1.0 EXECUTIVE SUMMARY

1.1 Introduction

The Delaware River Basin (DRB) in the coastal mid-Atlantic region of the United States covers 12,700 mi^2 of primarily forested land. The DRB is home to 7.2 million people, and an additional 7 million people in New York City and northern New Jersey rely on surface water diverted from the DRB for their water supply. Major watershed issues in the DRB are urbanization and forest fragmentation, abiotic and biotic stressors, diminished condition of forest soils and plants, and invasive exotic species.

In 1998 the U.S. Forest Service (USFS), the U.S. Geological Survey (USGS), and the National Park Service (NPS) formed the Collaborative Environmental Monitoring and Research Initiative (CEMRI) to test strategies for integrated environmental monitoring among the agencies. The initiative combined monitoring and research efforts of the participating Federal programs to evaluate the health and sustainability of forest and freshwater aquatic systems in the DRB. Forest ecosystem health issues addressed by the CEMRI effort included urbanization and forest fragmentation, productivity and carbon (C) sequestration, nitrogen (N) saturation and calcium (Ca) depletion, vulnerability to exotic insects, and the effects of interactions among these factors. Ongoing monitoring programs were enhanced with supplemental sampling locations and measurements, and models were developed or modified to associate intensive process-level information with extensive landscape-scale information from satellite, aerial, and ground monitoring systems. The CEMRI project illustrates a powerful approach for integrated tracking of environmental conditions, development of models for predicting responses of forest and aquatic processes to perturbations, estimation of future forest conditions, and identification of threats to watershed health and forest sustainability. This executive summary is an abridged version of the foundation document that discusses the development of the CEMRI in the DRB, with a focus on methods to address environmental issues across multiple spatial and temporal scales. The main body of the foundation document is available on the Internet at: http://www.nrs.fs.fed.us/pubs/

1.2 The Need for Multiscale, Multiparameter Monitoring

Resource management agencies are often expected to take a holistic approach to management of ecosystems, but few have the resources to support multicomponent ecosystem-level research and monitoring. As a result, agencies focus on ecosystem data needed to support their primary mission, and sharing of data among agencies is constrained by differences in protocols or sampling schedules that render the data incompatible for fully integrated interpretation (Committee on Environment and Natural Resources 1997). Lack of compatible multiresource (terrestrial, aquatic, atmospheric) and multiscale (temporal and spatial) data has become a limiting factor for developing whole-ecosystem approaches to resource management. In addition, process-level understanding of ecosystem responses to land use change and a changing environment needs to be integrated with large-scale observations of changes in ecosystem health indicators.

The CEMRI approach began with an evaluation of the capabilities of existing monitoring programs, followed by identification of opportunities and approaches to enhance these programs for addressing specific issues. By supplementing and adjusting existing monitoring

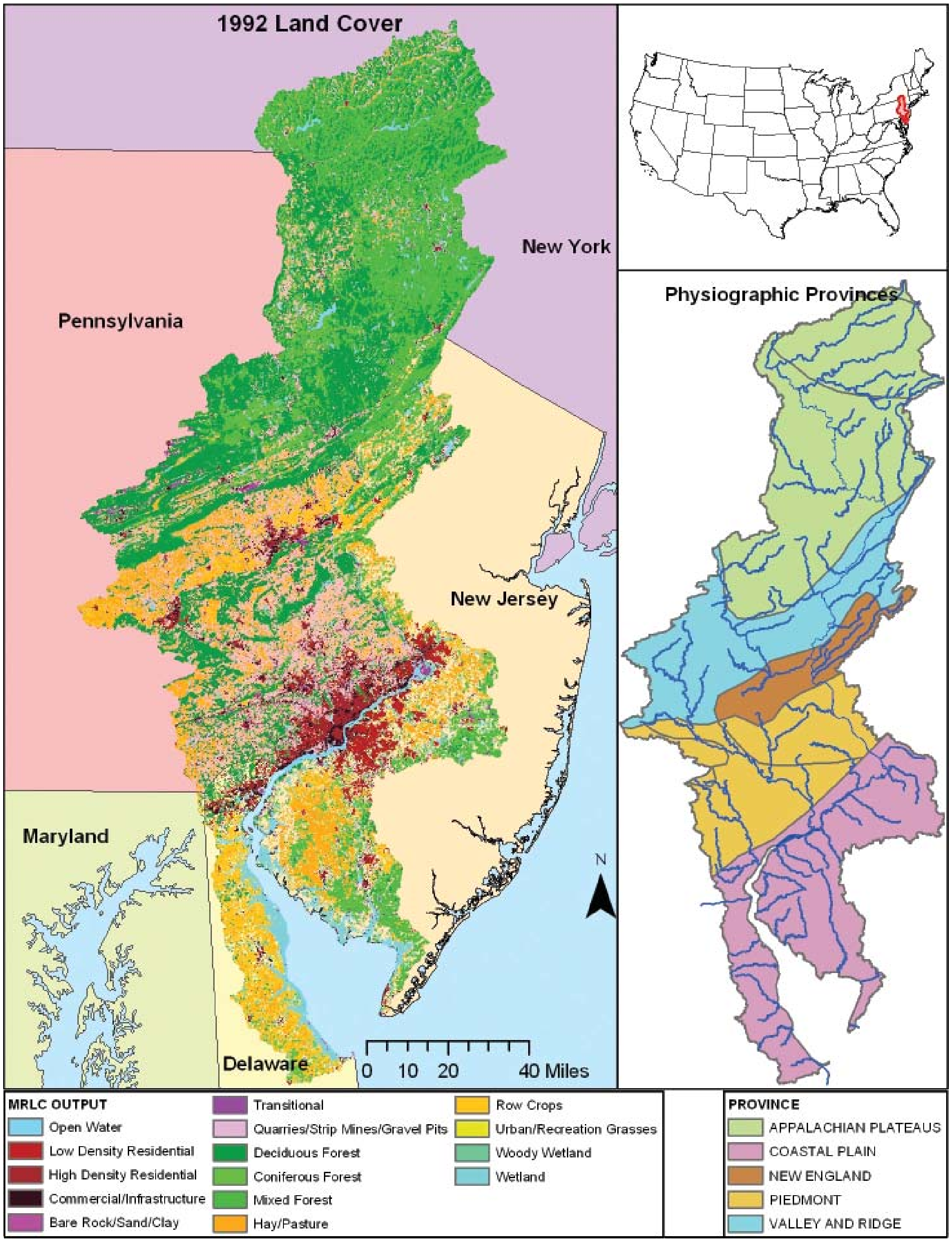

Figure 1.1.—Land cover and physiographic provinces of the Delaware River Basin.

and research strategies, collaborating programs can continue to meet specific agency missions while also contributing to multiscale, multiresource inventory and monitoring systems. To demonstrate this approach, three Federal agencies developed the CEMRI strategy to evaluate the condition of forests and associated waterways in the DRB (Fig. 1.1).

Databases derived from an ecologically and spatially integrated monitoring system, and incorporated into an analytical modeling framework, should allow for more accurate parameterization of scientific and resource management models to improve predictive capabilities. The ultimate goal was to improve our ability to detect environmental change rapidly and accurately, as well as predict future forest conditions under different environmental conditions and management strategies.

1.3 Rationale for Selecting the Delaware River Basin

The DRB in the Eastern United States was chosen as the study region because:

- Watersheds are logical conceptual units for integrating environmental information on a local to regional scale because aquatic systems integrate the biogeochemistry of large areas with well-defined physiographic boundaries.
- The DRB contains several intensive monitoring and research areas (IMRAs) maintained by the USGS and NPS, representing several of the major physiographic provinces typical of the mid-Atlantic region of the U.S., with ongoing long-term research and monitoring of ecological components and processes.
- Three existing agencies with programs operating in the basin accepted the challenge of designing an integrated monitoring strategy to address specific issues, based on existing monitoring systems.

Ecologically, the DRB is very diverse, with five physiographic provinces and multiple forest types that represent most of the major eastern type groups (Fischer et al. 2004). The mostly flat Coastal Plain in the south has soils underlain by unconsolidated sediments and is the northern limit of the southern pine forest type (Fig. 1.1). Further north are rolling lowlands and a series of broad uplands in the Piedmont Province, with soils underlain by metamorphic rock and covered by oak-hickory forests. North of the Piedmont, the New England Province and the Valley and Ridge Province consist of rock layers that have been deformed into a series of steep ridges and parallel folds that trend more northeast-southwest. Forests of this region are characterized by a mixture of oak-hickory, northern hardwoods, and northern conifers.

Analysis of 1992 satellite-derived Thematic Mapper (TM) land use data estimated that about 60 percent of the DRB is forested land, 24 percent is agricultural, 9 percent is urban and residential, and 7 percent is surface water bodies and miscellaneous land uses. Eighty percent of the population lives in the Piedmont and Coastal Plain Provinces in the southern portion of the DRB, which encompasses only about 40 percent of the total area.

1.4 Multi-tier Integrated Monitoring Strategy

The USFS and USGS conceived of evaluating several important watershed health issues in the Delaware Basin using a multiple spatial scale, multiresource approach, primarily by enhancing and integrating existing forest and aquatic resource monitoring programs. Shortly thereafter, the CEMRI was joined by the NPS Delaware Water Gap National Recreation Area (DEWA), and the National Aeronautics and Space Administration (NASA).

As originally conceived, the CEMRI approach assumed that specific monitoring strategies are required for effective monitoring at a given spatial or temporal scale (Fig. 1.2), but that those monitoring programs could be linked through common measurements or sampling schedules to allow a multicomponent, multiscale assessment of issues. Most current environmental monitoring programs primarily address issues of one resource type at one spatial scale, but could be enhanced or modified to share data effectively with other monitoring programs without losing the ability to meet their original mission.

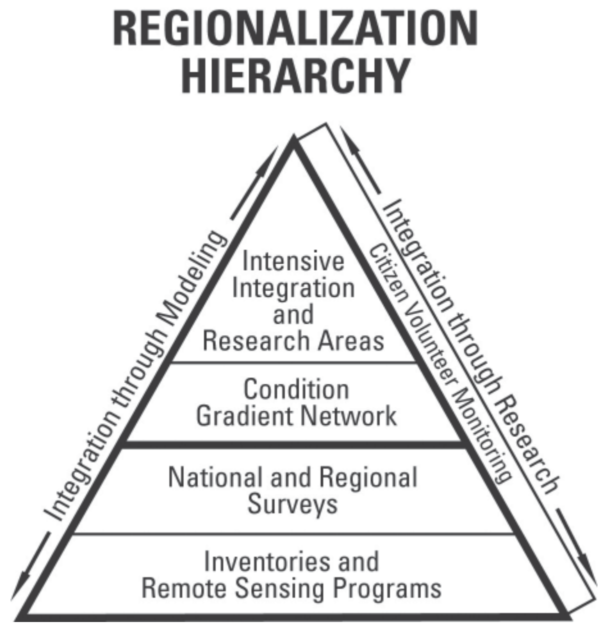

Figure 1.2.—Conceptual framework for achieving the multiple goals of environmental monitoring and research. (Committee on Environment and Natural Resources 1997)

The CEMRI pilot study integrated environmental data collection from intensive study sites (the Neversink Watershed, the DEWA and its tributary watersheds, and the French Creek Watershed) with regional ground-based monitoring networks using stream monitoring stations and a randomly distributed network of forest sampling locations. Remote sensing was used to characterize the land area on a spatially explicit basis over time, and the spatially integrated field datasets were used as ground truth. Four monitoring tiers were defined for the CEMRI:

- Tier 1 - Frequent monitoring and intensive research on ecosystem components and processes, and determination of cause-and-effect relationships at a limited number of intensively monitored sites within relatively small areas. The purpose is to determine key forest processes and to understand how these processes interrelate, how stressors affect these processes, and how these processes relate to macroindicators that could be monitored at large spatial scales. An example of a Tier 1 site is the intensive water-quality monitoring by USGS in the Neversink Watershed.
- Tier 2 - Medium-intensity monitoring at a network of points or watersheds representing a range of conditions for a specific issue. This is a new landscape monitoring concept developed for this study. Data collected provide statistical relationships between key stressors and land or water characteristics. The information may also be used to link process-level information to landscape-scale characterizations and to provide ground verification of remotely sensed parameters. An example of an existing Tier 2 network is the “synoptic” network of streams sampled by the National Water Quality Assessment program (NAWQA), designed to collect water quality and habitat data from rivers draining watersheds that represent a range of development (Gilliom et al. 1995).
- Tier 3 - Extensive ground-based monitoring (randomly selected sample plots and surveys) at large regional scales. The purpose of monitoring at this tier is to

document the extent, status, and change of resource conditions based on systematic sampling and field observations. Examples are the USFS Forest Inventory and Analysis (FIA) network of monitoring locations (Bechtold and Patterson 2005) and the surveys designed by the U.S. Environmental Protection Agency (EPA) Environmental Monitoring and Assessment (EMAP) program (USEPA 2002).

- Tier 4 - Large-scale mapping and monitoring with satellite remote sensing and aerial photography. Primary objectives at this tier are development of spatially and temporally continuous information, such as land use and land cover change, forest species distributions, and forest fragmentation. An example is the NASA Landsat satellite monitoring program (Cohen and Goward 2004).

1.5 Intensive Monitoring and Research Areas to Link Processes with Monitoring

Three watersheds in the DRB were selected as IMRAs for the process-level studies in forested landscapes. Each IMRA site contained existing process-monitoring infrastructures supported by the USGS, NPS, New York City Department of Environmental Protection, or other data collection programs. Land sampling and water sampling were enhanced at these sites to provide concurrent and integrated data with the Tier 2 and Tier 3 field surveys. The three IMRAs represent the range of climatic and forest conditions found in the Delaware Basin upstream of the Coastal Plain (Fig. 1.3).

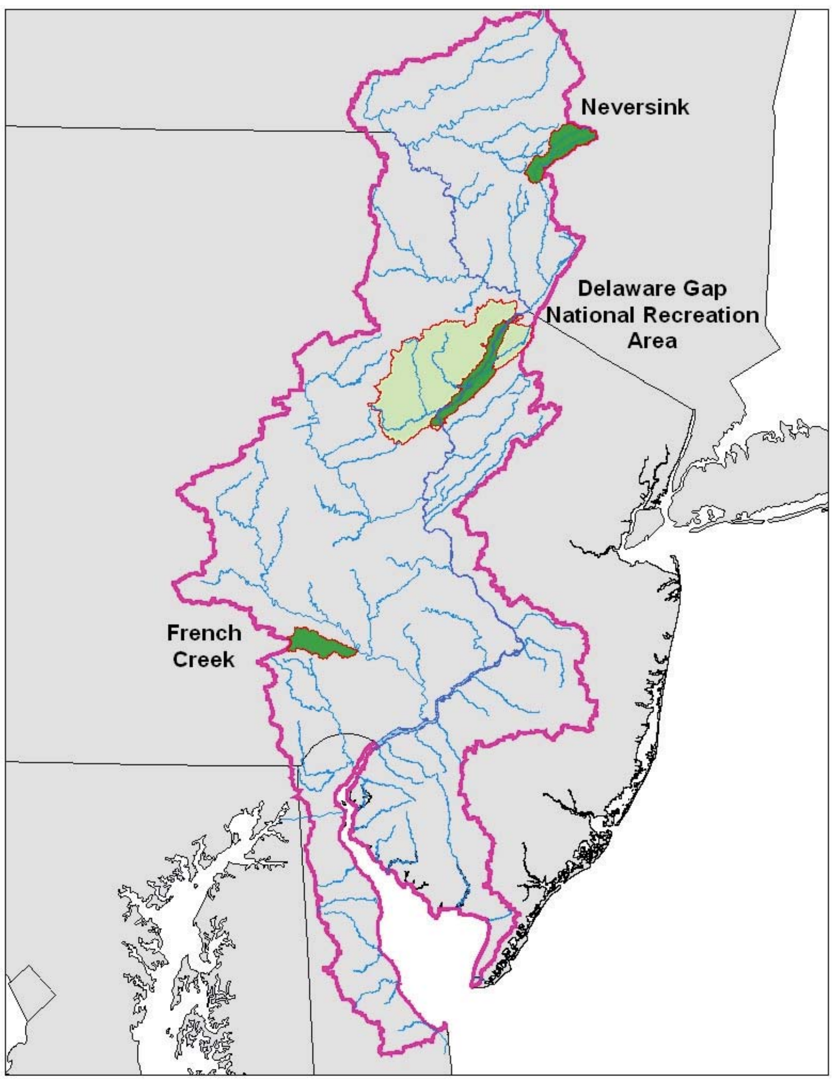

Figure 1.3.—Locations of intensive monitoring and research areas within the Delaware River Basin.

The IMRA sites selected for the CEMRI pilot were the following:

1) Neversink River Basin: Biogeochemical and hydrologic processes in the watershed of the Neversink River have been monitored by the USGS district research program since 1982. The Neversink lies within the northern, mostly forested region of the Appalachian Plateau Province and contains a set of nested discharge and water quality monitoring stations in basins ranging in size from 130 km^2 to 1 km^2. Research on terrestrial and aquatic acidificatio1n and best management practices for sustaining the quality of water in the New York City reservoirs has been going on since 1982.
2) The watersheds of the Delaware Water Gap National Recreation Area: These watersheds that drain through the DEWA lie within the central Appalachian Plateau Province, which is also mostly forested but rapidly developing outside of the park boundary. Discharge and water quality monitoring stations have been operated on tributaries and the main-stem Delaware River for several years and have been integrated into the NAWQA program since 1994 (Gilliom et al. 1995). The NPS established special forest plots within the park for studying the long-term effects of the introduced insect hemlock woolly adelgid.
3) French Creek Watershed: The French Creek Watershed is located in the midbasin Piedmont Province and contains a partially forested landscape that is being rapidly suburbanized. Discharge has been monitored continuously at French Creek since 1968, and water quality has been monitored periodically by the NAWQA program since 1994.

Tier 2 and Tier 3 monitoring was also intensified within the IMRAs to provide finer resolution data collection within the small watersheds where the long-term, process-level research was located, and to identify sampling locations for gradients of disturbance and forest type. Some forest sampling plots were intentionally placed directly within process-level research and monitoring studies to support the extrapolation of process-level results to the regional scale.

Finally, to provide an independent set of data to test scaling results for vegetation and carbon (C) estimates, additional regional "validation plots" and stream monitoring stations were established. A streamlined set of measurements was collected at these plots and withheld from the development of relationships among variables that can be used to scale up from intensive study areas to the region.

1.6 Identification of Resource Issues

Numerous meetings of the lead agencies, and the results of a stakeholder meeting hosted by the multi-state Delaware River Basin Commission, led to the identification of forested landscape issues that required data from multiple spatial scales and multiple resource groups:

- Measuring and monitoring forest C stocks and fluxes
- Identifying and monitoring forests vulnerable to non-native invasive insect species
- Monitoring effects of calcium (Ca) depletion and nitrogen (N) saturation in forests subjected to acidic deposition in the Appalachian Plateau
- Measuring and monitoring forest fragmentation and land use change, and associated ecosystem changes

- Integrating the effect of terrestrial ecosystem health and land use on the hydrology, habitat, and water quality of the Delaware River and Estuary

Addressing these five issues was the focus of the Delaware CEMRI pilot study. Descriptions of the measurements involved in addressing each issue, the capabilities of existing programs to provide pertinent data, and the approaches adopted for integrating and enhancing those programs as part of the CEMRI project are presented in this foundation document. A brief summary of the information in individual chapters is provided here.

1.7 Measurement and Monitoring of Forest Carbon Stocks and Fluxes

The goal of the CEMRI C study was to improve our capabilities to compute regional C budgets by integrating and augmenting terrestrial and aquatic data collection and analysis programs. Forests are thought to store close to 90 percent of Earth's terrestrial vegetation biomass (Dixon et al. 1994) and are important controllers of atmospheric carbon dioxide (CO_2) concentrations and thus the global C cycle. The rate of forest growth also affects the quality and quantity of water reaching streams, because photosynthetic rates are directly proportional to water use by plants, and thus the rate of tree growth also influences streamwater quantity. Finally, changes in river export of C to the ocean can significantly alter the biogeochemistry of coastal and estuarine ecosystems.

To create an approach for estimating C stocks and fluxes that incorporated terrestrial and aquatic C transformations, the CEMRI sought to

1) Improve the ability of the ground-based monitoring networks to more completely assess regional forest C stocks and fluxes
2) Integrate disparate monitoring networks to develop complete site-level and Basin-level C budgets including C loss by water transport
3) 3) Ground-truth estimates of forest biomass and net primary production (NPP) from available remote sensing products (Tier 4) with multiscale inventory data (Tiers 1, 2, and 3)
4) Characterize the effects of land use change and forest fragmentation on cumulative C stocks and fluxes

Tier 4 monitoring was available for the DRB through satellite-derived MODIS and Landsat thematic imagery and was augmented with AVIRIS imagery from aircraft in the northernmost sub-basins. Funding from NASA allowed improvements in the calibration of MODIS datasets for remote identification of eastern forest types. For Tier 3 monitoring, the foundation program was the USFS Forest Inventory and Analysis (FIA) network of sample plots (Bechtold and Patterson 2005). Research plots for intensive study of C fluxes within the IMRAs, and gradient sampling sites representing a range of forest types and condition for Tier 2 monitoring, were embedded within the FIA network to allow cross-scale comparisons. For Tier 1 C stock and flux estimation, a set of 10 research plots at each IMRA was established. These carbon plots featured, in addition to regular inventory measurements, collection of data on litterfall and annual stem increment and additional sampling of woody debris and soil. Enhanced measurements were made at plots within the Neversink River Basin in New York, the DEWA, and the French Creek River Basin in Pennsylvania. Terrestrial C budgets (sequestration and flux) were computed for each IMRA, and integration of the data across all four tiers of monitoring allowed for the development of a C budget for the entire DRB.

The NAWQA program and long-term river monitoring networks of the USGS provided CEMRI with the foundation data for C flux in surface waters, including C and sediment flux measurements at stations where stream discharge was already being measured. Trends in river C export were determined from long-term water quality and flow records for the head-of-tide on the Delaware River at Trenton, New Jersey, and in the headwaters of the Neversink River near Claryville, New York. The USGS added a survey of dissolved organic carbon (DOC) during the spring and fall in first-order forested streams throughout the upper DRB. The combined network allowed the assessment of basinwide estimates of C flux in surface waters.

1.8 Monitoring Methods for Forests Vulnerable to Non-Native Invasive Pest Species

The goal of the CEMRI invasive pest study was to develop methods for anticipating forest damage and associated surface water degradation by pests through mapping forest vulnerability to infestation and determining the hydrologic and biogeochemical conditions that would allow surface water degradation from forest disturbance. Non-native forest pests and pathogens are a great concern for forest ecosystems in the DRB. Some of the most destructive forest pests introduced into North America inhabit the region. For example, the gypsy moth was introduced into the United States well over 100 years ago and first appeared in the DRB around 1940, and the hemlock woolly adelgid was first noticed in the northern DRB less than 15 years ago (Liebhold et al. 2005). The Asian longhorned beetle is not known to be established in the basin, but it does attack forest types prevalent there and has entered North America through the port of New York City. Two major shipping ports near or within the DRB, New York City and Philadelphia, are a continuous source of potential new introductions. Exchanging overstory species in a riparian habitat through selective mortality induced by a non-native invasive species can alter water quality in the stream below.

Invasive species research in the DRB had three primary objectives:

- To develop and evaluate monitoring protocols for selected pests and resulting ecosystem damage at the IMRAs that could be cost effectively implemented as part of extensive monitoring programs
- To test a collaborative monitoring strategy for assembling pertinent information to track pest movement and mitigate the impacts of pest infestation in the DRB
- To develop maps of forest conditions in the DRB that depict areas most vulnerable to specific pests

Existing gypsy moth programs provided large-scale monitoring of the status and impacts of non-native invasive species and are an example of a Tier 2 foundation program used in the CEMRI. Gypsy moth monitoring in the DRB consisted of aerial sketch mapping of visible defoliation areas and autumn surveys to count egg masses. Data on other aspects of pest damage or environmental impact were limited, and physiographic, chemical, or climatic conditions that might influence defoliation intensity were not being documented. The existing program for hemlock woolly adelgid was a collaboration among the three State agencies bordering the upper DRB and the USFS. The State of Pennsylvania, the USFS, and the NPS maintain permanent monitoring plots to facilitate the documentation of tree health decline in the host trees over time. Existing monitoring programs for hemlock woolly adelgid provided information at the tree and small plot levels but not on the spatial distribution of the pest on a regional scale. Several types of remotely sensed information were investigated for development of tools to assess the degree of adelgid infestation and hemlock decline (Pontius 2004, Royle and Lathrop 2002). Pest-related tree damage was recorded at FIA plots for all trees larger than 5 inches diameter at breast height (dbh).

The CEMRI developed tighter links between large-scale spatial information and plot-level process studies. A pre-CEMRI history of damage resulting from hemlock woolly adelgid infestation was developed for the DRB using Landsat Thematic Mapper images (Bonneau et al. 1999, Royle and Lathrop 1997). Ground monitoring of the adelgid in the Delaware Gap IMRA was initiated with 14 pairs of plots (hemlock and hardwood) within the DEWA. Trees were evaluated annually using the FIA crown rating guide. Consistent and extensive monitoring of regional pest populations, extent, and damage over time, combined with indepth process-level research at intensive study sites, was needed to begin to address the ecosystem effects of invasive pests at large scales. The CEMRI study accomplished this by enhancing data collection within the hemlock intensive monitoring sites at the Delaware Water Gap IMRA, simplifying and augmenting regional sampling methods, developing forest vulnerability maps, and linking physical and chemical environmental data with data on pest infestation. Soil chemistry and water quality studies conducted by the USGS, assessment of pest infestation at FIA and NPS monitoring plots, and ancillary data from weather stations and other monitoring networks within the region were used to develop strategies for collaborative monitoring of the causes, extent, and consequences of forest pest infestation, and to form an initial regional assessment of the environmental parameters associated with pest outbreaks and an analysis of the resulting effects of those outbreaks on environmental quality.

1.9 Monitoring of Recovery from Calcium Depletion and Nitrogen Saturation

The goal of the CEMRI Ca-depletion/N-saturation study was to determine the cause-effect relationship between forest stress and soil Ca depletion in research plots representing multiple soil conditions, and to correlate forest health, soil chemistry, and surface water chemistry at a regional scale. Acid rain has been implicated in acidification of sensitive waterways, nitrate (NO_3) enrichment of surface waters, and fish population declines in poorly buffered mountain streams (Baldigo and Lawrence 2000, Murdoch et al. 1998). Scientists are also discovering that acid rain has had additional lasting and negative effects on soil and stream chemistry, and that the changes in soil chemistry may impact tree growth rates (Hallett et al. 2006). Determination of regions within the DRB where N saturation and associated Ca depletion are most acute would allow resource managers to plan forest harvest and development in those areas in ways that would limit the further degradation of the ecosystem.

The goals of this research and monitoring development project were to:

- Develop relationships between soil and foliar Ca, soil and stream Ca, forest N saturation, and tree productivity at IMRAs to quantify and verify the impact of Ca depletion on forest growth
- Develop methods for regional-scale monitoring of forest and stream recovery from acidification, Ca depletion, and other stressors

- Develop integrated map products of forest condition, soil chemistry, and stream chemistry for the Appalachian Plateau Province of the DRB where acid rain is having its greatest effect
- Develop methods for early detection of forest and ecosystem stress due to factors such as N deposition and soil Ca depletion

The USGS had been monitoring the effects of acidic deposition on forested watersheds and streams in the Catskill Mountains since the early 1980s and thus had significant monitoring infrastructure to serve as the foundation for collaborative study in the Neversink IMRA. Information about air quality, surface water quality and quantity, and forest growth have been collected by the EPA, USGS, USFS, and State agencies within the upper DRB. The USGS and USFS FIA programs have collected soils from a few locations within the basin, and the USDA Natural Resources Conservation Service has mapped soils in the basin based on limited pedon data, but data sufficient to draw accurate maps of soil Ca depletion were not available. At the time of the CEMRI, new methods for assessing tree stress were being developed by the USFS, but use of these methods was restricted to research plots.

The Neversink River Basin IMRA was chosen as the location for Tier 1 studies on the causes and effects of Ca depletion. Foliar chemistry, tree growth and dendrochemical history, wood polyamine content, soil chemistry, and drainage water quality were the primary components of the ecosystem measured as indicators of Ca and N stress. Research by the USFS was also conducted at the Neversink IMRA to develop methods for detecting tree stress, before visible signs appear, using foliar polyamine concentration in trees exposed to Ca depletion (Minocha and Long 2004). This research was nested within data collected from a network of watersheds (Tier 2) representing a range of stream and foliar Ca concentrations, a new survey (Tier 3) of soil chemistry at each of the FIA forest plots in the upper DRB, and a survey (Tier 3) of streams draining the nearest forested, first-order watersheds to the FIA plots. Maps of deposition rates were generated through modeling of data from deposition monitoring stations in the Northeastern U.S. by researchers at Pennsylvania State University (James Lynch 2003, written communication). Remote sensing methods for determining foliar chemistry (Tier 4) were under development during the CEMRI period (Pontius et al. 2005), but pilot areas in the upper Delaware River Watershed allowed the integration of all four tiers of monitoring in selected sub-basins. These combined measurements provided the first regional database in the United States to integrate forest condition, soil condition, and associated surface-water quality.

1.10 Monitoring of the Status and Impacts of Forest Fragmentation

The goal of the CEMRI forest fragmentation study was to improve the mapping of forest fragmentation features in the DRB and to relate those refined findings to water quality and habitat conditions in the basin's surface waters. Forest fragmentation in this study was defined as the spatial breakup of forest land by developed land uses. The proximity of humans and human development to forest land increases the use of the forest by people for recreation and other activities, changes the local hydrology, alters the types of forest management that can be used, and facilitates the invasion of exotic species. The type, density, and distribution of developed land uses within the surrounding area have the potential to change the physical and biochemical characteristics of the terrestrial and aquatic ecosystems, and to alter many of the ecological processes at work.

This project sought to:

- Identify and characterize forest fragmentation over large areas with the detail and accuracy required for studies of wildlife habitat, plant composition, and water quality
- Identify potential impacts of fragmentation on water quality
- Develop appropriate methods for achieving the first two objectives, with a focus on:
    - Identifying appropriate ways of describing and quantifying fragmentation
    - Identifying measures of and standards for accuracy assessment

Before this study, research focused on developing methods to quantify forest fragmentation using remotely sensed imagery. Two datasets being used in this region were 1:40,000 aerial photography and Landsat Thematic Mapper (TM)-derived land use/land cover classifications (Riitters et al. 2000). These monitoring strategies, while providing a relative measure of fragmentation for comparison with other areas within the region, provided little information about the impact of fragmentation on ecosystem health. Calculations from TM-derived datasets, while available over broad areas, were not necessarily consistent with reality at plot or stream locations on the ground and were highly dependent upon the accuracy of the original classification (e.g., Wickham et al. 1997).

For CEMRI, the French Creek and Delaware Gap IMRAs were chosen for Tier 1 monitoring in part because residential development had been occurring rapidly outside the greater Philadelphia area and the park, respectively, and there was concern that the development might affect water quality. Streamwater was monitored for signs of disturbance from development, and an intensified network of forest measurement plots was established in each watershed (Tier 2). The USGS NAWQA program had established measurement stations at 42 medium-scale tributaries to the Delaware River representing a gradient of development intensity in their watersheds (Tier 2), where water and sediment had been sampled and habitat had been assessed during the previous 3 years over a range of seasons and flow conditions (Fischer et al. 2004). Datasets containing fragmentation indicator variables were developed for each of the selected study watersheds by the USFS, and correlations were established between those indicators and aquatic chemistry, flora, and fauna. These watersheds were nested within the broader FIA network of forest plots and a regional random survey of stream chemistry (Tier 3). Data from other sources, such as the USGS National Hydrologic Database (NHD) and TIGER/Line roads database, were also used in this analysis (Tier 4). The data from these nested networks and fragmentation maps were used to develop improved correlations between forest fragmentation and stream habitat condition and to re-interpret satellite data on land use and land cover for developing regional forest fragmentation maps (Tier 4). This study helped determine to what extent TM- and MODIS-derived land use-land cover classifications are sufficient for quantifying parameters of forest fragmentation and established guidelines on TM classification protocols or requirements to improve the ability of TM-derived datasets to provide such fragmentation and context information.

1.11 Integrated Analysis and Scaling Methods

Because some common variables were collected among all monitoring tiers (i.e., at all spatial scales) and all within the same watershed framework, the relationship between biogeochemical processes and indicators developed at the IMRA sites could be used to interpret the condition of the forests at the larger spatial scales (Stolte et al. 2004). For example, a system for integrating process-level information on C cycling rates with data from the regionally extensive forest monitoring network and the USGS surface water monitoring programs was developed at the three IMRAs. Variables such as fine foliar litterfall, coarse woody debris production, foliar chemistry, and soil C and N stocks were measured at the Tier 1 sites, and relationships were developed between these variables and indicators such as forest type and basal area that can be efficiently measured at Tiers 2 and 3.

Because the USFS Tier 3 sampling is national in scope, the enhanced Tier 3 data within the DRB can also be compared to forest conditions in similar ecological strata outside the DRB. The CEMRI program integrated data across spatial scales (Tiers 1, 2, and 3) using two primary models on landscape and surface water data in the DRB: the SPARROW model developed by the USGS, and the PnET model developed by the USFS and the University of New Hampshire (Alexander et al. 2001, Ollinger et al. 1998, Pan et al. 2004).

The SPARROW model (SPAtially Referenced Regressions of contaminants On Watershed attributes) used data on watershed conditions from different programs collecting environmental data within the basin to predict downstream water quality (Alexander et al. 2001). The model can link process data from small-scale watershed studies with monitoring data from large-scale river sites. The SPARROW model used the CEMRI data collected on a watershed-wide basis in forested watersheds to estimate the river export of specific constituents from the forested landscape, and it compared that modeled export to estimates developed by the USGS NAWQA program for urban and agricultural landscapes. In this way, the model created overall estimates of watershed export of chemical constituents within the DRB. The model output could then be compared to measured export values computed at USGS monitoring stations nested within the DRB.

The PnET model is a process-based ecosystem model that uses spatially referenced information on vegetation, climate, and soil to predict the functioning of forest processes that control C storage, net primary production (NPP), water yield, and N leaching loss. The model was well validated for NPP and water yield predictions at locations within the Northeastern U.S. (Ollinger et al. 1998). In addition to general input information, the model also requires data on N deposition, ozone (O3), and atmospheric CO_2 to predict the impact of changing atmospheric chemistry on forest ecosystems. Ecosystem processes were analyzed at large spatial scales in the DRB using a combination of the new CEMRI databases and existing modeling of climate change scenarios and N deposition rates in forested regions of the mid-Atlantic and Chesapeake River Basin (Hom et al. 1998, Pan et al. 2004).

1.12 Preliminary Results

Although data analysis and final reporting are still in process, work to date is pointing toward some significant results emerging from the CEMRI process. Here are some examples:

- Initial results show that the basin is a small net C source. Within the basin, southern areas are losing C while northern areas are gaining C primarily because of historical patterns of land use change. Initial estimates of transfer of C via streams show small quantities relative to uptake by trees.

- Correlations between pest infestation and changes in stream chemistry were observed during the short period of the CEMRI assessment, and methods for tracking the effects of pest outbreaks on forest soil and stream biogeochemistry were developed and tested.
- Mapping and data analysis revealed important biogeochemical correlations among foliar chemistry, tree stress indicators, and both stream and soil Ca concentrations in the Neversink IMRA. There is a common pattern of low soil Ca concentrations and low stream acid neutralizing capacity in the western Pocono Mountains and the eastern Catskill Mountains, the areas receiving the greatest amount of acidic deposition.
- 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.
- Modeling of forest biogeochemistry with the PnET-CN model showed how N leaching from forests is responsive to levels of N deposition, and it indicated high levels of N leaching from forested landscapes to streams in the upper DRB.

1.13 Conclusions

The CEMRI approach of a) integrating and enhancing existing monitoring programs to address key forest health and sustainability issues at multiple spatial scales and b) using a large watershed as a common frame of reference is a practical solution for compiling the data from diverse monitoring systems necessary to address complex regional environmental issues. Implementation requires sponsorship by participating agencies, clearly identified issues to be evaluated, and a willingness to modify or enhance existing monitoring systems and analytical models. Once established, the integrated research and monitoring system results in a desirable template to attract other monitoring and research programs to this data-rich arena and greatly expands the interpretive capabilities of the individual programs involved.

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