Multi-Scale Evaluation of Watershed Health in the Delaware River Basin and CEMRI

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Abstract

The Delaware River Basin is in the coastal Mid-Atlantic region of the United States, covers 12,700 square miles of primarily forested land, and is home to 7.2 million people. Major watershed issues in the Delaware River Basin (DRB) are urbanization and forest fragmentation, varied abiotic and biotic stressors, diminished condition of forest soils and plants, invasive exotic species, and relationships between forest terrestrial and aquatic processes. In 1998 the U.S. Forest Service (USFS), the U.S. Geological Survey (USGS), and the National Park Service (NPS) formed a Collaborative Environmental Monitoring and Research Initiative (CEMRI). Initial efforts involved combining monitoring and research efforts of participating Federal programs to evaluate health and sustainability of forest and fresh water aquatic systems in the DRB. In 1999-2002, CEMRI focused on urbanization and forest fragmentation, carbon stocks and fluxes, nitrogen saturation and calcium depletion, vulnerability to exotic insects, and improving knowledge of associations between terrestrial and aquatic processes. Models were developed or modified to associate process-level information (from two long-term watershed monitoring sites representing three physiographic provinces) with landscape-scale information (from satellite, aerial, and ground monitoring systems). Eventual goals are development of models of responses of forest and aquatic processes to perturbations, estimation of future forest condition, and identification of threats to forest health and sustainability. This paper discusses development of CEMRI, utilization of the Intensive Site Monitoring component of the Forest Health Monitoring program, terrestrial and aquatic issues to be addressed by this collaborative effort, and proposed methods to evaluate issues across multiple spatial scales.

Keywords: watershed health, multi-scale assessments, carbon cycling, forest monitoring, calcium depletion

Introduction

Resource management agencies often seek a holistic approach to management of ecosystems, but few agencies have the resources to support multi-component ecosystem-level research. Much of the information collected by any one agency is often fragmentary and incompatible, because of the lack of resources to design and collect multi-resource data (terrestrial, aquatic, atmospheric, etc.) data at multiple spatial scales.

One solution is to develop a concept for "virtual" integration of the capabilities of diverse agencies to address environmental problems in a holistic manner. By supplementing and/or adjusting existing monitoring and research strategies, collaborating programs could continue to meet specific agency missions while also contributing to multi-scale, multi-resource inventory and monitoring systems. To test this approach, several federal agencies and academia developed a strategy to evaluate the condition of forests and associated waterways in the Delaware River Basin (Figure 1).

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Databases derived from an ecologically and spatially broad 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 capability. The ultimate goal is to improve the ability to monitor ecosystem status and change across a range of temporal and spatial scales, and thus provide earlier and more accurate detection and prediction of environmental change.

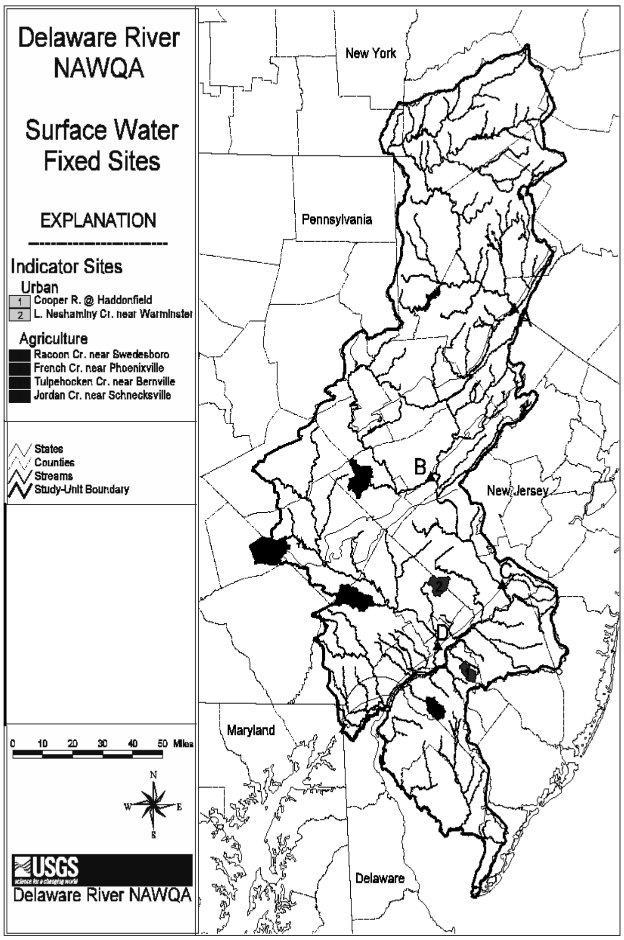

Figure 1. The Delaware River Basin in the Mid-Atlantic region of the U.S. is ecologically diverse. The USGS NAWQA program monitors water quantity and quality in forest and agriculture land types. Source: Gilliom et al. 1995.

The Delaware River Basin (DRB) in the eastern United States was chosen as CEMRI's first pilot region because:

- The river basin hosts several existing agencies and programs accepting the challenge of designing an integrated monitoring system to address specific issues, using their existing monitoring systems.
- The DRB is a relatively simple version of a river basin-to-estuary landscape delineation, with a single large river entering the estuary, as opposed to more complicated systems such as the Chesapeake Bay drainage.
- The DRB is a logical conceptual unit for integrating environmental information on a regional scale, because the aquatic systems are integrators of many environmental issues.
- The DRB contains several Intensive Monitoring and Research (IMR) sites (Neversink, DEWA, French Creek), representing two of five major physiographic regions, with long-term research and monitoring of ecological components and processes.

The DRB encompasses more than 12,700 mi^2 and includes parts of Pennsylvania (6,465 mi^2), New Jersey (2,969 mi^2), New York (2,363 mi^2), Delaware (968 mi^2), and Maryland (8 mi^2) (Figure 1). About 7.2 million people live within the Basin, and an additional 7 million people in New York City and northern New Jersey rely on surface water diverted from the Basin for their water supply.

Methods

The Untied States Department of Agriculture (USDA) Forest Service (FS) and the United States Geologic Survey (USGS), Water Resources Division initially conceived the approach of evaluating several important forest health issues in the Delaware Basin using a multi-spatial scale, multi-resource approach, primarily the integration of forest and aquatic resources. These strategies for multi-agency and resource collaboration became known as the Collaborative Environmental Monitoring and Research Initiative (CEMRI), and the initial pilot test was conducted in the Delaware River Basin.

Shortly thereafter, this initial CEMRI group was joined by the National Park Service (Delaware Water Gap National Recreation Area (DEWA), National Air and Space Administration (NASA), and the United States Environmental Protection Agency (EPA). The Delaware CEMRI pilot integrated environmental data collection across a range of temporal and spatial scales administered by diverse agencies, including process-level research sites (Neversink Watershed, Delaware Water Gap NRA, French Creek), regional ground monitoring systems using long-term, fixed-area plots, and wall-to-wall remote sensing programs (aerial photography and satellite pixels).

The CEMRI approach is an effective environmental monitoring strategy based on a collaborative structure for independent monitoring and research programs to combine complementary activities to address specific environmental questions at multiple spatial, temporal, and ecological scales. In general, most current environmental monitoring programs address issues of one resource type and at one spatial scale, yet information needs often require data from multiple resources that span three broad categories of spatial and temporal monitoring (Figure 2):

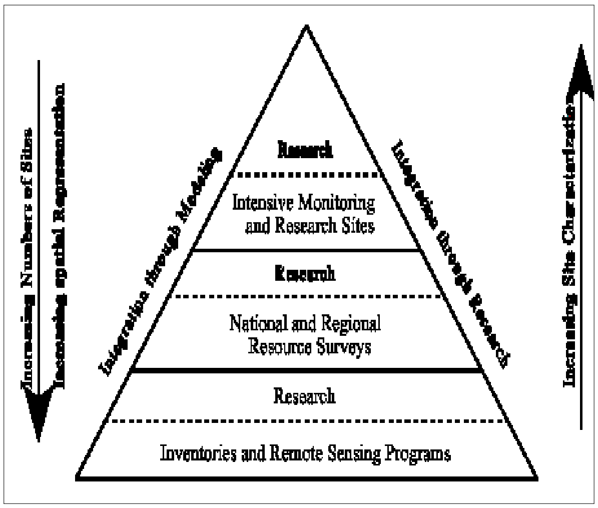

Figure 2. Conceptual framework for conducting evaluation of forest and watershed issues that span multiple spatial scales. Source: Murdoch and Jenkins 2003.

- **Tier 1** – temporally and spatially continuous landscape-scale monitoring and analysis (such as satellite remote sensing, aerial photography, etc.). Primary objectives are development of spatially-continuous coverage of information, such as land-use and change, forest species distributions, forest fragmentation, etc.

- **Tier 2** – frequent multi-point ground monitoring (plots and surveys) at large regional scales. Purpose is to document the status, change, and extent of unusual or disturbed conditions based on ground-collected information, link process-level Tier 3 information to landscape-scale Tier characterizations, and to provide ground verification of remotely sensed parameters in Tier 1.
- **Tier 3** – frequent monitoring and intensive research on components, processes, and determining cause-and-effect relationships at a limited number of intensively monitored sites within relatively small areas. The purpose is to determine key forest processes, understand how these processes inter-relate, how stressors affect these processes, and how these processes relate to macro-indicators that can be monitored at large special scales. In CEMRI these process-level sites are referred to as Intensive Monitoring and Research (IMR) areas.

One measure of the success of the CEMRI pilot will be the comparison of a pre-integration assessment of existing monitoring and interpretation capability with new information obtained in the post-integration assessments. The pre-integration assessment (Murdoch and Jenkins, 2003) addressed the five issues listed above, identified data gaps in existing monitoring programs, and provided a benchmark against which the benefits of the CEMRI approach in the Delaware Basin could be evaluated.

Physiographic Provinces

Ecologically the DRB is very diverse, with the mostly flat Coastal Plain in the south, with soils underlain by unconsolidated sediments (Figure 1). Further north rolling lowlands and a series of broad uplands in the Piedmont are found, with soils underlain by metamorphic rock. North of the Piedmont Province, the New England and the Valley and Ridge Provinces consist of rock layers that have been deformed into a series of steep ridges and parallel folds that trend more northeast-southwest.

The Appalachian Plateau occupies the upper one-third of the basin, and is characterized by rugged hills with intricately dissected plateaus and broad ridges. Bedrock in the Appalachian plateau consists of inter-bedded sandstone, shale, and conglomerate. Topography in the Basin ranges from sea level in the south to more than 4,000 feet elevation in the north.

During the last major glacial advance, the Appalachian Plateau and parts of the Valley and Ridge and the New England Provinces were glaciated. North of the line of glaciation, valleys typically are underlain by thick layers of stratified drift and till. The primary focus of the CEMRI pilot is in the forested landscape of the Appalachian Plateau section of the Delaware Basin. An assessment of urbanization, forest fragmentation, and water quality included both the Piedmont and Appalachian Plateau study areas.

Average annual precipitation ranges from 42 inches in southern New Jersey to about 50 inches in the Catskill Mountains of southern New York; annual snowfall ranges from 13 inches in southern New Jersey to about 80 inches in the Catskill Mountains (Jenner and Lins 1991). Generally, precipitation is evenly distributed throughout the year. Annual average temperatures range from 56°F in southern New Jersey to 45°F in southern New York.

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

Results

Explicit collaboration among the participating agencies was essential for collection of data that was both complementary and comparable, focused on the environmental issues identified below, and included data gaps identified in the pre-integration assessment.

Numerous meetings of the lead agencies led to the identification of issues that required data from multiple spatial scales and multiple resource groups. The regionally-integrated monitoring in the CEMRI pilot targeted five specific environmental issues that required data from multiple resource groups collected at three spatial scales:

- Measuring and monitoring forest carbon stocks and fluxes;
- Identification and monitoring of forests vulnerable to non-native invasive pest species;
- Monitoring recovery from calcium depletion and nitrogen (N) saturation in forests of the Appalachian Plateau;
- Measuring and monitoring forest fragmentation and associated ecosystem changes; and
- Integrating the effect of terrestrial ecosystem health and land use on the hydrology, habitat, and water quality of the Delaware River and Estuary.

Collection and synthesis of data were accomplished by augmenting existing monitoring programs already established in the DRB, including local, process-level studies, regional ground monitoring using fixed-area plots and surveys, and remote sensing with aerial photography and satellites.

For example, the FIA and FHM monitoring programs collaborated on the development of a national standardized monitoring system of fixed-area plots (1/16th acre plots composed of 4 subplots) (http://www.fia.fs.fed.us/). These plots are the basis for the collection of a broad suite of ecologically-based indicators that address many of the Criteria and Indicators of the Montreal Process (Anonymous 1995).

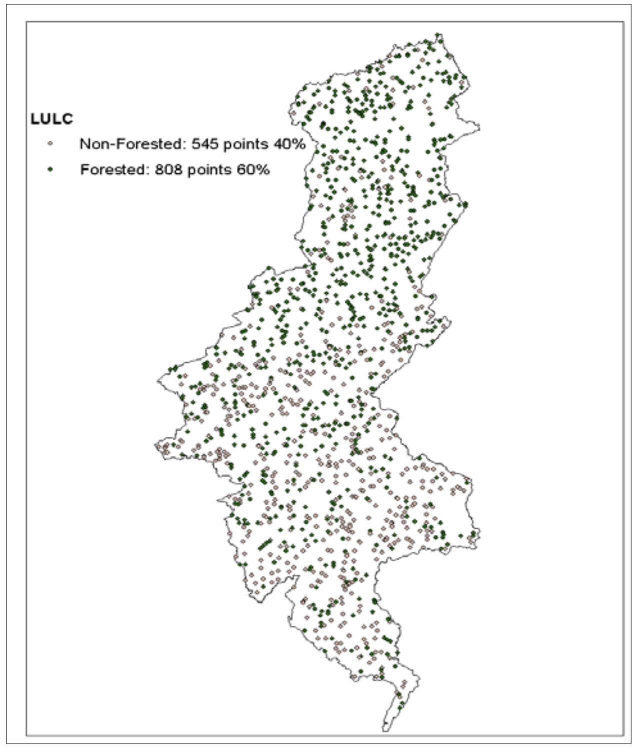

Figure 3. Distribution of FIA fixed-area plots within Delaware River Basin. Phase 2 plots are 1 plot per 6,000 acres. Phase 3 plots are 1 plot per 96,000 acres. Source: Murdoch and Jenkins 2003.

Within the Delaware Basin, these plots are the primary data source for carbon sequestration, forest composition, structure, and condition, and biological diversity. Information on trees is the primary focus of the Phase 2 (P2) sampling framework (1 plot per 6,000 acres), and information on forest health comes from the Phase 3 (P3) plots (1 plot per 96,000 acres) (Figure 3). P3 plots are P2 plots where data on soils, dead wood, air pollution indicators, fuel loading, understory diversity, etc. (Stolte et al. 2002) are collected with P2 tree data.

Intensive monitoring and research areas

Three watersheds in the Delaware River Basin were selected as Intensive Monitoring and Research area (IMRs) for the process-level studies in forested landscapes. Each IMR site was selected for process-level studies because it contained existing monitoring infrastructure or programs. Additionally, the three IMRs represent a range of climatic and forest conditions found in the Delaware Basin (Figure 4).

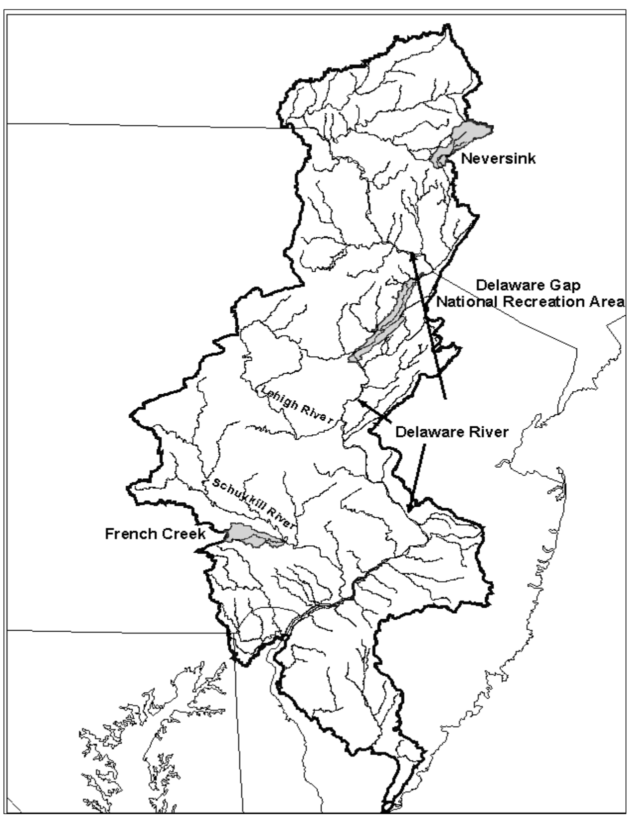

Figure 4. Site of intensive monitoring and research areas (IMRs) in the Delaware River Basin. Source: Murdoch and Jenkins 2003.

The IMR sites selected for the CEMRI pilot were:

1. The Neversink watershed has been monitored by the USGS District Research Program since 1982. It lies within the northern, more forested Appalachian Plateau province, and contains a set of nested discharge and water quality monitoring stations in basins ranging in size from 130 to 1 km^2.
2. The Delaware Water Gap National Recreation Area (DEWA) also lies within the Appalachian Plateau province. Discharge and water quality monitoring stations have been operated during the past 4 years on Flat Brook in DEWA as part of NAWQA (Gilliom et al. 1995). The National Park Service (NPS) has established special forest plots at DEWA for studying the effects of the introduced insect hemlock woolly adelgid (*Adelges tsugae*).
3. The French Creek watershed is located in the mid-basin Piedmont province and contains a partially-forested landscape that is being rapidly suburbanized. Discharge and water quality monitoring stations have been operated during the past four years on the main channel of French Creek.

At the Neversink and Delaware Water Gap IMR sites, the FIA and FHM programs have enhanced the P2 sampling frame to provide a finer-resolution fixed-area plot sampling of the watersheds where process-level monitoring was occurring. These plots are called Phase 4 (P4) plots. Also within each IMR, other P4 plots are intentionally placed directly within process-level research and monitoring studies. These latter plots are called Phase 5 (P5) plots (Figure 5).

Since the same data on trees, soils, down wood, etc. is collected at P2, P3, P4, and P5 spatial scales, all within the same plot framework, the relationship between processes and indicators collected at the IMR sites (P4 and P5) can be used to interpret the condition of the forests at the larger spatial scales, since they are all systematically linked in a common sampling frame with the same fixed-area plots and indicator data (Dunn and Stolte 2003).

For example, a system for integrating process-level information on C cycling rates with the regionally-extensive forest monitoring network and the NAWQA surface water monitoring program is being developed at the three IMRs. Variables such as fine foliar litterfall, coarse woody debris production, foliar chemistry, and soil C and N stocks will be measured at the P4 and P5 plots (Tier 3), and relationships between these variables and indicators typically measured at P2 and P3 plots (Tier 2), and also measured at P4 and P5 plots, such as forest type and basal area, will be developed and applied to develop regional estimates of C dynamics.

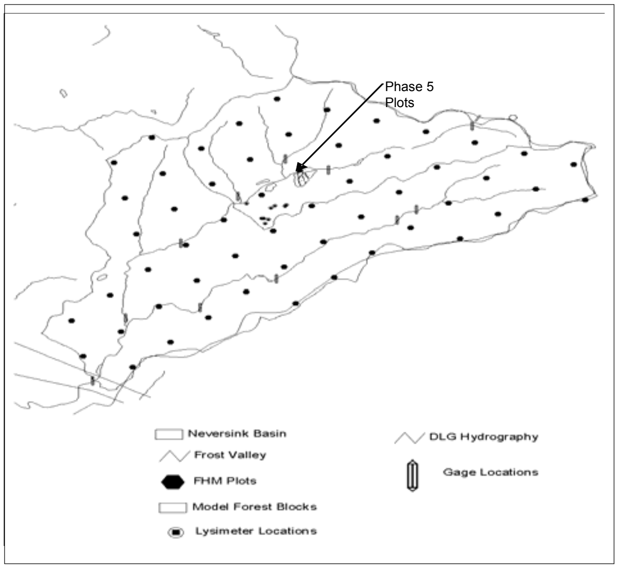

Figure 5. Locations of P4 and P5 plots within the Neversink watershed. IMR area. The watershed is highly instrumented to measure input/output budgets for C and N relationships between forests and aquatic systems. Source: Murdoch and Jenkins 2003.

Also, since the P2 and P3 (Tier 2) sampling is national in scope, the enhanced Tier 2 data within the DRB can also be compared to forest conditions in similar ecological strata outside the Delaware Basin. The CEMRI program will integrate data across spatial scales (Tiers 1, 2, and 3) using two primary models on forested landscape data in the Delaware River Basin – the SPARROW model developed by the USGS and the PnET model developed at the University of New Hampshire.

The SPARROW (Spatially Referenced Regressions of contaminants on Watershed attributes) will be used as a tool for cross-linking data from different programs collecting environmental data within the Basin. The model has the ability to link process data from small-scale watershed studies with monitoring data from large-scale river sites.

The SPARROW will use an empirical model to evaluate the CEMRI data collected on a watershed-wide basis in forested landscapes, and will link that modeled export to estimates developed by the USGS NAWQA program for urban and agricultural landscapes – in this way, the model will create overall estimates of watershed export of chemical constituents within the DRB. The model output will then be compared to measured export values computed at USGS monitoring stations nested within the DRB (Murdoch and Jenkins 2003).

Thus smaller-scale stream segment data will be independently generated by the development of the National Hydrologic Dataset (NHD) by the USGS for the DRB as part of the collaborative effort. The NHD is a 1:24,000 river-reach dataset with full GIS capability. The NHD for the Delaware River Basin will be compiled and referenced to a 30 m digital elevation model (DEM), and to a 10 m DEM in selected portions of the watershed.
Ecosystem process modeling for the DRB can be derived from a combination of the CEMRI databases and existing work on climate change scenarios and N deposition on forested regions of the mid-Atlantic and Chesapeake River Basin (Hom et al. 1998, Pan et al. 2000) using the PnET family of models.

The PnET model is a process-based ecosystem model that uses spatially referenced information on vegetation, climate and soil to make estimates of important variables of forest ecosystems such as carbon storage, net primary production (NPP), water yield, and N leaching loss. It includes a series of compatible sub-models. 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, and atmospheric CO_2 in order to examine the impact of changing atmospheric chemistry on forest ecosystems.

Conclusions

The CEMRI approach of virtual integration of existing monitoring programs to address key environmental issues at multiple spatial scales is a practical solution that requires determination of participating agencies, clearly identified issues to evaluate, and modifications of existing monitoring systems and analytical models. The combined research and monitoring systems created produces a desirable template to attract other monitoring and research programs to this data-rich arena. Other groups have joined the CEMRI pilot, and additional assessment issues now include the cooperation of groups that focus on the study of urban and suburban land dynamics. The CEMRI group is continuing to pursue collaboration with monitoring and research groups working with agricultural landscapes, and groups working with the estuary environment of the Delaware Basin.

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