors that have the potential to affect regeneration, differential species survival, and the number of exotics or invasives introduced (e.g., Airola and Buchholz 1984, Heckscher et al. 2000, Saunders et al. 1991, Zipperer and Pouyat 1995).

Scale is another important factor in the study of the effects of human development on forest and hydrologic systems. For example, effects on water chemistry and quality may be local (affected by streamside land use), regional (affected by the land use composition and configuration of the entire watershed), or perhaps broader if contaminants are airborne. Effects of forest fragmentation on forest composition may be local (invasive species from neighboring land uses) or local and regional (human recreation pressure). Fragmentation measures at multiple scales will thus likely be important until the relative magnitude and thresholds of these effects are better understood.

7.3 Existing Monitoring and Regional Assessment Capability

Before this study, efforts to monitor fragmentation focused on developing methods to quantify it using remotely sensed imagery. Two existing programs in this region were a) the sample point interpretations of 1:40,000 aerial photography at FIA phase 1 points (Riemann and Tillman 1999) (Fig. 7.1) and b) statistics generated from Landsat Thematic Mapper (TM)-derived land use/land cover classifications (Riitters et al. 2000) (Fig. 7.2). Other efforts such as point or area interpretation from 1:40,000 aerial photography at FIA plot locations (Collins 1995, Rudis 1995) did not provide regional maps of these variables, but did provide fragmentation or context statistics for those point locations and areas large enough to contain a sufficient number of plots (Fig. 7.3). Other efforts improved small area estimates by increasing the sampling intensity of these photointerpretation points with subsequent tradeoffs in cost or number of variables collected (Azuma et al. 1999). Still other efforts used related and already available information such as roads or road density to describe and quantify human impact in an area (Fig. 7.4).

These monitoring strategies, while providing us with a relative picture of how fragmented an area is in comparison with other areas within the region, often gave us little information about the impact of fragmentation on ecosystem health because the measures being monitored were not yet linked to studies of impacts on forest or water quality, or the thresholds of impact were not well understood. Similarly, techniques had not yet been

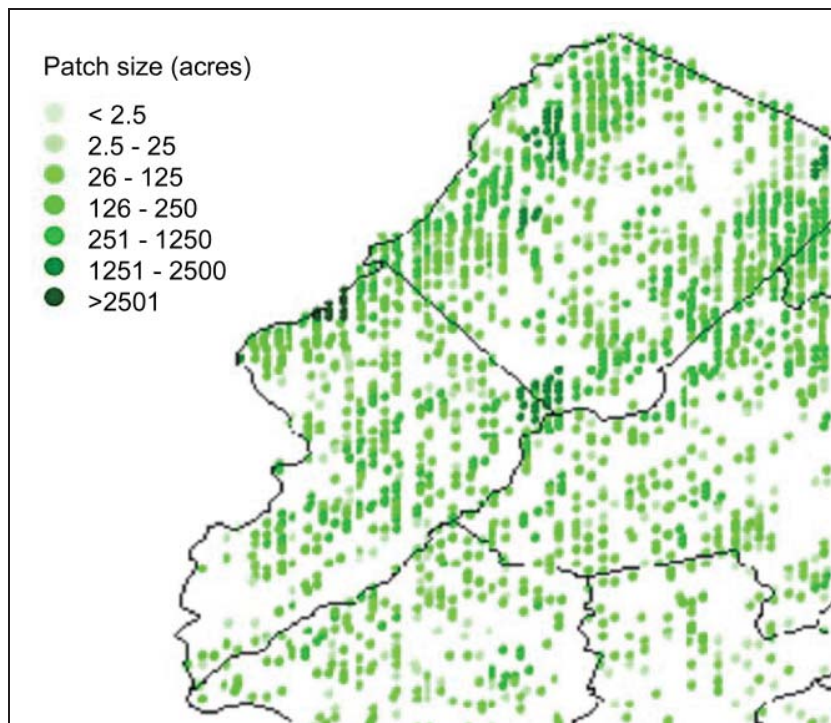


Figure 7.1.—Point-sample interpretation from high resolution imager—example of forest patch sizes in northern New Jersey.

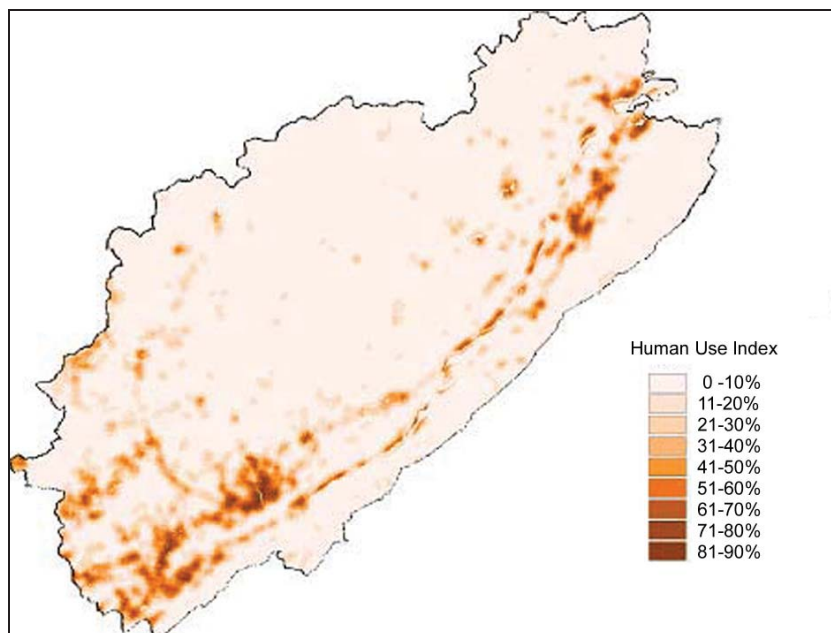


Figure 7.2.—Calculation of a human-use index from a TM-derived land use-land cover map using a 27x27 cell window—example from the Delaware Water Gap IMRA tributary watersheds. Human-use index is the proportion of agriculture plus developed land cover types in the window and is a measure of general land use pressure by humans. From: Riitters et al. (2000).

Figure 7.3.—An illustration of area-sample interpretation around FIA plots—example from the Delaware Water Gap IMRA tributary watersheds.

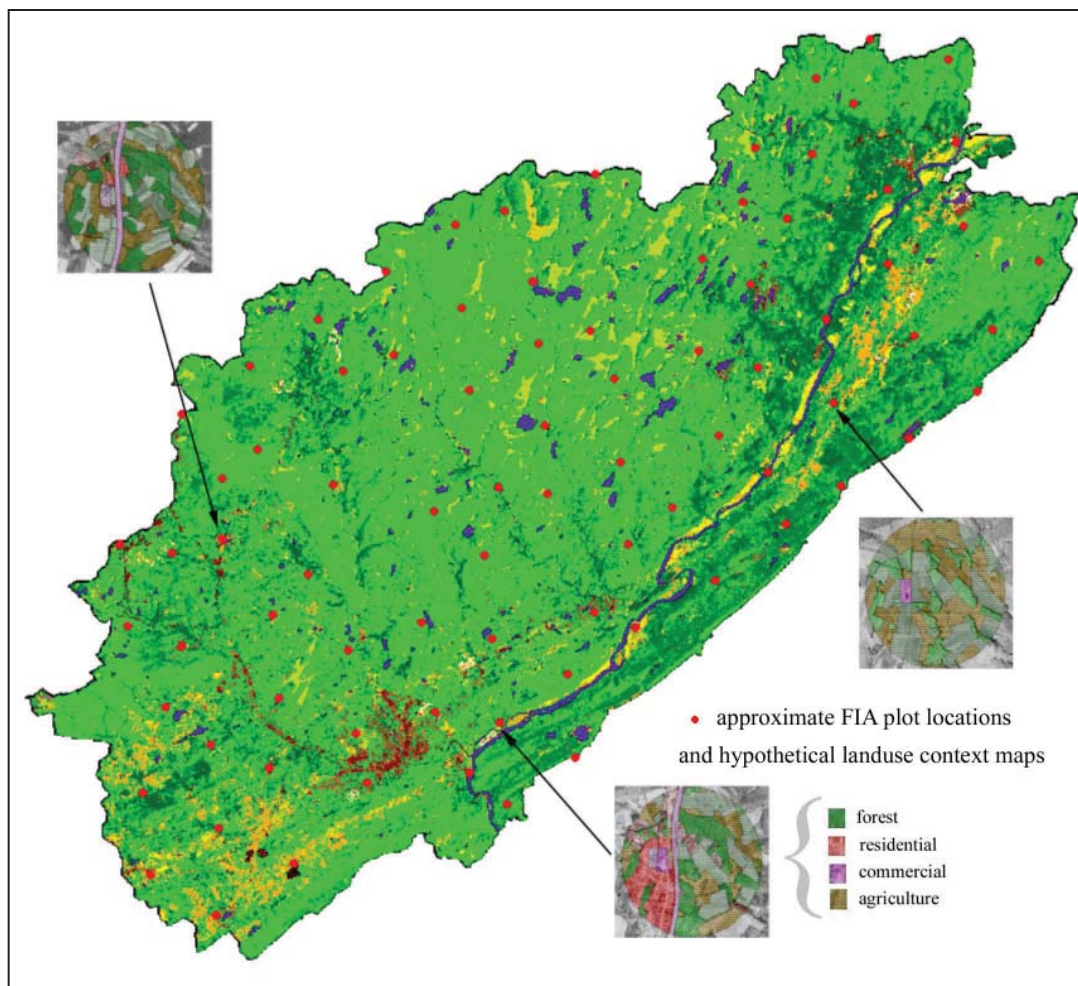
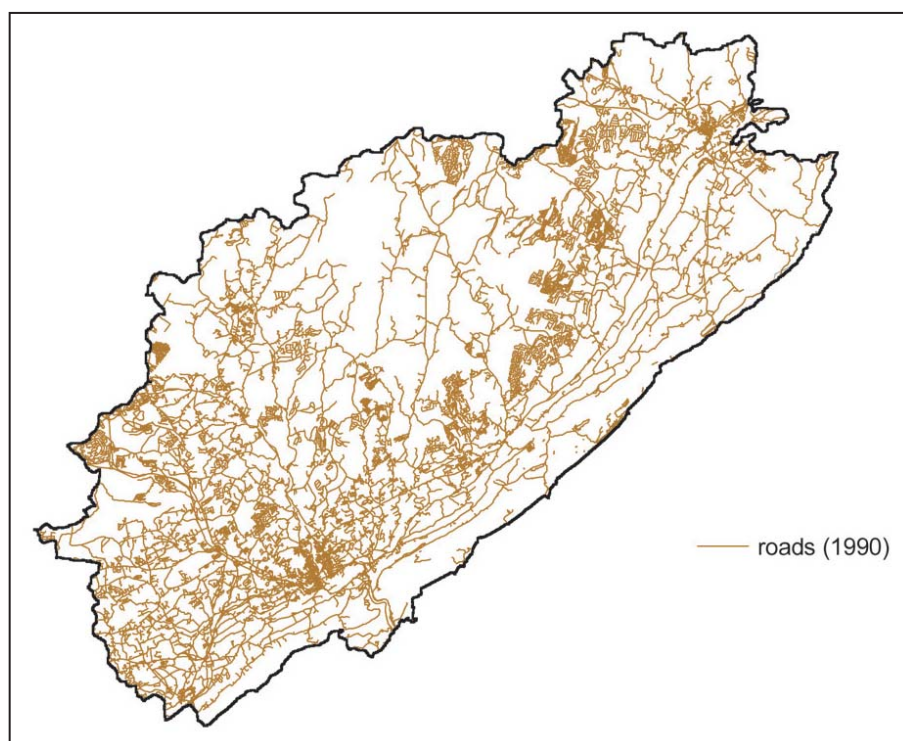


Figure 7.4.—Human impact described by local road density—example from the Delaware Water Gap (IMRA) tributary watersheds.



established for accurately monitoring those measures that research had found were linked to changes in the forest ecosystem. Some of the data collected at FIA plot locations in other regions have the potential to tell us more about these impacts on forest ecosystem characteristics through the linking of fragmentation data to forest inventory data. However, the FIA data alone lack the information either to create maps of the results allowing spatial analysis of the situation or to link the fragmentation data with locations not coincident with the original plot locations.

7.4 Limitations of Existing Monitoring Programs

Although the monitoring by existing independent programs was useful in providing maps of regional characteristics or relating data collected at individual plot locations, each of the existing monitoring programs has limitations for developing regional assessments of fragmentation and its effects on aquatic ecosystems. Manual photointerpretation is too time-consuming for large areas except through probability-based point or area samples, which means no continuous data are available from which to summarize information for locations lacking interpreted aerial photography or for variables or scales not originally interpreted. There is also a lower limit to the area for which statistics can be accurately calculated. On the other hand, measures calculated from TM-derived fine-resolution land use/land cover datasets, while available over broad areas, are not necessarily consistent with reality at plot or stream locations on the ground and are highly dependent upon the accuracy of the original classification (e.g., Wickham et al. 1997). These classification datasets are rarely, if ever, checked for accuracy of the spatial distribution or configuration of classes or for the accuracy of land use composition data over the small areas frequently of interest with forest fragmentation. In addition, the types of areas of particular interest in fragmentation studies include those in which residential land uses are occurring in previously forested land and those areas that have a lot of edges between different land uses—both of these have traditionally been difficult areas for TM-derived datasets to classify accurately.

Methods for providing maps of forest fragmentation and landscape context used in previous studies were based on imagery and data readily available over large areas, such as the 1992 National Landscape Characterization Dataset (NLCD'92). It was not known for what variables or to what extent these data could be scaled down to provide information relevant to individual streams, point locations such as FIA plots, or intensive research areas for which we have detailed forest and water measurement data. Similarly, where there were particular variables or parameters significantly related to changes in water quality, methods were needed to project that high-resolution information to a region—by relating it to the fragmentation and context information available over large areas, by improving the classification or resolution of what is available so that it is more strongly related, or by area-sample or point-sample interpretation of high-resolution imagery.

Many researchers and natural resource managers have observed that increasing development and other human influence on forested landscapes can harm forest ecosystems, and several parameters have been identified as indicators. Yet frequently we have only an elementary or local understanding of specifically how fragmentation, changes in forest context, and increasing proximity of forest to developed land uses are related to changes in water quality, aquatic habitat, forest composition and structure, incidence of invasive pests, and changes in forest chemistry. Although we can measure urbanization and forest fragmentation in several

different ways, and we have identified many potential impacts of these conditions on forest ecosystems, there is no clearly articulated body of knowledge relating scales and measures of fragmentation with specific types, degrees, and thresholds of changes in terrestrial and aquatic resources—details that are important if we are to make management decisions to address these changes. In addition, the links between currently monitored fragmentation measures, the scale at which forest fragmentation is measured, and the impacts of fragmentation on forest characteristics and ecosystem processes are tenuous at best. As a result, it is difficult to scale up the fine-scale factors to regional levels or to be sure the lower resolution information is accurate enough to address the process-level questions. The goal of the Delaware CEMRI was to develop a collaborative ground-based monitoring program that would significantly improve our ground-truthing capabilities for remote sensing interpretations of the DRB and improve the accuracy of those interpretations.

Coordination between Federal natural resource agencies, State and local regulators, and research units was also very weak before the Delaware CEMRI, limiting the connection between those monitoring forest fragmentation and those involved in regional surveys and process-level studies of water quality, invasive pests, multiple stressors on forests, and other issues of interest to resource managers. The result was fragmentation statistics and maps that were not necessarily relevant to managers, planners, policymakers, or researchers working with those issues. This situation occurred because those making the maps did not know which measures were actually indicators of potential changes, did not know which thresholds were important, did not know the level of accuracy sufficient for process-level studies, and provided measures of sufficient complexity to make it difficult to hypothesize the source cause(s) and thus determine and influence the relevant parameters through policy and management. During the Delaware CEMRI, the National Water Quality Assessment (NAWQA) program was assessing the effect of urbanization on water quality in the DRB using a gradient-based survey approach. Land use interpretations in the watersheds being studied were based on Landsat imagery without sufficient consideration of its applicability and accuracy and did not include detailed fragmentation statistics. Detailed analysis of fragmentation in the NAWQA watersheds as part of the Delaware CEMRI significantly increased their capability for the effects of urbanization and fragmentation.

Finally, there were no standard protocols for classifying most remotely sensed imagery into land use-land cover classes to evaluate forest fragmentation. As a result, significant differences exist between available datasets because of different minimum mapping units, classification methods, and class definitions. The consequences were frequently substantial differences in the calculation of urbanization and forest fragmentation around fine-scaled features (Fig. 7.5).

Without the benefit of integrated regional monitoring linked with intensive site-level research, and the benefit of improved linkage between natural resource agencies specializing in forests and water, our understanding of the status and impacts of urbanization and forest fragmentation as well as the links between fragmentation and terrestrial and aquatic characteristics were based on best guesses about the factors that drive fragmentation and its effects. A comprehensive effort combining new monitoring technologies and techniques being applied by existing programs with up-to-date, accurate land use and land cover datasets, as well as other sources of information about the impacts of fragmentation from intensive study sites, was required to develop an effective monitoring protocol.

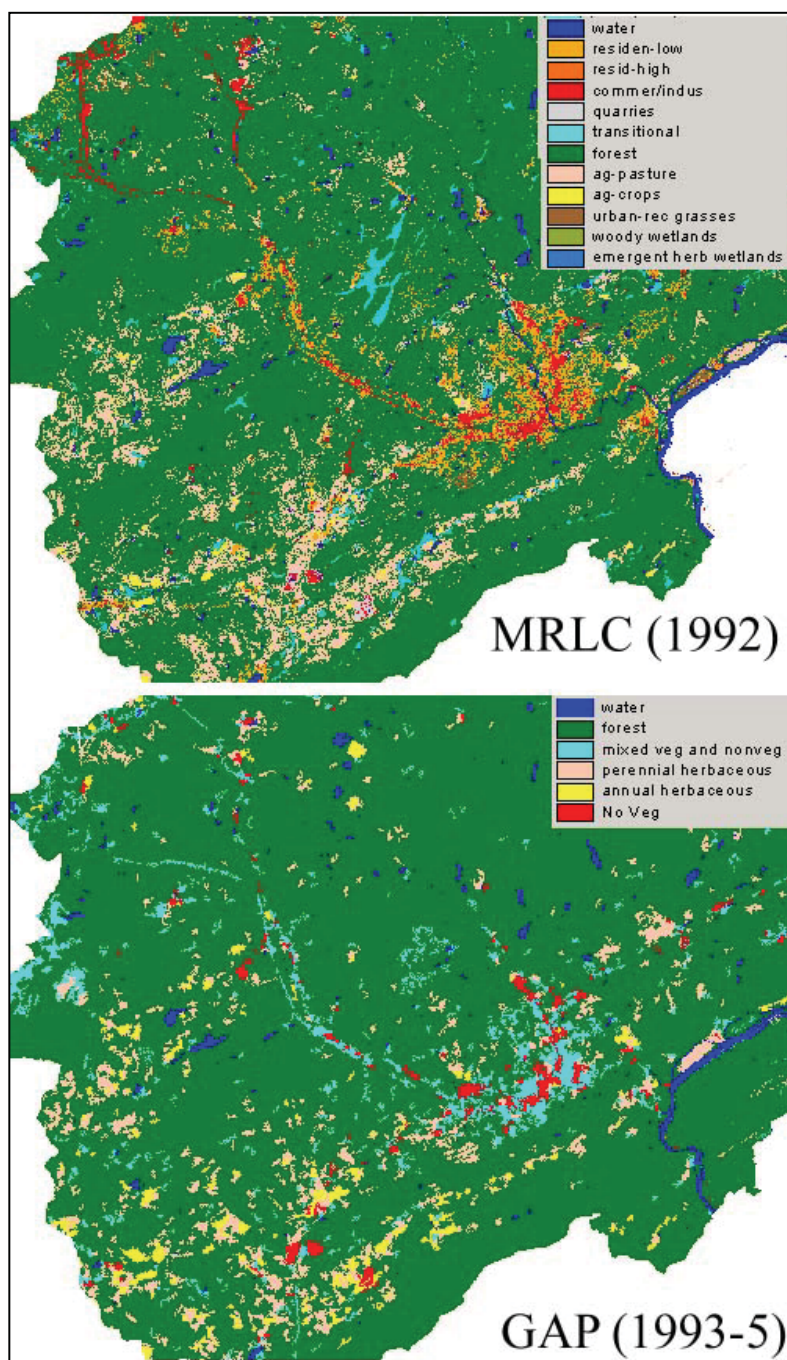


Figure 7.5.—Two land cover-land use maps for the Delaware Water Gap IMRA, both derived from TM imagery but classified by two different sources. These differences in land cover-land use classifications would affect summaries of fragmentation and landscape composition.

7.5 The CEMRI Program for Monitoring the Status and Impact of Forest Fragmentation

A summary of the components of an effective research and monitoring plan to address the status and impacts of forest fragmentation is presented in Table 7.1. The knowledge gathered during this research was applicable to all tiers of the framework. The French Creek and Delaware Gap IMRAs were chosen in part because residential development has been occurring rapidly outside the park and the greater Philadelphia area, and there is concern that development might affect water quality (Fig. 7.6).

Table 7.1.—Key variables and analyses for assessing the status and trends of forest fragmentation

Tier 1: Intensive sites

Relationships between land use type and temporal fluctuations in water quality/quantity

Relationships between development, forest condition, and temporal fluctuations in water quality/quantity

Tiers 2 and 3: Gradient sites and regional surveys

Relationships between landscape characteristics and water quality/ quantity

Relationships between land use type and sediment

Relationships between forest patch size/context and water quality/ quantity

Relationships between measures of urbanization and fragmentation and water quality/ quantity

Define exports (especially nitrogen and sulfur, maybe phosphorus, potassium K, other) from different development, logging, etc. scenarios

Water quantity and quality, and sediment

Flora and fauna surveys

Tier 4: Remote sensing and mapping

Atmospheric deposition

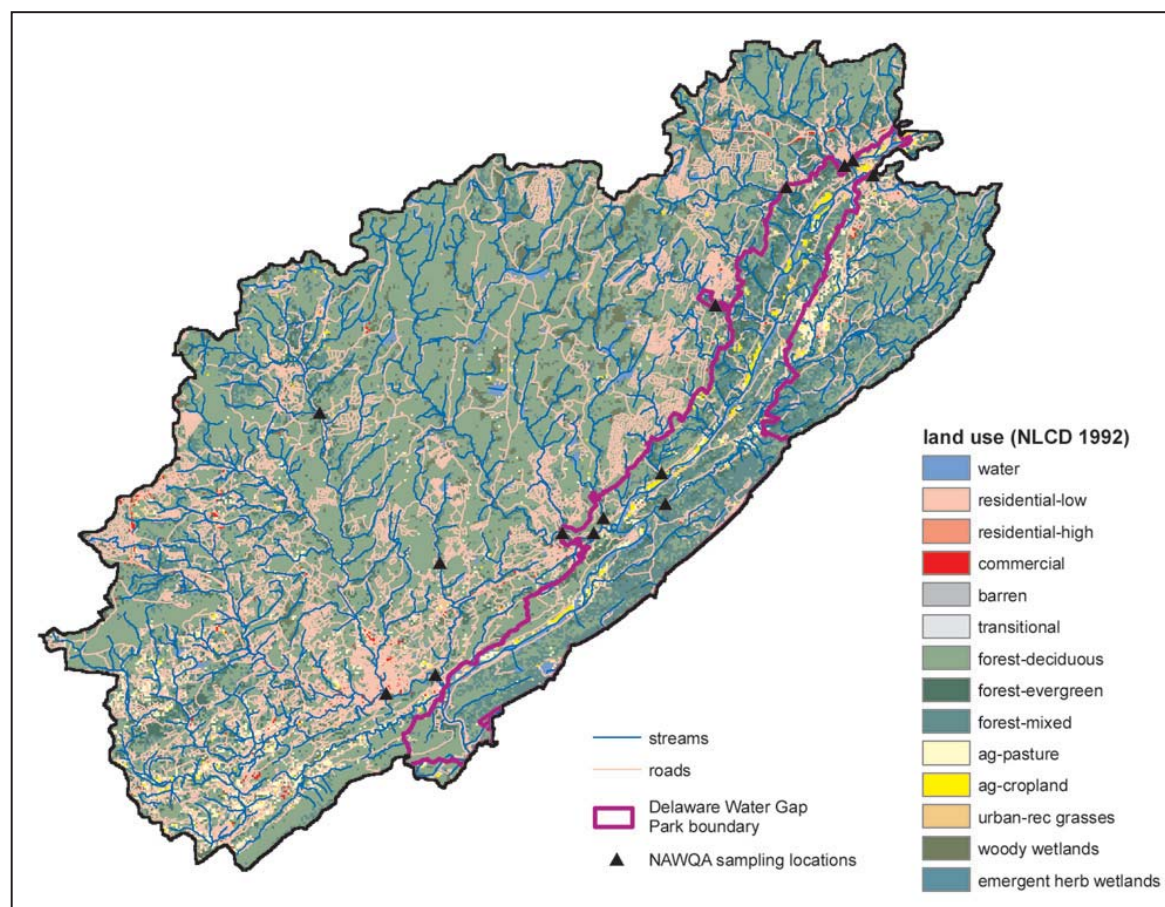


Figure 7.6.—Map of streams, development, park boundary, and NAWQA sampling points within the area.

7.5.1 Intensive Site Research and Monitoring (Tier 1)

Joint research activities among the participating agencies were established within each IMRA, but were focused on the tributary watersheds draining through the Delaware Gap NRA where development surrounding the park has become the most pressing environmental issue. A joint USGS-National Park Service (NPS) project to characterize the water quality of the tributary streams at the boundary of Federal and private lands was established in the second year of the Delaware CEMRI. Stream samples were collected approximately monthly except during the winter and analyzed for major ions, pesticides, and indicators of suburban runoff (boron, bromide, chloride, caffeine) (Fig. 7.6). These sampling points defined the watersheds for which the USFS developed land use, land cover, and fragmentation data from high-resolution aerial photography. Intensified ground-based sampling of forest condition was established within three of these watersheds representing high, medium, and low degrees of development, and the USGS established stormwater sampling for a 1-year period on the two of these watersheds that represent the highest and lowest development intensity. Stormwater samples were analyzed for nitrate, chloride, sulfate, boron, and dissolved and total organic carbon.

Intensification for the forest fragmentation issue in the other IMRAs was limited. Stormwater sampling was established as part of the Delaware CEMRI, and habitat and invertebrate assessments were conducted by the NAWQA program at the mouth of the main river draining each area. A USGS streamgauge provided multiple years of 15-minute flow records at each monitoring station. These data, and the intensified network of FIA forest plots established within each IMRA, served as a ground-truthing database for the aerial photointerpretation, and the intensive streamwater data provided a temporal context within which the gradient study of fragmentation-water quality relationships described below could be assessed.

7.5.2 Gradient-based Data Collection Network (Tier 2)

The NAWQA program established measurement stations at selected sites along a gradient of development intensity, where water and sediment sampling and habitat assessment have occurred during the past 3 years over a range of seasons and flow conditions. The effects of forest fragmentation and human development context on the water chemistry, sedimentation, aquatic habitat and aquatic wildlife populations of streams draining these watersheds were analyzed through a combination of field data collected by collaborating programs and modeling techniques. To pull together this information on the impacts of forest fragmentation, we used gradient surveys established by the NAWQA program in the summer of 2001, the NPS monitoring activities in the DEWA, USGS district research and monitoring activities associated with the CEMRI in the summer of 2002, detailed photointerpreted data on fragmentation, and regression modeling. Datasets of fragmentation indicator variables were developed for each of the selected study watersheds, and correlations were established between those indicators and aquatic chemistry, flora, and fauna.

7.5.3 Regional Survey Monitoring (Tier 3)

Terrestrial ecosystem effects of forest fragmentation were investigated using the forest composition, structure, and condition measurements currently collected on FIA plots. Selected phase 3 plots were visited by a USFS research botanist, and additional data were collected on exotic and invasive species using two different detection methods. The results of these studies were linked to the landscape-scale variables of recreation, forest fragmentation, and urban gradients to allow the development of recommendations for how to collect exotic species information on FIA plots.

Probability-based stream surveys were conducted within each of the IMRAs and for the Catskill Mountain region of the upper DRB as part of the Delaware CEMRI. The data collected were used to create cumulative frequency curves for selected chemical constituents known to increase in river water with increased suburbanization. The surveys thus allowed investigators to assess what portion of the population of stream reaches within the IMRAs were represented by the intensive monitoring stations.

7.5.4 Remote Sensing and Mapping (Tier 4)

One of the first products of the CEMRI research on forest fragmentation and its effects was a map of land use and land cover using classification most appropriate for summarizing and calculating indices of fragmentation and context, and using a scale most appropriate for describing fragmentation in the DRB. Several data sources were examined: 1) high-resolution imagery (in this case 1:24,000 color infrared or 1:40,000 panchromatic digital aerial photography), 2) 30-m TM imagery from Landsat 7 (both in-house and existing land use/land cover classifications), and 3) a combination of TM and higher resolution satellite imagery. In the photointerpretation of the high-resolution imagery, additional land cover information was interpreted and attributed to each urban polygon. Data generated from the high-resolution imagery was used to help accurately assess and iteratively classify the TM-derived classifications if necessary.

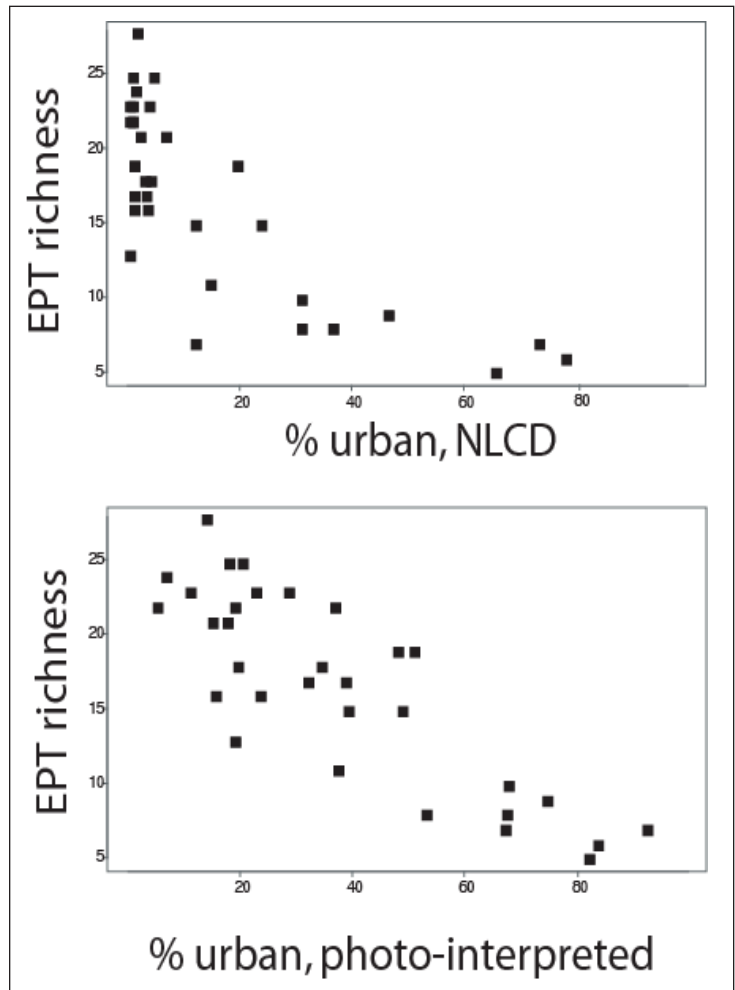
From this manually photointerpreted or digitally classified information, we summarized and calculated a variety of urbanization and fragmentation measures, focusing on those that have particular relevance to water quality as well as those suspected of being of general relevance to changes in forest composition, structure, health, wildlife habitat/use, invasive pests, forest chemistry, and multiple stressors.

Data from other sources, such as the USGS National Hydrologic Database (NHD) and TIGER/Line roads database were also used in this analysis. Statistics were calculated for local areas (e.g., around plots, research sites, and streams), sub-watersheds and watersheds. Emphasis was placed on those indicators that describe real differences in the landscape and that are less sensitive to small differences in manual and automatic interpretation that may unavoidably occur during any classification conducted at two different times. In addition, both point-sample and area-sample approaches were simulated using the data from the manual interpretation of digital aerial photography to determine what intensity of sampling would be necessary to generate accurate summary information for watersheds, by either of these two methods, for those measures that are poorly captured by the TM-derived data sources. Final interpretations of remote imagery were mapped to overlay on the USGS National Hydrologic Dataset of hydrology and a linked digital elevation model for topography.

7.6 Preliminary Results

Analysis of macroinvertebrate and stream chemistry data along with forest fragmentation and landscape composition data from interpretation of color infrared aerial photography showed a much stronger correlation between declining water quality and increasing urbanization and forest fragmentation than was possible using land use data derived from satellite remote sensing, even at relatively low levels of disturbance (Fig. 7.7)(Murdoch et al. 2003). The remote sensing data source had a large influence on the response pattern observed, especially at lower levels of disturbance, which was due partly to an underestimation of residential and

Figure 7.7.—Patterns of correlation between an indicator of water quality (EPT richness) and two different remote sensing datasets: National Land Cover Data (NLCD) from the Landsat Thematic Mapper, and color infrared aerial photography.



other urban-developed land uses in areas of high tree cover in the TM-derived data source. The correction of the more widely available satellite land use/land cover data by overlaying road density information, and correction of the widely available percent impervious information by incorporating road density, holds promise for broader scale studies of forest fragmentation and urbanization in similar settings. The collaboration of two existing monitoring programs provided significantly improved and refined understanding of the effects of changing land cover on stream-water quality.

This study helped determine to what extent current TM-derived land use/land cover classifications are sufficient for quantifying parameters of forest fragmentation, and whether the addition of more sophisticated classification techniques or higher resolution satellite imagery increases the spatial and class accuracy of the TM-derived classes sufficiently to improve ability to provide information on fragmentation, context, and proximity to fine-scale features such as streams, vernal ponds, FIA plots, and IMRA sites. This study established guidelines on what TM classification protocols or requirements can be suggested to improve the ability of TM-derived datasets to provide such fragmentation and context information, in terms of both the spatial resolution of the imagery and the classification resolution and class types. Finally, because manual interpretation of high-resolution imagery is necessary for some important indicators, this study established some guidelines concerning what sampling intensities are necessary to effectively capture that information.