Baltimore Ecosystem Study

Annual Report

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Covering

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Urban LTER: Human Settlements as Ecosystems: Metropolitan Baltimore from 1797 – 2100

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www.beslter.org

Preface to the Annual Report

On the following pages is the Annual Report of the Baltimore Ecosystem Study (BES) for the period 2005-2006. The Baltimore Ecosystem Study, a Long-Term Ecological Research (LTER) project, was initiated in 1997. The BES is one of 26 LTER projects, representing diverse ecosystems and research emphases. It is funded by the National Science Foundation to learn how an urban area works as an ecological system. Over the last eight years we have learned new, and sometimes surprising, things about Baltimore's urban ecosystem. This report summarizes the most recent scientific and educational contributions BES has made.

As one of only two Long-Term Ecological Research sites located in an urban environment, we want to know the ecological interactions in the whole range of habitats—from the center city of Baltimore, out into the surrounding rural areas. We are conducting research on the soil, the plants and animals on land and in the streams, the water quality, and condition of the air in and around Baltimore. For that information to make sense, we are also studying how families, associations, organizations and political bodies make decisions that affect ecological processes. In other words, we are treating the whole collection of suburban and rural areas as a complex urban ecological system that includes people and their activities.

This is a really unusual approach to ecology because it combines with social sciences, physical sciences, and education to understand a big metropolitan area as an ecological system. Saying that an urban area is a system just means that we are concerned with the interactions between wild and domestic organisms, people and their organizations, the natural and built environment, and how they all affect one another. It is these relationships that determine the quality of the environment we experience.

The program brings together researchers from many disciplines and organizations to collect new data and synthesize existing information on both the ecological and engineered systems of Baltimore. Our interest is not only with the present environment, but with the historical changes that have led to the conditions that exist today, and with the environmental trends into the future. The ecological knowledge BES creates helps support educational and community-based activities. Indeed, the interactions between our researchers and the Baltimore community are important components of our project. We hope that the information produced by our work, which integrates many disciplines and the efforts of many research and educational institutions in Baltimore and beyond, is of interest and use to you.

You may contact the researchers, educators, and professional members of the Baltimore Ecosystem Study through the Project Facilitator, Holly Beyar (BeyarH@ecostudies.org), and locate updated information and additional information on the project through its website (http://www.beslter.org).

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Acknowledgment and Disclaimer

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"Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation."

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Activities

How cities and suburban areas function as integrated, ecological systems remains an open frontier. This gap in knowledge means that our basic understanding of ecology does not yet fully embrace one of the most widespread and extreme human interventions in the biosphere. It also means that people's ability to assess options for ecological management, design, and restoration in and around cities and suburbs is limited. The ecological knowledge gap in urban areas is a crucial lapse because urbanization in all its forms is a growing component of global change.

The Baltimore Ecosystem Study LTER (BES) has three components: 1) Research, 2) Education, and 3) Community Engagement or Outreach. The research component employs two complementary approaches needed to build ecological knowledge of urban systems. First, social and economic processes are combined with physical dynamics and ecological processes. Second, because cities and suburbs are characterized by rapid change, both retrospective and long-term perspectives are critical. The third component of BES recognizes the responsibilities and opportunities of conducting research in an inhabited system. Developing and making the most of a broad range of educational opportunities satisfies the responsibility to share ecological knowledge with the widest audience. Applying ecological knowledge to management, environmental quality, and environmental equity acknowledges society's needs. Finally, the use of new ecological knowledge of urban systems in planning, design, and restoration provides an important opportunity both to test ecological theory and to improve urban quality of life.

The scientific knowledge gap, new scientific opportunities, and our responsibility to the public have prompted us to pose three questions to guide our scientific research and our interactions with citizens in metropolitan Baltimore:

1. How do the spatial structure of socio-economic, ecological, and physical factors in an urban area relate to one another, and how do they change through time?

2. What are the fluxes of energy, matter, capital, and population in urban systems, and how do they change over the long term?

3. How can people develop and use an understanding of the metropolis as an ecological system to improve the quality of their environment, and to reduce pollution loadings to downstream air- and watersheds?

In our eighth year we have continued and enhanced core long-term activities, and initiated new work that promotes the goals of the Long-Term Ecological Research Network. Field studies continue to emphasize the 17,150 ha Gwynns Falls watershed, a forested reference watershed at Oregon Ridge County Park, an urban atmospheric flux tower at Cub Hill, and a highly urbanized storm drainage – Watershed 263 – in West Baltimore. Gwynns Falls includes stable agricultural land, farms that are currently being converted from agricultural to suburban uses, as well as areas that have been intensively urbanized for centuries. The Cub Hill site is on the edge of the city and represents extensive suburban landscapes. In addition to these intensively studied sites, our research also includes 200 sample points for soils, vegetation, and surfaces, spread throughout the city. We list key activities under each of our three guiding questions.

Ongoing Major Activities Addressing Question 1: How do the spatial structure of socio-economic, ecological, and physical factors in an urban area relate to one another, and how do they change through time?

To answer Question 1, we are conducting the following major research activities:

- Quantify the biological, built, and social patch structure of Baltimore.
- Document patch change.
- Discover biotic changes.
- Survey soil heterogeneity and quantify heavy metals.
- Operate a meteorological network.
- Conduct modeling at various scales.
- Compare gradients within metropolitan Baltimore, and with other cities.
- Model and empirically test ecological-social relationships.

The activities answering Question 1 address the spatial structure, the temporal dynamics, and the integration of the social, ecological, and physical components of the Baltimore ecosystem. The specific research projects are listed below. Additional detail appears in the research section of the BES web page at http://beslter.org

New Activities Addressing Question 1:

1. ***Dasymetric Mapping and Environmental Equity***.

Dasymetric methods for improving the resolution of historical and present-day census data, and its application for environmental equity research were investigated. By overlaying census boundaries with land use and land cover information in a GIS database, census data can be partitioned into places where, from the land use information, people are known to live. This method is particularly helpful in parts of cities and suburbs where residential land use is uneven, such as new subdivisions or industrial neighborhoods.

2. ***Effects of Historical Events on Plant Species Distribution***.

Our historical watershed research focuses on understanding how events since the first Europeans settled in the Baltimore area have influenced processes that dictate the distribution of trees, shrubs and herbs, including exotic species. We divided the Gwynns Falls Watershed into an upland region and a riparian region, because agriculture and urbanization result in the movement of soil by erosion from the upland regions and the transport and deposition of the soil in the riparian areas. The processes involved are likely to affect plant distributions differently.

In the upland Gwynns Falls watershed, trees, shrubs and herbs were identified, counted and measured in 79 randomly located 100 m^2 plots. Geologically, the northern or upper watershed is underlain by schist with some serpentinite. Amphibolite, gneiss and schist are dominant in the middle section, while the lower part as far as the Fall Zone is characterized primarily by amphibolite and mafic rocks. Beyond the Fall Zone, the substrate consists of Coastal Plain sands, clays, and human generated fill. Schist generally weathers into a soil which is moderately high in water holding capacity and richer in nutrients than the other substrates. Soils derived from gneiss have abundant silica and aluminum, while amphibolite evolves into a less acidic soil with more iron and magnesium, and a lesser water holding capacity. Soils weathered from schist provide the most desirable habitat for trees, followed by gneiss, amphibolite, with mafic being the poorest habitat.

In the riparian zone, trees, shrubs and herbs were identified and measured in 111, 100 m^2 plots located along 45 randomly selected transects crossing floodplains of first, second, third and fourth order streams in the Gwynns Falls Watershed. At each transect location, stream bank relative to stream channel elevation was measured.

The following table (Figure 1) summarizes the history of the watershed and the effect of these historical events that would influence the distribution of species.

LAND USE HISTORY IN THE GWYNNS FALLS WATERSHED AND ITS EFFECT ON THE RIPARIAN SYSTEM

DISTURBANCE	DURATION	EFFECT ON LANDSCAPE	EFFECT ON RIPARIAN ZONE
Charcoal production (lower third)	1730-1810 1731 – Baltimore Iron Works formed	Deforestation Row cropping	Less tree buffering of streams; damming for furnace bellows; increased sediment supply
Agriculture	1664 – beginning agriculture Pre-1800 forest cover 80% 1900- peaked – forest cover 20% 1930s – decline in agriculture	Soil eroded from plowed fields; reduced infiltration; increased runoff; increased nutrients from fertilizers (after 1950) Decreased sediment supply and Q2, but higher than pre-agric	Over 80 years, up to 2 m vertical accretion of floodplains due to a 6-fold increase in sediment supply; decrease in stream width; floodplains less frequently flooded; loss of wetlands drained for agriculture
Mill Dams	1728 – first mill built 1770s – numerous mills built to accommodate wheat trade 1852 – 73 mills in Baltimore area	Water diverted from streams into mill races; sediment trapped behind dams	Decreased base flow below dams; permanent inundation above dams; fish blocks
Removal of dams	1914 – majority of dams removed or breached	Sediment remobilized	Sediment removed from upstream of dam and deposited for some distance downstream
Chrome mining (upper)	1820-1880	Local mine shafts	Increased sediment inputs to streams; riparian area disturbed for placer mining
Urbanization	1957 and ongoing	High initial sedimentation with construction; increased impervious surfaces, sediment and water runoff; more rainfall channelled through gutters/sewers	Stream channels incised as peak flow increased, base flow and sediment yield decreased; stream banks increase in elevation

Figure 1.

3. ***Refining a New Urban Land Cover Classification***.
The High Ecological Resolution Classification for Urban Lands and Ecological Systems (HERCULES) was revised to Version 7. This new version makes the system easier to use, share, and automate. The patch layer of the entire Gwynns Falls watershed and Baisman Run study regions were completed using Version 7. Work is underway to automate the quantification of landscape elements within each of the HERCULES patches, and to visualize the classification system in ways that will engage urban designers and the public.

Automation will employ a method called "object-oriented image classification" to characterize land cover at a very fine scale. In this method, we "segment" digital aerial imagery into small polygons, representing areas of contiguous homogeneous cover, and then classify those polygons (e.g. tree, grass, tree shadow on grass, impervious, etc.) based on a set of rules relating to reflectance, shape and context. Many of these polygons are as small as an individual lawn, tree or driveway. This database of land cover "primitive objects" will then be used to classify land into patch types, using the HERCULES land classification system. Land cover information will be summarized by property parcel, so that analysis can be conducted at both the patch and parcel levels.

4. ***Dynamic Modeling of Urban Land Use and Development***.
A dynamic model of urban land use and development for the Baltimore Metropolitan Statistical Area (MSA) based on the four types of capital (built, human, natural and social) was developed. The initial model was designed to operate at the spatial scale of the census neighborhood block group.

5. ***Statistical Comparison of the BES Social Survey over Two Time Periods.***
Statistical analysis of the most recent BES social survey was completed by a social science team in 2006 and a paper was submitted to *Environment and Behavior* (see Wilson et. al. 2006). The survey assessed environmental knowledge, environmental decision making by households, as well as the level of satisfaction with social and ecological components of neighborhoods.

6. ***Testing a New Social-ecological Theory.***
To test our theory of an Ecology of Prestige, we examined the relationship between population density, social stratification, lifestyle behavior, age of housing and the area of land available for vegetation and the extent of vegetation cover in riparian areas, Public-Rights-of-Way (PROW), and private lands.

Using parcel level data from across Baltimore, we have analyzed the predictors of private land vegetation. We generated two measures. "Possible stewardship" refers to the proportion of private land that does not have built structures on it, and hence has the possibility of supporting vegetation. "Realized stewardship" refers to the proportion of possible stewardship land upon which vegetation is growing. These measures were generated at the parcel level and averaged by US Census block group. Realized stewardship was further defined by proportion of woody vegetation and grass. Data about expenditures on yard supplies and services by block group were used to help better understand where current vegetation conditions appear to be the result of current activity, past legacies, or abandonment. PRIZM™ market segmentation data were first tested as predictors of possible and realized stewardship and yard expenditures at the Block Group level. PRIZM™ segmentations are hierarchically clustered into 5, 15, and 62 categories, which correspond to population density, social stratification (income and education), and lifestyle clusters, respectively.

7. *Diversity and Abundance of Insect Pollination in Urban and Suburban Gardens.*

Since 2003, we have been sampling urban community and suburban private gardens in the New York City metropolitan area to estimate the diversity and abundance of insect pollinators in developed landscapes. Although the data we report here are specific to New York City, in 2006 we began to contact private and community gardeners across the Baltimore metropolitan area, in anticipation of expanding our research efforts to the Gwynns Falls and Patapsco River watersheds in the spring of 2007.

Between October 2005 and October 2006, we have used a combination of water pan trapping and hand collections to quantify the diversity of insect pollinators, with a specific focus on the Apoidea, in eighteen urban community gardens in East Harlem and the Bronx, New York City, and 21 private suburban gardens in Westchester County, NY. The water pan traps consisted of plastic cereal bowls (500 ml) painted UV yellow, UV Blue or white. The traps were filled with soapy water and placed into gardens for 24 hours. The specific number of pan traps in each suburban garden was determined by area of the garden that was devoted to flowerbeds versus lawn.

Bees were hand collected in the Bronx and East Harlem gardens for a period that was scaled to garden area. In suburban Westchester County, bees were hand collected for an amount of time that was scaled to the amount of the garden that was dedicated to flowerbed and lawn. The flowering plant species from which each specimen was collected was noted.

To assess pollinator density, we set up 10-15 m transects, adjacent to a flowerbed, through each garden. Transects were slowly walked, and any bee within 0.5 meter on either side of the transect was counted. Bees were identified to species when possible. Otherwise, bees were identified to general morphotype.

8. Pollination Services in Urban Gardens.

Since 2005, we have examined the relative presence of pollination services among community gardens in the Bronx and East Harlem, NY. Using cucumbers as the assay plant, we have been assessing the impact of the garden area, floral abundance and landscape level green space on fruit yield in cucumbers, which require a high pollination load in order to set fruit.

In the summer of 2005, we assessed the impact of Pollinator Conservation Areas (PCA) on pollinator abundance and cucumber yield within gardens. Pollinator conservation areas are clusters of native, nectar-producing plants that are recommended to gardeners who want to attract pollinators into their gardens. A sunny area for each PCA was agreed to by all community gardeners. Pollinator conservation areas contained goldenrods (*Solidago cassia*, *S. rigida* and *S. rugosa*), common blue wood aster (*Aster cordifolius*) smooth aster (*Aster laevis*), black eyed Susan (*Rudbeckia hirta*) and butterfly weed (*Asclepias tuberosa*), common milkweed (*Aesclepias syriaca*), Joe Pye weed (*Eupatorium fisulosum*), and mountain mint (*Pycnanthemum virginianum*). All plants are native to the northeastern United States and were chosen to ensure that at least some species would be in bloom during all times of the summer and early fall. PCAs were established in nine of our eighteen urban gardens.

Bee abundance was quantified through counts of morphotypes that are identifiable without capture. Bees were identified in the field as follows: Bombinae (Apidae), *Apis mellifera* (Apidae), Halictididae (not including small Dialictus spp.), *Xylocopa virginianum* (Anthophoridae), *Melissodes* spp. (Anthophoridae), *Osmia* spp. (Anthophoridae) and Megachilidae. The variable of interest was the sum abundance of all of these groups. The number of quadrat counts conducted per garden was scaled to garden size. All bees landing on flowers within the quadrat were recorded during 60 seconds of observation time. Care was taken not to count individuals twice.

To assess whether pollinator conservation areas increased cucumber yield, potted cucumber plants were placed in each of the ten urban gardens on June 20, 2005, just as the plants were beginning to produce flower buds. Five of the gardens contained pollinator conservation areas. The other five gardens served as controls. We harvested all cucumbers and measured wet mass, dry mass, circumference, length and volume.

9. ***Bird Populations and Diversity.***

The second year of the BES Bird Monitoring Project was conducted in 2006. This project links bird composition and abundance data to 100 UFORE (Urban Forest Effects model) sampling points in Baltimore City and to 100 UFORE points in Watershed 263. Watershed 263 is a small storm drain catchment undergoing neighborhood greening, removal of excess impervious surface, and community revitalization to test the effects of these interventions on storm water amount and quality. A small project assessing bird response to tree pruning was also initiated.

A robust long term bird monitoring protocol was developed for Baltimore. This will run in parallel with bird monitoring at CAP LTER. Both bird monitoring projects consist of two components. First, there are randomly located sites drawn as a subset from core LTER monitoring sites – UFORE sites in Baltimore and Survey200 sites in Phoenix – that are sampled in the same way. Second, we have a stratified sample of the same core LTER monitoring sites. In Baltimore, these were chosen using two sets of BES data: PRIZM™ (a market segmentation system used to discriminate spatial clusters of human life styles and environmental decision making) and HERCULES (see # 3). This second set of sites will allow us to measure associations of bird populations and communities with both human social groups and biophysical patch structure. Site selection aimed as much as possible for a blocked design with most HERCULES patch types falling into multiple PRIZM™ social groups. We expect, based on pilot data, that PRIZM™ classification will be a stronger predictor in sites with low housing density HERCULES patch types. At higher housing densities, we expect a fully expanded HERCULES classification to perform best at predicting bird community structure.

10. ***Forest Change in Random Point Samples.***

A main activity for this past year has been data entry and analysis of the year 2004 permanent plots from the cities of Baltimore, MD and Syracuse, NY. The goal of this project is to assess urban forest change (1999-2004) for both cities to quantify rates of change and how change varies by such factors as land use, species and tree size.

11. ***Biocomplexity, Urban Design, and Nitrogen Retention.***

The integration of ecology and urban design is a frontier actively being explored through the Baltimore Ecosystem Study. A biocomplexity project associated with BES is evaluating the role of new ecologically based urban designs in the amelioration of nitrate pollution in urban streams. A new conceptual framework called "The Cycle of Ecological Design," has been elaborated to support this research. The project integrates research on HERCULES, modeling heterogeneity in control of water flow paths in the city and suburbs, inclusion of the experience of local managers and policy makers in water quality management, creative urban design, the spatial and social capacity of different neighborhoods to accommodate the proposed designs, focus groups and social research to understand the reasons communities accept or reject designs, and finally, the modeling of the impact of acceptable designs on future nitrogen retention. The automation of HERCULES (see # 3) will facilitate this work. Object primitives will be attributed with information relevant to the flux of Nitrogen, such as the greenness of the lawn, using Normalized Vegetative Difference Index (NDVI) and the height of the vegetation, using light detection and ranging data (LiDAR).

12. ***Ecology of Invasive Species.***

Earthworm invasion has recently been recognized as an important process. In the Mid-Atlantic Region the Asian pheretimoids are of special importance, because in the growing season they can dominate urban and suburban habitats. Very little is known about the life history of megascolecids in their new environment. We monitored a suburban population of *Amynthas hilgendorfi*, a common Asian invader, from early April, when the first juveniles emerged. The objective of the study was to obtain information on the population structure over time as well as to compare growth rates in the laboratory and in the field. Field samples of about 100 animals were taken biweekly, weighed, and returned to the field. For the laboratory experiments we collected 50 *Amynthas* from the same backyard and placed them individually into containers. We also collected ten large *Amynthas* from another urban area and placed them individually into containers as well. These animals were weighed weekly.

13. ***Wireless Sensor Networks.***
We have developed and deployed an experimental soil monitoring system in an urban forest. Wireless sensor nodes collect data on soil temperature, soil moisture, air temperature, and light. Data are uploaded into a SQL Server database, where they are calibrated and reorganized into an OLAP data cube. The data are accessible on-line using a web services interface with various visual tools. Our prototype system of ten nodes has been live since September 2005, and in five months of operation over six million measurements have been collected.

14. ***Effects of Parks and Green Space on Property Values.***
While urban parks are generally considered to be a positive amenity, past research suggests that some parks are perceived as a neighborhood liability. Using hedonic analysis of property data in Baltimore we determined whether crime rate mediates how parks are perceived and valued. Transacted price was regressed against park proximity, robbery rates for the surrounding neighborhood, and an interaction term, adjusting for a number other variables.

15. ***Modeling Urban Vegetation Dynamics.***
A dynamic model will be developed in SIMILE, a spatial modeling software environment, to simulate neighborhood change. This model will focus on Watershed 263 in Baltimore, but will be applicable to other areas as well. It will examine how investments in urban greening (e.g. gardens, street trees, landscaping, pavement removal) interact with other strategic investment and planning decisions (e.g. police and crime fighting, school and park programs, municipal infrastructure, joint public-private commercial investments) to change the state of these neighborhoods. An important component of this project is its mediate nature, meaning that neighborhood stakeholders will have input into the design and assumptions of the model through group meetings.

The fifteen new projects or new additions to ongoing work in BES span the range from basic biophysical and social research on spatial pattern and change, to integrated projects that link ecological and social patterns, to research that addresses pressing needs of managers and communities. This work on ecosystem structure forms the basis for the flux oriented research of Question 2, detailed next.

Ongoing Major Activities Addressing Question 2: What are the fluxes of energy, matter, capital, and population in urban systems, and how do they change over the long term?

To answer Question 2, we are conducting the following major research activities:

- Document human demographic and social processes.
- Quantify stream flow, chemistry, and key biota.
- Measure extreme storm water flows and flooding.
- Measure vegetation processes and nitrogen flux in riparian zones.
- Measure biogeochemical pools and fluxes in contrasting upland patch types.
- Quantify meteorological exchanges between surface and atmosphere using flux tower technology.
- Model atmospheric, hydrological and socio-economic fluxes in and across contrasting watersheds.

The research aimed at answering Question 2 takes into account the spatial structure of the Baltimore ecosystem, seeks feedbacks between socio-economic and biogeophysical processes, and has established sites in which long-term status and changes in fluxes are being measured. Integrated models, which incorporate ecological, hydrological, built, human and social capital, are key tools for understanding processes of flux and projecting changes into the future. The specific research projects contributing to answering Question 2 are outlined below.

New Activities Addressing Question 2:

1. ***Effects of Development Spatial Patterns on Water and Nutrient Cycling.***

This work makes use of a spatially explicit simulation model (RHESSys - Regional HydroEcological Simulation System) to investigate the role of spatial pattern of development (e.g. spatial pattern of impervious surfaces, drainage systems) on water and nutrient cycling and export. Given a specific amount of land cover, how does spatial pattern either promote export or retention of storm water and the materials it carries? Can we optimize urban planning to reduce impact of neighborhood development on stream ecosystems? This approach may complement the commonly used Best Management Practices for stormwater management (BMPs).

2. ***Metal Concentrations in Gwynns Falls Riparian Sediments***.

Metal concentrations in 26 archived cores collected in 1999 from Gwynns Falls riparian areas spanning stream orders and the rural-urban gradient were measured. Cores were divided into horizons and a sub sample of each horizon was digested in the laboratory. A suite of metal concentrations in these digestions were measured using ICP-MS technology. Analysis of these samples is ongoing and is being prepared for a manuscript.

3. *Timing and Magnitude of Nitrogen Flux from Urban-rural Gradient Catchments.*

Increasing watershed development has been shown to severely alter the local hydrologic cycle, most notably by causing increasing flashiness in stream discharge. Increasing development also has a significant impact on nutrient availability, as inputs from lawn fertilizers, septic and sanitary systems are added to the watershed. These inputs can have a direct impact on water quality, resulting in higher concentrations of nutrients such as nitrogen and phosphorus. Given the negative effect of elevated nutrient loading on aquatic ecosystems, a better understanding of urbanization-induced alterations in nutrient export patterns is needed if the effects are to be successfully mitigated. We explore the impact of urbanization on nitrogen export in a set of small watersheds that are part of the Baltimore Ecosystem Study.

4. *Response of Watershed Nitrogen Exports to Sanitary Sewer Improvements.*

In April 2002, the city of Baltimore reached a consent decree agreement with the Department of Justice, the Environmental Protection Agency and the state of Maryland to upgrade its sanitary sewer infrastructure to bring the city into compliance with the Clean Water Act. The improvements will cost approximately $940 million over fourteen years to end chronic discharges of raw sewage into local waterways.

The consent decree represents a nearly $1 billion experimental manipulation of the BES main study watersheds, and is a centerpiece of our LTER II research. Our six years of weekly stream sampling provide a strong pre-treatment data set for this "natural" experiment. Our long-term sampling network includes four main channel sites along the Gwynns Falls as well as several smaller (5-1000 ha) watersheds within or near the Gwynns Falls. The longitudinal, main channel sites provide data on water and nutrient fluxes in the different land use zones of the watershed (suburban, rapidly suburbanizing, old residential, urban core), while the smaller, more homogeneous, watersheds provide data on specific land use types (forest, agriculture, suburban, urban core). The consent decree specifies which streams will be most affected by infrastructure improvements allowing us to make predictions about which of our long-term monitoring sites will be "treated" and which will serve as "reference" sites. While the Dead Run and Carroll Park sites will be significantly affected by infrastructure improvements, our other long-term sites will function as forested (Pond Branch), agricultural (McDonogh), unsewered residential (Baisman Run) and sewered residential (Glyndon, Gwynnbrook, Villa Nova) reference sites. Two small, heavily contaminated tributaries to the lower Gwynns Falls (just above Carroll Park), Maidens Choice and Gwynns Run, that will be strongly affected by consent decree activities, were added to our weekly sampling program in 2005 (Figure 2).

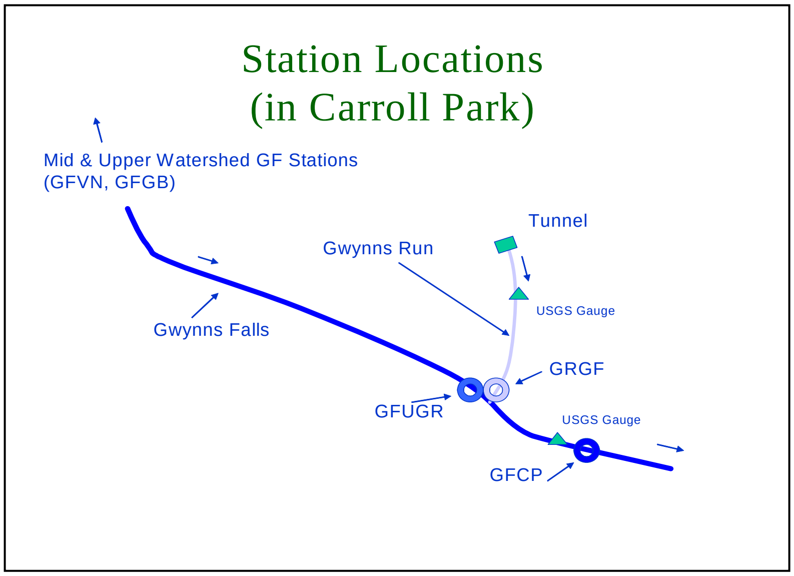

Figure 2. Map showing the location of the heavily contaminated Gwynns Run tributary relative to the long-term Carroll Park (GFCP) sampling site. Samples are taken just above and just below Gwynns Run to allow us to evaluate the contribution of Gwynns Run to the total nutrient load at Carroll Park and how this contribution will respond to infrastructure improvements associated with the consent decree.

BES stream gauging stations are maintained by the US Geological Survey. USGS operates six stream gauging stations using full or partial support from BES that provide part of the base infrastructure for physical investigations by BES. In addition, USGS operates five additional stations in the Gwynns Falls watershed and 32 other stations in the Baltimore region using USGS and cooperator funding.

USGS, in cooperation with US EPA, has continued to investigate the relationship of stream restoration and riparian zones and their impact on water quality, with an emphasis on nutrients. Work was conducted in Minebank Run, which is just east of Gwynns Falls and close to the US Forest Service air monitoring tower. One additional stream-gauging station was established. USGS has collaborated on the Baltimore Flash Flooding project with other BES investigators and the National Weather Service.

USGS is also collaborating with the US Environmental Protection Agency and Montgomery County, Maryland to investigate impacts of urbanization on stream ecology in the Clarksburg Special Protection Area. A unique element of this work includes partial operation of stream gauging stations by County staff using USGS protocols, and the refinement of standard operating procedures to ensure data quality to meet USGS standards.

Weekly water chemistry samples are collected (subsamples filtered) and stored in 150 mL Nalgene bottles. Blanks and spikes are processed along with samples in our laboratory at the University of Maryland Baltimore County (UMBC) each week and are shipped to IES for chemical analysis. A Dionex LC20 series ion chromatograph is used to quantify nitrate, sulfate and chloride, and a Lachat Quikchem 8000 flow injection analyzer (FIA) is used for phosphate. Total nitrogen and phosphorus are analyzed by persulfate digestion followed by analysis of nitrate and phosphate. Nitrate in these digests is analyzed on a Lachat Quikchem 8000 flow FIA. The weekly BES samples are analyzed for *E. coli* using standard techniques as well as by DNA molecular (standard PCR and RAPD approaches) and immuniomagnetic electrochemiluminescence (IM-ECL) techniques for the pathogens *E. Coli* 0157, *Cryptosporidium*, and *Giardia* (Shelton et al. 2003, submitted).

5. ***Influence of Trees on Pedestrian Exposure to UVB.***

Ultraviolet radiation (UVB) is monitored in central Baltimore. The influence of tree cover on pedestrian exposure in different land use classes during summer months was determined by modeling trees and their influences on UV radiation transmission to ground level.

6. ***Land Cover Influences on Air Temperature.***

Air temperature measurements at six locations with varying land cover are compared to temperature at a central Baltimore location with high impervious cover. GIS analysis is used to derive average impervious, tree, and water cover over a range of distances in the upwind direction from each point. Regression analysis is used to develop prediction equations for temperature difference as a function of cover difference and forcing conditions such as atmospheric thermal stability.

7. ***Bacteria in Baltimore Streams.***

US Forest Service, USDA-Agricultural Research Service, and Morgan State University personnel collaborated on a project from June 2004 to June 2005 to identify bacteria culturable from streams measured in the LTER BES program, including the stations at Gwynns Run, Pond Branch, and McDonogh.

8. ***Surface-Atmosphere Transport at the Cub Hill Eddy Flux Tower.***

The eddy flux tower, drawing on a suburban footprint, has provided a continuous, quality controlled data stream for four years. These data were subjected to a Local Scale Urban Meteorological Parameterization Scheme (Grimmond and Oke 2002) to evaluate the patterns emerging from the data.

9. ***Carbon Storage in Residential Lands.***

Across the United States, and with few exceptions, residential landscapes are maintained as predictable sets of tree, turfgrass, shrub, and garden combinations. This land base is large and growing, and it contains substantial amounts of natural vegetation. Diurnal, seasonal, and annual patterns of net ecosystem exchange (NEE) in residential areas are driven strongly by vegetation carbon (C) uptake, and substantial C sequestration undoubtedly occurs in these human-dominated systems. Still, very little is known about the magnitudes and drivers of C cycling in residential landscapes.

We are quantifying the magnitudes of C stocks and fluxes in the vegetated component of residential landscapes in Baltimore, MD. By choosing a cross-section of sites in the region with particular characteristics, we will also identify the relative importance of urban ecosystem structure, soil functional properties, historical land use, and land management practices as drivers of these C stocks and fluxes.

There are four phases in the project: 1) land classification (applying and groundtruthing the HERCULES classification system for the Baisman Run neighborhood); 2) site selection (gathering appropriate datasets, identifying suitable parcels for sampling, contacting landowners and soliciting citizen participation in the project); 3) field sampling (including initial plot characterization and sampling to assess C stocks as well as ongoing C flux monitoring); and 4) data analysis and writeup. We have made progress on phases 1-3 in the past year, as described below:

In order to test the field methods for this project, in the summer of 2005 a set of plots was established at a chronosequence of sites in South Burlington, VT. Measurements made in South Burlington were identical to those planned for Baltimore, and the chronosequence approach made it possible to test hypotheses about the variation of turfgrass and soil C stocks and fluxes over time since residential development.

10. *Organic Forms and of Nutrients in Relation to Land Use and Air Pollution.*

Nitrogen and phosphorus are key limiting elements. Organic forms of N and P can comprise a substantial proportion of the total N and P in surface waters. Yet, the cycling of organic N and P has been poorly incorporated into existing paradigms due to the common assumption that they are not biologically available. We are measuring these organic forms in our weekly stream water samples.

11. *Restoration of Denitrification in Coastal Watersheds.*

Urbanization leads to predictable changes in the hydrologic and geomorphic properties of stream channels. One common alteration is the routing of water to deeper flow paths caused by channel incision and lowering of the water table. This results in transport of nitrate-rich groundwater from polluted sources that can circumvent active zones of denitrification. Our work investigates the effects of large-scale hydrologic manipulation on restoration of denitrification rates in a coastal watershed by direct measurement of N_2, N_2O, and NO gases in the field using ^{15}N tracer techniques.

12. *Increased Salinization of Fresh Waters Due to Suburban and Urban Growth.*

The BES long-term stream records were examined for changes in salinity. This record was combined with the still longer run of records maintained by the Baltimore City Department of Public Works. Comparisons with ecosystems elsewhere in the Northeastern US have been made as well.

13. ***Tracing N Sources and Transformations along Flow Paths.***
Quantification of the transport of anthropogenic N from dispersed sources has relied primarily on mass-balance estimates. This approach, however, does not allow sources to be discriminated along flow paths. We have modified and tested a technique that uses ^{15}N isotope signatures in algae and aquatic food webs to identify and quantify N from domestic wastewater to streams in the Colorado Rockies. We are transferring these methods to Baltimore.

14. ***Urban Flooding Dynamics***.
We address the following research questions:

1) How does the scale-dependent flood response of urban drainage basins depend on the space-time structure of rainfall for warm season systems of thunderstorms?

2) How does flood response vary with land-surface properties including impervious cover and structure of the urban drainage network?

3) What is the relative role of changing channel/floodplain morphology due to urbanization, as compared with geologic controls of channel floodplain morphology, in determining the transmission and attenuation of flood waves in an urbanizing drainage basin?

The observations used in this study were 1) high-resolution (1 km, 5 minute) radar rainfall estimates; 2) field-collected storm-total rainfall data; 3) high-resolution topographic data derived from airborne LiDAR, supplemented by field surveys of channel topography using a total station; 4) water-level records collected at five stations in the Dead Run watershed; 5) stream flow records provided by the US Geological Survey for stations in the Dead Run, Moores Run, Gwynns Falls and Whitemarsh Run watersheds; 6) field surveys of high-water marks and flood inundation zones in our watersheds conducted in the aftermath of floods; 7) field surveys describing interior geometry of bridges and culverts acting as hydraulic obstructions along streams; and 8) GIS representations of urban infrastructure, including storm drains, road embankments, bridges and culverts.

Rainfall data and hydrologic records from USGS gages were used in analyzing storm event runoff ratios and centroid lag times for a range of storm events with varying spatial patterns of rainfall. Spatial heterogeneity and seasonal variations of the storm event water balance were examined for the Dead Run watershed. During the project, record floods occurred in Moores Run and Dead Run and there were numerous smaller flood events induced by summer thunderstorms.

Hydrologic modeling for the Dead Run watershed has been conducted using the EPA Storm Water Management Model with detailed information on stormwater detention basins and storm sewers. Hydraulic modeling reconstructed flood magnitudes, patterns of inundation and flood-wave propagation along channel systems modified by urban infrastructure. At one site in the Dead Run watershed we were also able to use historical maps and construction plans to generate a finite-element representation of the 1953 landscape; hydraulic modeling simulations were used to assess how changes related to urban development might have altered patterns of flood inundation. The primary hydraulic modeling system used was TELEMAC-2D but additional comparative analyses were carried out using the HEC-RAS 1-d model.

15. ***Interpretation of Urban Soil Survey and Heavy Metal Exposure.*** The detailed soil survey data, which extends to the scale of within-parcel heterogeneity, has been analyzed in detail for heavy metal content and capacity to sequester carbon. Interpretation of detailed soil survey is important for devising management strategies for contaminated brownfields and residential properties.

The new projects and new developments in ongoing projects relevant to Question 2 are advancing our ability to understand the fluxes within urban systems. The linkages between ecological and social fluxes, and the determination of urban ecosystem function by the interaction between built and engineered, and biological components are revealed by research focusing on this question. How this ecological knowledge is shared with the public and with students at various levels is the subject of the next section.

Ongoing Major Activities Addressing Question 3: How can people develop and use an understanding of the metropolis as an ecological system to improve the quality of their environment, and to reduce pollution loadings to downstream air- and watersheds?

To answer Question 3, we conduct the following major education, interaction, and research activities:

- Develop or participate in educational partnerships.
- Analyze the ecological knowledge base and its use in different social contexts.
- Interact with governmental agencies at various levels to exchange ecological knowledge and information.
- Interact with communities, community groups, and non-governmental organizations to enhance ecological understanding.
- Design social and educational assessments to determine the changing role of ecological knowledge in Baltimore.
- Manage information to enhance flow of data and knowledge within BES, and between BES and agencies, communities, and individuals.
- Participate in assessment of storm drain Watershed 263 restoration activities and evaluation.
- Provide internships for secondary, college, and graduate students, and fellowships for teacher involvement in ecological research.
- Focus studies in Minebank Run stream restoration project.

In addressing Question 3, partnerships are crucial. Because this question deals with the flow of information and its use, our activities recognize the diversity of sources and users of ecological and other relevant information, and the need to maintain two way flows of information and joint understanding of ecological issues. Of the three areas of activity in BES, this one is the most fluid and developmental, since it depends on evolving and expanding relationships in the Baltimore region as well as evolving and expanding ecological understanding. Specific new and developing activities we are currently undertaking in pursuit of Question 3 are listed below:

New Activities Addressing Question 3:

During this reporting period the Baltimore Ecosystem Study has spearheaded and supported many educational endeavors, as well as professional training, and sharing information with communities and government agencies.

1. *KidsGrow After School Program.*

We have continued to develop and provide curriculum and teacher professional development activities to the Parks and People Foundation KidsGrow After-School Program, which is attended by elementary and middle school students at two highly urban Baltimore City Public Schools. A new unit on hurricanes was introduced in the fall term in response to Hurricanes Katrina and Rita. The curriculum provided a forum for students to understand and process what was happening scientifically, ecologically and socially. Several long term phenology activities were integrated into the KidsGrow program including adopting a tree and observing "green down" and "green up," planting and following the growth of tulips, and noting human phenology throughout the school year.

Students came back from winter break ready to embark on a unit that continued until the close of the school year in early June; the Ecology of Food, Agriculture & Nutrition. This comprehensive unit began with the students planting "winter garden crops" in cups to grow indoors under plant lights. Then they tackled learning about inputs and outputs by focusing on the human body, something immediately familiar if somewhat embarrassing to the students when it came to outputs. They moved on to Food Production Ecosystems. Students began to grasp both where our food comes from and what impact food production systems have on the environment (water, air, soil, habitat). We made nutrition a focal point to both reinforce food inputs and to begin to address an important health problem; poor nutrition and obesity among urban children. This portion of the curriculum was enriched by field trips to the Maryland Science Center human body exhibit, Cromwell Valley Organic Farm, and Hollins Market and by in-class presentations by two nutritionists. Food logs were kept and combined in a culminating Food Mural entitled "How Much Does One Kid Eat in a Year?" The students at both sites also planted, maintained and harvested schoolyard vegetable gardens and visited each other's gardens where they conducted the Cornell University Garden Mosaics Community Garden Interview. Both sites participated in a culminating Salad Extravaganza where they made salad featuring their garden produce and healthy salad dressing with local chefs.

2. ***Responsive Teaching Study.***

We have continued to support classroom teachers involved in this intensive, long-term study of how high school environmental science teachers modify curriculum in response to student thinking. We are integrating our work on the Environmental Science Literacy project to provide the teachers with frameworks of "big ideas" in ecology to help focus their attention when listening for and responding to student thinking. Eight Baltimore City and County teachers constitute the environmental science team which, along with teams of biology and physics teachers, is planning research and teaching activities for the coming school year. The BES team is led by Co-PI Janet Coffey with contributions by Co-PI Alan Berkowitz. The BES Education Coordinator has facilitated teacher attendance at bi-weekly meetings, arranged professional development sessions on BES units at these sessions and provided supplies and direct support to teachers while they are teaching the units to their students.

3. ***Adopt a School and Curriculum Development.***

In April 2006, Co-PI Quin Holifield was asked to take the lead in the implementation of the USDA Forest Service Northern Research Station's "Adopt a School Program." The Program, science education for Grades 4-5 at Franklin Square Elementary School in Baltimore, was initiated by the Director of the Northeastern Station of the Forest Service, Michael Rains, in response to the US Department of Education mandate of "No Child Left Behind." Working together, Education Coordinator Janie Gordon, Baltimore Schools Elementary School Science Curriculum Officer Joyce Wheeler, and Dr. Holifield participated in all aspects of the curriculum development. Dr. Holifield ensured scientific accuracy of knowledge presented, assisted with writing curriculum text, and worked with teachers. Upon approval, the science curriculum will be adopted and implemented as a pilot program for the academic year of 2007-2008, and will be later used by science teachers from all 125 schools in the Baltimore City Public School System, that will include levels of instruction for elementary, middle, and high schools in Baltimore. The pilot program to promote and enhance both required science content and environmental literacy will be implemented at Franklin Square Elementary School beginning in August 2006. The program will include professional development with the 4th and 5th grade teachers, schoolyard investigations, and all season gardening and will be closely aligned to the Voluntary State Curriculum. Fifth graders will visit Soldiers Delight Park in Baltimore County which has serpentine soil unique to this area. The students will do comparison studies between the soil in West Baltimore and the soil at Soldiers Delight.

4. ***Urban Environmental Education Inventory.***

We actively participate in the Urban Ecology Collaborative Education Committee, which consists of representatives from six northeast cities. All six cities conducted a comprehensive survey of environmental education providers who deliver services to their city. In Baltimore, we had 33 responding groups, including all major environmental education providers with the exception of Living Classrooms

Foundation. Results include information about 118 distinct education programs, the topics they teach and the primary methods of instruction used.

5. ***Research Experience for Teachers (RET).***

We received an RET supplement award for Ms. Karen Watson, a science teacher at Doris M. Johnson High School. She worked in summer 2006 with the IES research and education community to carry out a cutting-edge investigation, working closely with a mentor scientist, Dr. Richard Pouyat. The BES Education Team Leader and Education Coordinator served as mentor educators to help Ms. Watson develop applications of her ecological research to her teaching, and other members of the BES team provided support throughout the program. The program aims to make a contribution to the BES research mission to understand the structure of the urban ecosystem, to provide training for the participating teacher, to directly benefit students in an innovative Baltimore City high school, and to lead to the development of new instructional materials for educators across the city and beyond.

The research is located at Clifton Park, a 263 acre Baltimore City Park, in which Ms. Watson's school, Doris M. Johnson, an Expeditionary Learning High School is located. The park houses three schools, green space, tennis courts, a golf course and community gardens. Of the 400 students enrolled in 2005-2006; 64% meet eligibility requirements for the free or reduced price lunch program and 99% are African-American. Fifty-nine percent (59%) of 9th graders were promoted to the 10th grade in the 2004-2005 school year, the first year the school was operational.

During summer 2006, Dr. Pouyat mentored Ms. Watson in implementation of an Entitation Survey in Clifton Park undertaken by the Baltimore City Department of Recreation and Parks. Sharon Schuler, from Recreation and Parks, worked closely in the field with Ms. Watson. Entitation, a method of land classification for urban parklands, was piloted by Dr. Pouyat and colleagues in New York City. It is designed to delineate discrete vegetation units and detailed representations of the spatial vegetation pattern. Ms. Watson worked with the team to learn the Entitation methodology and will apply the method in Clifton Park and study the survey results to identify research questions appropriate for investigation by her students during the 2006-2007 school year. For example, a biodiversity survey with a focus on tree diversity is a potential topic to pursue in conjunction with doing the Entitation study.

6. ***School-based Urban Rural Gradient Ecosystem Studies (SURGES).***

We are planning for a new program that will facilitate unique learning experiences for students in Baltimore City and County. Teachers from three schools along an urban to rural gradient will be recruited to have their classes collect data on environmental services provided by their local ecosystems. There will be ongoing exchange between the classes with each school hosting students from the other two schools; showing them around and highlighting areas where data was collected and sharing intriguing results. The exchange will end with a forum for participating teachers and students from each of the three schools.

7. ***Environmental Justice Curriculum.***

Dr. Chris Boone, working with the Education Coordinator and a teacher, developed a high school curriculum on urban land use. This curriculum addresses issues of environmental justice. The new curriculum has been completed.

8. ***Development of Graduate Courses.***

A course entitled "Urban Ecosystems" was developed by Co-PI Cadenasso at Yale University, in Fall 2005. The twenty-five graduate students enrolled were exposed to topics such as 1) unifying concepts, 2) ecosystem approach, 3) nutrient cycling - nitrogen, carbon, and phosphorus, 4) meteorology and atmospheric processes, 5) soils, 6) vegetation, 7) wildlife, 8) hydrology and habitats, 9) urban design, and 10) integrating frameworks.

Cadenasso also developed a graduate course at Yale University in the Spring 2006 entitled "Ecology and Urban Morphogenesis." Students from the School of Forestry and the Architecture schools collaborated on semester long projects. The projects investigated an event in the history of Baltimore and evaluated how the 1) biogeophysical constraints and opportunities, 2) social-cultural context, and 3) infrastructural template of the system influenced the event and how the event, in turn, influenced the urban system. The three projects undertaken by the students focused on 1) redlining of residential neighborhoods in the 1930s, 2) establishment of the Orioles and Ravens stadia, and 3) development of the B & O railroad. Students in this course were taken on a field trip to Baltimore.

9. ***Neighborhood Restoration and Greening in an Urban Storm Water Catchment.***

Working with federal, state, and local government and community-based organizations a restoration plan for a 900-acre storm drain watershed (Watershed 263) incorporating eleven neighborhoods in Southwest Baltimore was developed and implemented. This project was intended to demonstrate the impact of greening strategies on quality and quantity of storm water runoff and quality of life in the neighborhood. The Parks and People Foundation facilitated establishment of, and worked with Watershed 263 Stakeholder Council to develop indicators to monitor and evaluate outcomes of large-scale watershed restoration project. The project represents a collaboration between the BES scientists in the US Forest Service and collaborators in the Baltimore City Department of Public Works to collect baseline data for assessing impact of restoration activities. Numerous maps for analysis of environmental and social conditions were created for Watershed 263.

10. ***Provision of Data to City Government and NGOs.***
BES scientists and community development specialists worked with Baltimore City agencies to advise the Mayor's CityStat program, and the Baltimore Neighborhood Indicators Alliance (BNIA) on environmental data and indicators. Data on environment/ecology indicators for citywide assessment were contributed to the BNIA Vital Signs Report.

11. ***Youth Summer Training and Employment.***
The BRANCHES (Building Resources and Nurturing Community Health & Environmental Stewardship) youth forestry training and summer employment program was implemented through the Baltimore City Department of Recreation and Parks in three parks. The program provided economically disadvantaged youth with training and employment experience to develop useful job skills that lead to long-term opportunities in tree care related professions. Coordination between BES scientists and Department of Recreation and Parks staff developed restoration work plans and training for youth team supervisors.

12. ***Informed Congressional Staff on Urban Watershed Forestry.***
Congressional staff were informed about the needs and opportunities for improved urban forestry, to conduct applied urban environment/ecology research and restoration. The benefits of establishing an Urban Watershed Forestry Cooperative to further these goals were explored.

13. ***Analysis of Barriers and Opportunities for Community Involvement in Urban Forestry.***
Data were collected and GIS data layers were created and analyzed on a variety of environmental indicators for success in community forestry, including tree locations, size and species; location and condition of vacant lots; and location and condition of stormwater inlets. Analyzed data from MERGE (Methods for Engaging Residents and Grassroots in the Environment) informal neighborhood surveys to identify opportunities and barriers to increased citizen involvement in urban forestry; wrote and presented report of findings.

14. ***Assistance to Baltimore City for Forest Assessment in Parks.***
Working with city staff a forest assessment protocol for city park lands was developed and executed. This work involved USDA Forest Service scientists.

15. ***Established a Neighborhood Ecology Center.***
Developed and secured funding for Neighborhood Ecology Center at Harlem Park Elementary School to provide students and teachers with increased access to educational resources and scientific information on environmental issues that affect urban communities such as Harlem Park through offering hands-on experiments performed at learning stations and teacher training workshops. Programs and

concepts learned in the Ecology Center will be reinforced through field trips to local environmental venues and student directed outreach environmental projects including storm drain stenciling and installation and care of schoolyard habitats.

16. ***Development of Teacher Materials on Urban Birds.***
Because birds are one of the most conspicuous biotic components of the urban ecosystem, Co-PI's Nilon and Warren collaborated with the education program on the development of teacher materials on these visible and engaging organisms.

The activities for Question 3, outlined above, advance the ability of urban decision makers and communities to understand and use ecological information. Both practical communication of new or needed information, and research on understanding the impact of that information transfer are important. The next section summarizes activities that are specifically aimed at outreach, or perhaps more appropriately engagement, with the various communities and constituencies with which BES members must interact.

Outreach

Outreach is fundamental to the mission and success of the Baltimore Ecosystem Study. As a research question, we are concerned to know how people develop and use knowledge of the metropolitan area as an ecological system. In addition, we have learned from the literature and from a ten year social science and community restoration research program in Baltimore predating the LTER effort, that informing and working with communities and constituencies is required to conduct ecological research in the city and suburbs. Hence, we conduct a wide variety of community and educational activities.

1. ***BES Annual Meeting and Community Open House***.

Formal public outreach was accomplished through the BES Annual Meeting, attended by scientists, educators, community members, and decision leaders from the Baltimore region as well as by BES researchers and educators. The Annual Meeting was attended by approximately 110 people in 2005 and approximately 150 people attended the Open House. The evening Open House is held annually, during the Annual Meeting, in conjunction with the Parks and People's Annual Greening Celebration. Over time, the number of attendees at these functions has grown. At the 2005 Open House, it was announced that Mayor Martin O'Mally had declared the day "Baltimore Greening Day" in recognition of the community improvements facilitated by the Parks and People Foundation, and related to BES research. We held three additional Science Meetings at roughly three month intervals focused on research planning and results but open to potential collaborators and clients for the information. The interaction with the Baltimore public health community and agencies in the June Science Meeting opened a new frontier for BES outreach.

2. ***Revitalizing Baltimore Technical Committee***.

This committee, which meets once a month under the auspices of the Parks and People Foundation’s Revitalizing Baltimore project, is an important venue for engagement with the management, policy, and civic institutions of Baltimore. In the past, this has been a source of insights that have led to new BES research initiatives (e.g., the Watershed 263 Neighborhood Greening and Storm Water Quality Project), or prompting important applications of BES research results. The Urban Tree Canopy goal projects (see # 11) were stimulated by interactions at the Revitalizing Baltimore Technical Committee.

3. ***Relevance of HERCULES to Urban Design.***

The importance of integrating built and non-built components of the landscape in a theoretically well justified land cover classification has been discussed and presented to urban designers, city planners, and landscape architects in academia and the private sector. This new model has generated great interest in the design professions.

4. ***Community Engagement and the Watershed 263 Greening Project.***
A community organizing plan was developed and carried out for a storm drain watershed restoration project in Southwest Baltimore, working with community-based organizations in eleven neighborhoods to engage community residents. A community forum and other meetings were held to discuss opportunities for community restoration projects to improve water quality and ecosystem function in Watershed 263 and recruit members for the new Watershed 263 Stakeholder Council.

5. ***Reveal Baltimore Initiative.***
Discussions with business leaders, city agencies and community-based organizations were held to promote and shape the Reveal Baltimore Initiative to address sanitation and environmental pollution issues and improve the natural environment in underserved Baltimore neighborhoods. New youth programs are an intended outcome of this initiative.

6. ***Linking Science and Decision Making.***
Content for the "Linking Science and Decisionmaking" section of BES website was developed, following discussions with decision leaders in Baltimore, highlighting role of the Urban Resources Initiative and Revitalizing Baltimore in coordinating research on and restoration of Baltimore's urban ecosystem.

7. ***Situating and Promoting BES Research in Neighborhoods and Communities.***
BES scientists and staff were aided by the URI Coordinator at the Parks and People Foundation in developing relationships with local public agencies, non-profits, community groups and residents. These relationships are key to the success of urban ecological research. The coordination of contacts for a large and diverse set of researchers is important for effective placement of projects.

8. ***Baltimore Sanitary Sewer Oversight Coalition.***
To help address polluted urban streams, and to ensure the availability of scientific information, BES members participated in the meetings of this Coalition.

9. ***Report on Vital Signs for Baltimore's Neighborhoods.***
BES contributed to Baltimore Neighborhood Indicators Alliance report on Vital Signs for Baltimore's Neighborhoods. This summarizes environmental and other data in an attempt to inform neighborhood leaders, citizens, and agencies about the needs and opportunities for neighborhood improvement and sustainability. The report is available on line at http://www.bnia.org.

10. ***The Urban Ecology Collaborative.***
The Urban Ecology Collaborative brings together researchers, policy makers, community leaders, educators, and restorationists from Boston, New Haven, New York, Baltimore, Pittsburgh, and Washington, DC. Meetings and a website promote transfer of information. Joint funding of proposals is being developed and joint projects implemented in these cities. This year, the Watershed 263 restoration model was transferred to partner organizations in Washington, DC and Boston. BES member Mary Cox is Chair of the Restoration Tools working group of the UEC.

11. ***Urban Tree Canopy Goals.***
Information from BES research alerted policy makers in Baltimore and the Chesapeake Bay region of the paucity of tree canopy, the high rate of urban tree mortality, and the rarity of regeneration of urban trees. As a result, several policy makers asked for assistance in documenting the needs and opportunities for expanding urban tree canopy in their jurisdictions. The city of Baltimore sought assistance from BES scientists in the development of Urban Tree Canopy (UTC) goals. Chesapeake Bay-wide initiatives are also being addressed. Based upon data, data analyses, tools, and reports provided, Baltimore Mayor Martin O'Malley set a goal of doubling the City's canopy cover from 19 to 38% over the next 30 years. Tools, data, and report templates have also been adopted by Annapolis, MD, and New York City, NY.

12. ***Meteorological Information for KidsGrow.***
Information on meteorology and meteorological instruments was provided for teacher and intern use in the KidsGrow program, an education program in the Baltimore City schools.

13. ***Integrating Streams into Classrooms.***
Presentations were given to teachers at the Maryland Science Center and NOAA Research Experience for Teachers program on ideas for integrating urban stream ecology into classrooms. In addition, public presentations were also given at the University of Maryland Center for Environmental Sciences, Appalachian Laboratory open house, and to various student groups throughout the semester.

14. ***Green Horizons in New York City.***
"Green Horizons Environmental Science Career Day" October 2005. The Tenth Anniversary of Green Horizons, a New York City middle school student environmental careers conference, convened on October 19, 2005 at the Brooklyn Botanic Garden, in Brooklyn, New York. Dr. Quintaniay Holifield, Soil Scientist led a career station in her area of expertise.

15. ***Future Pathways to Conservation.***
On June 17, 2006, Future Pathways to Conservation, an Urban Connection Program of the USDA Forest Service in Boston, Massachusetts, hosted its second annual event at the Franklin Park Zoo. The program introduced high school students to career opportunities in the field of environmental and natural resources. Dr. Quintaniay Holifield led a soils station, highlighting soil testing and its importance in the growth and development of healthy trees in an urban environment. Over 135 students participated in this event.

16. ***Watershed 236 Environmental Justice Panel.***
On August 16, 2006, The Watershed 263 Project conducted "The Environmental Justice Summer Program Career Panel" for 23 participating high school students from the neighborhoods within the community. The program was sponsored in part by the Parks and People Foundation. As a soil scientist with the USDA Forest Service, Dr. Quintaniay Holifield was invited to participate as a career panelist, along with Mr. Connie Brooks, Director of Baltimore City Parks and Recreation, Mr. Phil Lee, Environmental Engineer with the firm of Moffat and Nicholas in Baltimore; Ms. Kidada Fields, Community Liaison, Parks and People Foundation, and Mr. Jaleel Nash, Community Greening Program Director, Parks and People Foundation. The purpose of this program was for each panelist to share information with the students about the various environmentally related jobs and career paths that are available to them. During the discussions, the most important information that each panelist talked about was how they progressed "step by step" from elementary school to finishing high school and earning college degrees, doctoral degrees and establishing respected positions within the scientific community. In short, the students developed a new appreciation for commitment and dedication that each panelist shared about protecting the environment and serving the needs of the community.

17. ***Radio Interviews on Community Gardening and Ecology***.
Outreach activities during the October 2005-October 2006 period included two radio interviews with WFUV (Fordham University NPR affiliate), one talk to Cornell Cooperative Extension Service master gardener program and multiple ad hoc meetings and interactions with gardeners and other local residents at the garden study sites.

18. ***Field Trips and Presentations for Underrepresented Groups.***
Presentations were made on several occasions at field sites in connection with field trips for educators and for minority undergraduate students through the SEEDS (Strategies for Ecology Education, Development and Sustainability) program. This program, run by the Ecological Society of America, aims to increase the participation of persons of color in ecology and environmental careers.

On June 9, 2006, Co-PI, Quintaniay Holifield hosted "The Rosebuds of Baltimore" and their Director, Ms. Vanesa Johnson, on the campus of the University of

Maryland, Baltimore County. The Rosebuds of Baltimore is an educational enrichment program with emphasis on the urban ecosystem and is sponsored in part by the Parks and People Foundation. The focus of this program is to introduce young girls and young women from the ages of four to eighteen about the possibility of a career in science and natural resources. Twenty girls and young women participated in an outdoor laboratory exercise where soil testing and other hands-on activities were conducted, emphasizing the importance of a healthy soil for an urban community.

In February 2006, three African-American BES scientists were invited to visit the KidsGrow program and make presentations, lead field trips, or involve the students in hands-on activities. These visits were a part of the Black History Month activities in KidsGrow.

19. *Incidental Outreach during Research.*

Field investigations in some of our urban and suburban watersheds have often led to informal conversations with community residents. For example, discussions about urban flood hazards, water quality and other aspects of urban streams, often come up with stream researchers.

20. *Information on Flood Hazards.*

In the aftermath of a flood that led to drowning of three workers in Dead Run in November 2003, Dr. Andrew Miller was contacted by the Maryland Emergency Management Agency to provide information about the conditions associated with flood hazards. Personnel from public agencies in Baltimore City and Baltimore County who have responsibility for management of stormwater and handling of complaints related to flood activity have also taken advantage of the expertise of BES researchers. We have exchanged information both about the technical content of our findings and also about what we have learned in talking with community residents with respect to their understanding of flood hazards. We have been invited to make a presentation to staff at the Baltimore County Department of Public Works. We have been in frequent contact with personnel at the US Geological Survey, particularly with regard to the question of how to improve collection of data at urban stream gages in order to create more reliable stage-discharge relationships. We have had some supplementary support from the Maryland Department of Environment, with sponsorship from the Federal Emergency Management Agency, and at the invitation of our sponsors have taken part in several public conferences and in specialized workshops for employees of public agencies and private-sector consulting firms on the use of LiDAR and hydraulic models for assessment of flood hazards.

21. *Forest Management Plan for Oregon Ridge County Park.*

Working with Don Outen and Pat Cornman of the Baltimore County Department of Environmental Protection and Resource Management, appropriate survey techniques, sampling intensities, and forest inventory design were selected by Dr.

Mark Twery to manage the forest in this large Baltimore County park. The information was used to develop an RFP for a contract to prepare a forest management plan for Oregon Ridge. In addition, consultation with the successful contractor will ensure that the scope of the work and the design of the inventory are understood. On-site training in the use of NED software to accomplish inventory summary and data analysis for the plan was conducted. This work involved two site visits to Oregon Ridge.

22. ***Participation in LTER Network Activities.***

Co-PI Morgan Grove is a member of the LTER Executive Committee and the chair of the LTER Social Science Committee. He has participated on the National Environmental Observatory Network (NEON) advisory board and helped organize a social science workshop for NEON with David Foster and Billie Turner. He is also a member of the NEON Integrated Science and Education Plan (ISEP) group that is responsible for re-writing the current ISEP report. Co-PI Matthew Wilson participated as the social science representative on the organizing committee for the LTER All Scientists Meeting, September 2006 in Estes Park Colorado. In addition, Groffman and Grove are assisting with preparation of the LTER Trends Book, and Cadenasso is the BES Site Representative for the LTER Network Planning Grant process. BES Information Manager, Jonathan Walsh has been a member of the Information Manager's Executive Committee since 2004. He was also part of the development team for EML (Ecological Metadata Language.).

Presentations, Posters and Websites Considered Outreach Activities

Presentations

Bain, D.J. 2006. Trace metal cycling in watersheds and landscapes. University of Pittsburgh Department of Geologic and Planetary Sciences, Pittsburgh, PA. February 28.

Bain, D.J. 2006. Trace metal cycling in watersheds and landscapes. Wright State University Department of Geological Sciences, Dayton, OH. March 13.

Bain, D.J. 2006. Human decisions and trace metal cycling: coupling social and natural science in urban systems. Yale School of Forestry, New Haven, CT. March 29.

Bain, D.J. 2006. Impacts of urbanization and land use history on chemical and sediment cycling. University of Illinois at Urbana-Champaign Department of Natural Resources and Environmental Sciences. Urbana, IL. April 13.

Bain, D.J. 2006. Urban ecology: understanding and managing our cities. North Carolina State Department of Forestry and Environmental Resources. Raleigh, NC. May 1.

Band, L.E. 2005. The Baltimore Ecosystem Study: lessons for hydrologic observatories. Invited lecture, Oregon State University. May.

Band, L.E. 2005. Integrated water, carbon and nutrient cycling in the 'burbs'. Invited Lecture: University of Buffalo. October.

Band, L.E. 2006. A tale of three catchments: coupling water and nitrogen cycling in the Baltimore Ecosystem Study. Invited Lecture: University of South Carolina. January.

Belt, K.T., R.V. Pouyat, C.M. Swan, S.S. Kaushal, A.J. Miller and P.M. Groffman. 2006. Transport & processing of organic matter in small urban streams: the effects of altered hydrology and landscape position. BES Quarterly Science Meeting, UMBC, Baltimore, MD. January 18.

Belt, K.T. 2006. Urban streams: altered states. Invited lecture: in *Geomorphologic and Ecologic Foundations of Stream Restoration*, a Department of Geography & Environmental Engineering course at Johns Hopkins University taught by Dr. Peter R. Wilcock. March 13.

Belt, K.T. 2006. Urban runoff and altered hydrology: pathogens, temperature, and organic matter. Invited lecture: presented in GEOG 302B, *Selected Topics in Geography: Water in the Urban Environment*, a 3 credit Summer 2006 Department of Geography and Environmental Systems course taught by Dr. Andrew Miller, that features urban ecological research being conducted as part of the Baltimore Ecosystem Study. June 22.

Belt, K.T., R.V. Pouyat, W.P. Stack, G.M. Heisler, P.M. Groffman, U. Ghosh, A. Taylorson, D. Schindler and J. Zhou. 2005. Watershed 263 small headwater storm drain catchment hydrology: update on water quality results. Abstracts published on the BES website. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 19-20.

Belt, K.T., C.M. Swan, R.V. Pouyat. 2005. Breakdown of sycamore leaf litter in small urban and forested streams: the effects of altered hydrology and landscape position. Abstracts published on the BES website. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 19-20.

Berkowitz, A.R. 2006. What should/could be the role of the Hubbard Brook community in environmental/science education? – an outsider's view. Committee of Scientists Meeting, Hubbard Brook Ecosystem Study. Institute of Ecosystem Studies, Millbrook, NY. January 5.

Berkowitz, A.R. 2006. How is ecology being taught in Baltimore Schools? A preliminary report from the ecology teaching study. Cornell Graduate Student workshop at the Institute of Ecosystem Studies, Millbrook, NY. May 1.

Berkowitz, A.R. 2006. Human settlements as ecosystems. Half-day field course. River Summer Faculty Development Program. Poughkeepsie, NY. July 17.

Berkowitz, A.R. and C. Brewer. 2005. Ecology teaching in K-12 schools: status and vision. Emerging Issues Forum of the ESA Education and Human Resources Vice President. Evening Discussion Session. Ecological Society of America Annual Meeting. Montreal, Canada. August 9.

Berkowitz, A.R. 2005. Investigating urban ecosystems: exploring watersheds in Baltimore. Introduction to the BES unit. Responsive Teaching Study. Baltimore, MD. September 13.

Berkowitz, A.R., J. Coffey, J. Gordon, C. Rinke, S. Marusdas and R. Bell. 2005. How is ecology being taught in Baltimore Schools? A preliminary report from the Ecology Teaching Study. Abstracts published on the BES website. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 19-20.

Berkowitz, A.R., J. Gordon, T. Newcomer, E. Ellis and D. Dillon. 2005. Cities are ecosystems! exploring the Gwynns Falls watershed and Baltimore Ecosystem Study (BES) research sites. *Full-day Field Course*. Strategies for Ecology Education, Development and Sustainability (SEEDS)/United Negro College Fund faculty development program. Baltimore, MD. November 18.

Berkowitz, A.R., C. Rinke, S. Marudas, R. Bell, J. Coffey and J. Gordon. 2005. How is ecology being taught in Baltimore Schools? a preliminary report from the ecology teaching study. Invited Talk. Annual Environmental Education Briefing. Maryland State Department of Education. Patuxent, MD. November 28.

Boone, C.G. and J.M. Grove. 2006. Environmental justice and well-being in Baltimore: measuring accessibility to parks and open space. Baltimore Ecosystem Study Quarterly Research Meeting, Baltimore, MD. April 18.

Buckley, G.L. 2006. Frederick Law Olmsted, Jr. and the Leakin Park controversy. International Conference of Historical Geographers, Hamburg, Germany. August.

Buckley, G.L. 2006. Professional forestry in Baltimore: historical roots and enduring legacies. Annual Meeting of the Maryland Recreation and Parks Association, Ocean City, MD. April.

Buckley, G.L. 2006. Professional forestry in Baltimore: a historical perspective. Annual Meeting of the Association of American Geographers, Chicago, IL. March.

Buckley, G.L. 2005. Exploring the Peabody Heights Improvement Association file, 1909-1933. Abstracts published on the BES website. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 19-20.

Cadenasso, M.L. 2005. Heterogeneous landscapes and ecological flows: building understanding across forest, savanna, and urban systems. University of Massachusetts, Amherst, Amherst, MA. October 3.

Cadenasso, M.L. 2005. Reconceptualizing urban land cover. New York University, New York, NY. November 3.

Cadenasso, M.L. 2006. Reconceptualizing urban land cover. EDAW, Inc., New York, NY. February 23.

Cadenasso, M.L. and S.T.A. Pickett. 2005. Reconceptualizing land cover in urban areas to improve understanding of landscape structure and ecosystem function. Abstracts published on the BES website. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 19-20.

Carlson, C., M.L. Cadenasso and G. Barrett. 2005. The relationship between breeding bird diversity in urban forest patches and human-mediated resources located in the surrounding neighborhood mix. Abstracts published on the BES website. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 19-20.

Costanza, R. 2006. Ecological economics: designing a sustainable and desirable future. Invited Seminar: Institute of Water and Environment, Cranfield University, Silsoe, UK. January 4.

Costanza, R. 2006. Ecological economics: designing a sustainable and desirable future. Invited Seminar: Cogito (think tank connected with the Swedish Parliament), Stockholm, Sweden. January 9.

Costanza, R. 2006. Ecological economics: designing a sustainable and desirable future. Invited Seminar: KTH/Swedish Royal Institute of Technology, Stockholm, Sweden. January 9.

Costanza, R. 2006. Ecological economics: designing a sustainable and desirable future. Invited Seminar: Lund University Centre for Sustainability Studies (LUCSUS), Lund, Sweden. January 10.

Costanza, R. 2005. Ecological economics: reintegrating the study of humans and the rest of nature to create a sustainable and desirable future. Invited plenary speaker: 26th Annual Darwin Festival. Salem State College. Salem, MA. February 15.

Costanza, R. 2005. Modeling integrated human and natural systems dynamics. Invited speaker in symposium - New Developments in Human and Social Dynamics: Social Science for Public Policy. AAAS Annual Meeting, Washington, DC. February 19.

Costanza, R. 2005. The local politics of global sustainability. Invited Speaker: 2005 Urban Sustainability Forum, Seattle Department of Planning and Development, Seattle, WA. April 4.

Costanza, R. 2005. Ecological economics and EPA. Invited speaker: USEPA Region 2. New York, NY. April 14.

Costanza, R. 2005. Ecological Economics: Reintegrating the study of humans and the rest of nature. Invited speaker: New York Academy of Sciences. New York, NY. April 14.

Costanza, R. 2005. Ecological economics. Invited plenary speaker: Ohio Agricultural Research and Development Center, Annual Conference on Adding value to the ecological paradigm. Ohio State University, Columbus, OH. April 21.

Costanza, R. 2005. Ecological Economics: Reintegrating the study of humans and the rest of nature. Invited lecture: University of Nebraska, College of Agriculture and Natural Resources, Lincoln, NE. April 25.

Costanza, R. 2005. Valuing New Jersey's natural capital and ecosystem services. Research and Technology Seminar Series, New Jersey Department of Environmental Protection, Division of Science, Trenton, NJ. June 7.

Costanza, R. 2005. Ecological economics: assessing the true costs of alternatives. 2005 Annual Meeting, SEATAC North Atlantic Chapter. Invited plenary speaker, session on Emerging Issues. Burlington, VT. June 9.

Costanza, R. 2005. The value of a restored earth and its contribution to a sustainable and desirable future. Invited inaugural plenary speaker: World Conference on Ecological Restoration. Zaragoza, Spain. September 12-18.

Costanza, R. 2005. Ecosystem Services and Natural Capital. Invited plenary speaker: Joint Sino-US symposium on Ecological Complexity and Ecosystem Services, Burlington, VT. October 21.

Costanza, R. 2005. Ecosystem Services: if they're so important, why do we continue to abuse them? Invited Plenary speaker: Henry A. Wallace/CATIE Inter-American Scientific Conference: Integrated Management of Environmental Services in Human-Dominated Tropical Landscapes. CATIE, Turrialba, Costa Rica. November 1-3.

Doebber, R. and L. Bardon. 2005. Watershed ecology education in Watershed 263. Abstracts published on the BES website. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 19-20.

Grimmond, C.S.B. 2006. Understanding urban climate: measuring and modeling surface-atmosphere exchanges. Royal Meteorological Society, London, England. February 16.

Grimmond, C.S.B., B. Crawford, J. Hom and B. Offerle. 2006. Variability of carbon fluxes in urban areas. 6th International Conference on Urban Climate [ICUC6], Göteborg, Sweden. June 12-16.

Grimmond, C.S.B. 2005. Understanding urban climate: measuring and modeling surface-atmosphere exchanges. Environmental Fluid Dynamics, Department of Mechanical and Aerospace Engineering, Arizona State University, Phoenix, AZ. October 5.

Crawford, B., C.S.B. Grimmond, J. Hom, B. Offerle, D. Golub and M. Patterson. 2005. Carbon dioxide fluxes in a suburban area of Baltimore, MD: 2002-2004. Abstracts published on the BES website. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 19-20.

Grimmond, C.S.B. 2005. Understanding urban climate: measuring and modeling surface-atmosphere exchanges. Geography and Interdepartmental Environmental Sciences Seminar, Indiana University, Bloomington, IN. November 4.

Grove, J.M., M.L. Cadenasso, W.R. Burch, S.T.A. Pickett, J.P.M. O'Neil-Dunne and A.R. Troy. 2006. Data and methods comparing social structure and vegetation structure of urban neighborhoods in Baltimore, Maryland. International Symposium for Society and Resource Management, Vancouver, CA. June.

Grove, J.M., A.R. Troy, J. O'Neill-Dunne, M.L. Cadenasso, S.T.A. Pickett and W.R. Burch, Jr. 2005. Spatial organization of households and lifestyles as environmental drivers. Abstracts published on the BES website. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 19-20.

Harvey, J., K. Szlavecz, R.V. Pouyat, I. Yesilonis, A.R. Berkowitz and J. Gordon. 2006. Schoolyard worms and soil: a user-friendly urban ecology unit. Maryland Association of Environmental and Outdoor Educators (MAEOE) Annual Meeting. Ocean City, MD. February 4.

Heisler, Gordon, Jeffrey Walton, Sue Grimmond, Richard Pouyat, Ken Belt, David Nowak, Ian Yesilonis, John Hom. 2006. Land-Cover Influences on air temperatures in and near Baltimore, MD. 2006. Presented at 6th International Conference on Urban Climate Göteborg, Sweden, June 12-16.

Hom, J., K. Clark, N. Skowronski, C.S.B. Grimmond, B. Offerle, B. Crawford, M. Patterson, and I. Yesilonis. 2006. Carbon flux associated with management and disturbance, along an urban to rural gradient from Baltimore, MD to the New Jersey Pine Barrens. LTER All Scientist Meeting, Estes Park, CO. September 20-24.

Jenkins, J.C., P.M. Groffman, M.L. Cadenasso, J.M. Grove, M. Cox, S.T.A. Pickett, R.V. Pouyat and R.D. Boylan. 2005. A pilot study of carbon and nitrogen dynamics in a chronosequence of suburban lawns. Abstracts published on the BES website. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 19-20.

Kaushal, S.S. 2006. Influence of land use on sources and transformations of nitrogen in streams. Duke University, Nicholas School for the Environment. Durham, NC. February 10.

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www.umbc.edu/cuere – Website for BES contributing organization—Center for Urban Environmental Research and Education.

http://cuereims.umbc.edu/website/bes **–** This is a clickable Arc-GIS map which includes BES data collection points.

www.lifeunderyourfeet.org **–** Website dealing with soil invertebrates investigated in BES.

http://www.as.phy.ohiou.edu/Departments/Geography/lter.html – Ohio University webpage describing faculty, students, publications and theses related to BES.

www.fsl.orst.edu/climhy/ **–** Meteorological data supplied to the ClimDB, an interest-available dataset for public access to LTER climate and hydrological data. The CLIMDB/HYDRODB, is a centralized server to provide open access to long-term meteorological and streamflow records from a collection of research sites.

http://ecovalue.uvm.edu/ **–** Based at the University of Vermont, the EcoValue project provides an interactive decision support system for assessing and reporting the economic value of ecosystem goods and services in geographic context.

http://md.water.usgs.gov/BES **–** USGS webpage describing BES and USGS related activity.

http://nwis.waterdata.usgs.gov/ – Data for six streamgaging stations supported by BES and many other stations in or near the study area are publicly available at this site.

http://www.residentialcarbon.org – The site supports community outreach for the Residential Carbon Project, educates landowners about the project, and describes the work to interested parties.

http://www.unb.ca/enviro/research_baltimore.html – Describes the analysis work on Organizational Partnerships and Natural Resource Management in the Gwynns Falls Watershed.

Findings

For each of the three overarching research questions for BES, we highlight new findings below.

Findings Addressing Question 1: Structure, Integration, and Dynamics of Ecological, Socio-economic, and Physical Factors in the Baltimore Ecosystem.

BES is founded on the hypothesis that urban ecosystem function is related to urban ecosystem structure. Therefore, findings concerning the structure of patchiness throughout the metropolitan ecosystem are crucial.

1. ***Dasymetric Mapping and Environmental Equity.***
African-Americans are most concentrated in the city of Baltimore, accounting for 64.3 % of the population. However, there are significant clusters in the wider metropolitan area as well. As expected, Toxics Release Inventory (TRI) sites are clustered in the industrial districts of southeast and south Baltimore, and generally coincide with the harbor and major transportation routes in the region. TRI sites in Baltimore City tend to be near neighborhoods where the black to white ratio is very low. Zonal statistics, comparing distance values from TRI sites with demographic characteristics at chosen distance intervals, bear out the general mapped patterns. Even though blacks are the majority in Baltimore City, whites are consistently the larger percentage of the total population at each distance interval from TRI sites. Taking the deviation from the mean for the total population of both groups also shows that whites tend to overrepresented near TRI sites and blacks tend to be underrepresented. A long history of residential and occupational segregation in Baltimore created an industrial and residential geography of whites living close to well-paid work in factories, and the present landscape reflects those differing notions of preferred locations in the past. For the Baltimore Metropolitan Region, results differ from those of Baltimore City. In each distance zone from TRI sites, the majority of the population is white, but blacks tend to be overrepresented within each zone. When Baltimore City is removed from the analysis, the distributions along the distance gradient from the TRI sites are relatively proportionate to white and black populations.

2. ***Effects of Historical Events on Plant Species Distribution.***
Tree distributions in the uplands are closely related to geologic substrates. Tulip poplar and red maple are the dominant trees on schist, gneiss and marble substrates with the highest water-holding capacity; beech and green ash on the less acidic amphibolite but with a lower water-holding capacity than gneiss and schist; red oak and black gum on the dry mafic substrates, and American elm and black locust on the Coastal Plain sand/clay/fill substrate. The distributions of some common upland species are restricted to particular geologic substrates, with beech occurring only on amphibolite and

pin cherry only on schist. Other less common species are also restricted to one substrate.

Despite a heterogeneous history of land use, which now ranges from rural suburban to densely urban, geology appears to play a fundamental role in the distribution of trees on the upland portion of the watershed.

In the riparian zone, the ten most common trees at one meter elevation contain only one species that favors a wet environment, whereas the most common species at elevations > 1 meter include most riparian species. However, at these higher elevations, most populations consist of one to a few large trees and very few small individuals. The Gwynns Falls watershed has changed from forest to agriculture to urban and suburban land over the last 250 years. The distribution of wetland and upland species reflects not only the influence of the more recent urbanization on stream incision, aggradation and flooding, but also the historical influence of agriculture on streams prior to urbanization. In general, trees occurring in areas bordering streams with steeper banks where flooding no longer occurs consist of large individuals of riparian species including sycamore, green ash, black walnut, and black willow, with very few small stems. This indicates that these areas represent former floodplains that no longer function as riparian areas. The occurrence of species that prefer dry habitats at the lower elevation suggests that modern floods which are of short duration and the possibility of a lowered water table have minimized the amount of available water required by riparian species.

Approximately 50% of the herbaceous species in both the riparian and upland parts of the watershed are exotics. Indian strawberry (exotic) and jack-in-the-pulpit (native) are the most widely distributed species in the upland areas and Japanese stilt grass (exotic) and Indian strawberry the most widely distributed in the riparian zone. Japanese stilt grass increased from nine plots in the riparian area in 1999 to 47 plots in 2004.

In the riparian area, wetland and upland herbaceous species are more or less evenly divided, whereas in the upland area, the majority of the species prefer drier habitats, except for jack-in-the-pulpit which is one of the most widely distributed species in the uplands. In both the riparian and upland areas, most herbaceous species are found in one or two plots, indicating that the majority of these species have restricted, albeit abundant, distributions.

3. ***Refining a New Urban Land Cover Classification.***

HERCULES, our new land cover classification developed to improve categorical resolution and assessment of urban heterogeneity, was better able to predict nitrate yield from the Gwynns Falls Watersheds than the Multi-Resolution Land Classification (MRLC), which is derived from the traditional Anderson classification and used by the State of Maryland. Furthermore, HERCULES permitted analysis of the vegetation component of land cover, and revealed that total bird species richness was higher in forest patches surrounded by neighborhoods with higher levels of tree cover. This relationship would not have been possible to evaluate using MRLC or Anderson derived systems. Finally, neotropical migrant bird richness was positively correlated with the tree and large woody component of the matrix vegetation cover, and negatively associated with fine textured vegetation such as turf in the surrounding matrix. This finding rejects the usual assumption that forest patch area is the primary driver of bird species richness.

4. ***Dynamic Modeling of Urban Land Use and Development.***
Insufficient data existed to operate the model at the fine scale, and a second version was built by aggregating up to the tract level. Initial attempts were made to calibrate the model to data for the Baltimore Metropolitan Statistical Area (MSA) with promising results, although convergence of the parameters was not achieved. In the process, several metrics, both aggregate and spatial, were developed to guide the calibration process. The dynamic model for the Baltimore MSA was applied to a sample "city" built on a grid with each cell representing a neighborhood. This was used to assess the behavior of the model with several interesting dynamics identified. The dynamic model and the findings from the sample "city" simulations were written up and included as a chapter in Kenneth Mulder's doctoral dissertation at the University of Vermont, "The stoichiometry of resource utilization in economic and ecological systems." A paper based on that chapter is currently in draft form.

5. ***Statistical Comparison of the BES Social Survey over Two Time Periods***.
In our analysis, we found support for the previous theoretical arguments in the literature proposed to explain higher life satisfaction in the city. Importantly, however, our findings reveal that these results are strikingly scale dependent. For individuals, higher incomes contribute to higher levels of life satisfaction, yet social capital does not. For neighborhoods, more social capital strongly increases life satisfaction, but higher incomes do not; and access to a clean natural environment always contributes to higher satisfaction, regardless of the scale of analysis. Given these findings, the research team has concluded that future research must carefully match the 'scale' of life satisfaction measurements with the explanatory variables used as we seek to better understand what determines a high quality of life in urban environments.

6. ***Testing a New Social-ecological Theory***.
We found that the PRIZM market segmentation data resolved into fifteen classes best predicted variation in possible stewardship. In contrast, PRIZM resolved to the finest level of 62 classes best predicted variation in realized stewardship. These results were further analyzed by regressing each dependent variable against a set of continuous variables reflective of each of the three PRIZM groupings. Housing age, vacancy, and crime were found to

be critical determinants of both stewardship metrics. In addition, the percentage of African Americans was positively related to realized stewardship but negatively related to yard expenditures. This research has been submitted for publication to Environmental Management.

7. ***Diversity and Abundance of Insect Pollination in Urban and Suburban Gardens***.

A total of 49 species of bees, all in the superfamily Apoidea, and representing eighteen genera, have been found in urban gardens of the Bronx and East Harlem. A total of 46 species of bees, representing eighteen genera, have been identified from suburban gardens of Westchester County. From the urban gardens, the species within a single recalcitrant genus *(Dialictus*) await identification by an expert in this group.

In urban gardens, we found that bee diversity significantly increases as a function of within-garden characteristics such as garden area (Figure 3A), mean floral area (Figure 3B), and sunlight (Figure 3C). We also found a non-significant trend towards increasing bee diversity as a function of landscape level greenspace surrounding gardens (Figure 3D). Curiously, we have found no significant relationship between floral abundance and pollinator diversity in suburban gardens. A comprehensive analysis of the relationship between landscape level greenspace in and pollinator diversity in suburban gardens is forthcoming. However, a preliminary analysis suggests that ground nesting bees are more abundant in gardens that are surrounded by a greater degree of development. That ground-nesting bees are more abundant in gardens surrounded by a high degree of development may reflect their greater concentration in these gardens, and not their greater abundance in such landscapes.

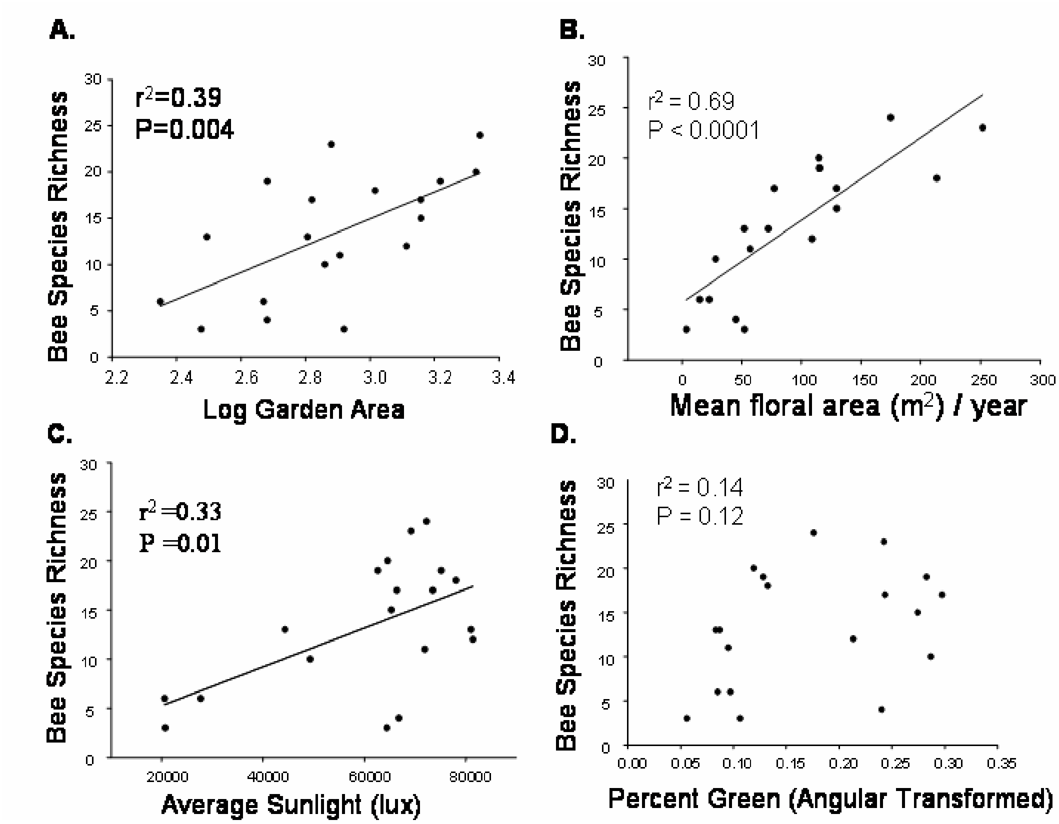

Figure 3: Relationship between bee species richness across 18 urban community gardens in East Harlem and the Bronx, NY and: (A) garden area (log transformed), (B) floral area within a garden, (C) sunlight and (D) percent greenspace in the surrounding landscape (angular transformed).

8. ***Pollination Services in Urban Gardens***

Pollinator conservation areas were found to increase the local density of insect pollinators in urban community gardens (Figure 4A). However, this local increase in pollinators did not translate into increased cucumber yield. In fact, there was no difference in wet mass of cucumbers harvested from gardens with pollinator conservation areas versus those harvested from control gardens (Figure 4B).

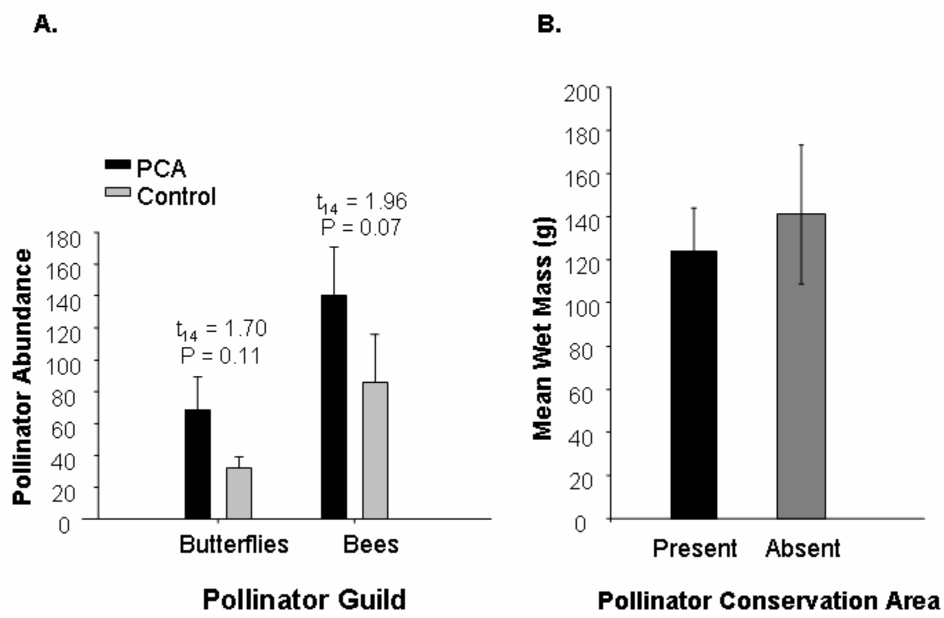

Figure 4: Impact of pollinator conservation area additions to (A) pollinator abundance and (B) cucumber yield (reported in grams of wet mass). There was a trend towards more pollinating insects in gardens with PCA additions. However, this increase in the local abundance of pollinators did not translate into increased cucumber yield. There was no difference in cucumber yield in gardens with versus without PCAs.

However, it is important to remember that our addition of pollinator conservation areas into these community gardens represented a relatively minor manipulation to the overall abundance and diversity of flowers within each garden. The overall abundance and diversity of flowers was subject to decisions by the individual gardeners within each garden. In fact, it was the overall abundance of flowers within gardens that was found to influence cucumber yield. There was a trend towards increased bee abundance in gardens with more flowers (Figure 5A). However, there was also a trend towards decreased cucumber yield in gardens with more flowers (Figure 5B). We attribute this result to the potential negative effects of heterospecific pollen deposition on cucumber stigmas, or of competition among flowering plants for a finite number of pollinators in urban gardens. Discriminating between the potential importance of these two factors is the focus of our current research.

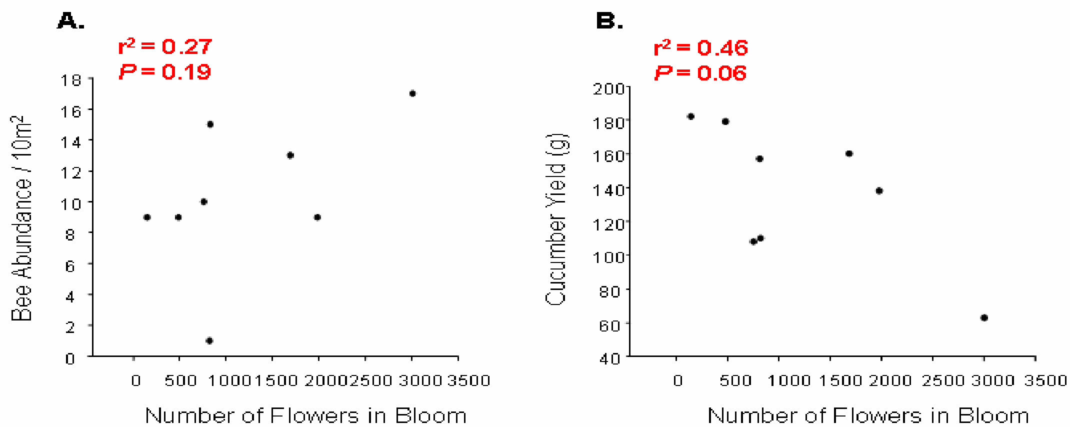

Figure 5: Impact of total floral abundance within gardens on (A) bee abundance and (B) cucumber yield (reported in grams of wet mass). There was a trend towards greater bee abundance in gardens with more flowers. However, this increase in the local abundance of bees did not translate into increased cucumber yield. In fact, there was a trend towards reduced cucumber yield in gardens with more flowers in bloom.

9. ***Bird Populations and Diversity.***

Analyses of the two years of avian sampling are under way.

10. ***Forest Change in Random Point Samples***.

Analyses of the two time periods of vegetation status in the 200 random sampling points are under way.

11. ***Biocomplexity, Urban Design, and Nitrogen Retention***.

New intensive small watershed sampling sites have been selected, and initial sampling for water quality is underway.

12. ***Ecology of Invasive Species.***

Contrary to our expectations, the laboratory population did not grow better than the field population. Mortality rates were also high in the laboratory. It is not clear why *Amynthas* is difficult to keep in the lab. While average live weight increased over time in the field population, so did variance indicating that small juveniles were continuously emerging. These can be either offspring of the large individuals or hatched late from last fall's cocoons.

13. ***Wireless Sensor Networks***.
At a high level, our experiment was a success: we detected variations in soil condition corresponding to topography and external environmental parameters as expected. However, we encountered a number of challenging technical problems, including a need for low-level programming at multiple levels, calibration across space and time, and cross-reference of measurements with external sources. Based upon the experience with this system we are improving both the hardware and software. Our plan is to deploy 200 nodes with close to a thousand sensors spread over multiple sites in the context of the Baltimore Ecosystem Study LTER.

14. ***Effects of Parks and Green Space on Property Values***.
Our results indicate that park proximity is positively valued by the housing market where neighborhood robbery rates are under 650% of the national average (the average rate for Baltimore is 723% of the national average), but negatively valued where park robbery rates are above 650%. The higher or lower the robbery rate is above or below 650%, the steeper the relationship is between park proximity and home value. This research has been submitted for publication to Urban Studies.

15. ***Modeling Urban Vegetation Dynamics.***
The dynamic model and the findings from the sample "city" simulations were written up and included as a chapter in Kenneth Mulder's doctoral dissertation at the University of Vermont, "The stoichiometry of resource utilization in economic and ecological systems." A paper based on that chapter is currently in draft form.

Findings Addressing Question 2: This question evaluates fluxes of energy, matter, capital, and population in the Baltimore ecosystem.

1. ***Effects of Development Spatial Patterns on Water and Nutrient Cycling.***
This level of spatial detail is new in our modeling efforts, and results are forthcoming.

2. ***Metal Concentrations in Gwynns Falls Riparian Sediments***.
Early findings of measurement of metal concentrations in archived cores include the following: 1) The change in physiographic provinces at the Fall Line has profound impacts on the physical and chemical characteristics of riparian sediments, leading to coarser sediments with less organic material and secondary minerals; 2) However, there are also increases in potentially toxic trace metal concentrations (e.g., Pb and Zn) as contributing areas

become increasingly urbanized, including these areas dominated by coarse sediments; 3) As coarse sediments typically are less effective at retaining and sequestering metal species, this combination of contamination and sediment geography should enhance metal species mobilization from floodplains to surface and bay waters; 4) In addition to trace metal patterns, there is a pronounced increase in Ca concentrations with urbanization. However, this increase does not seem to correspond with enhanced chemical weathering due to acidification or simple changes in atmospheric Ca inputs.

3. *Timing and Magnitude of Nitrogen Flux from Urban-rural Gradient Catchments.*

Urbanized watersheds display elevated baseflow nitrogen concentrations compared to a control site, and that the timing of nitrogen export is also significantly altered as development increases. We developed a statistical model to relate export characteristics to land cover, and apply this model across a stream network. This spatial extrapolation has potential applications as a tool for identifying variations in export timing across a stream network, and prioritizing areas within the network for restoration.

4. *Response of watershed nitrogen exports to sanitary sewer improvements.*

Continuous stream data are published annually by the USGS, with some stream-gaging station data available in near real time. These data position BES well to evaluate the effects of the sewer retrofit in Baltimore. Results from Gwynns Run, a heavily contaminated small tributary to the lower Gwynns Falls, located just above our long-term Carroll Park sampling location, suggest that infrastructure improvements associated with the consent decree may markedly reduce nitrogen exports from the Gwynns Falls watershed. A major sewage leak in the Gwynns Run watershed was repaired in early May 2004, resulting in an immediate and dramatic decline in total N in the stream (Figure 6 - top). Fecal coliforms also declined precipitously in response to this repair. Interestingly, nitrate levels in the stream increased following the repair, perhaps due to increased oxygen levels in the stream following reduction in sewage inputs. A major long-term question is how changes in the chemistry of tributaries such as the Gwynns Run are reflected in the main stem of the Gwynns Falls. Gwynns Run is just upstream of our most downstream sampling site (Carroll Park) along the main stem. Changes in the chemistry of this much larger stream are harder to see than in Gwynns Run (Figure 6 - bottom), but similar reduction in total N and increased nitrate appear there. Long-term data, and advanced trend analysis techniques will shed light on these trends over the next several years.

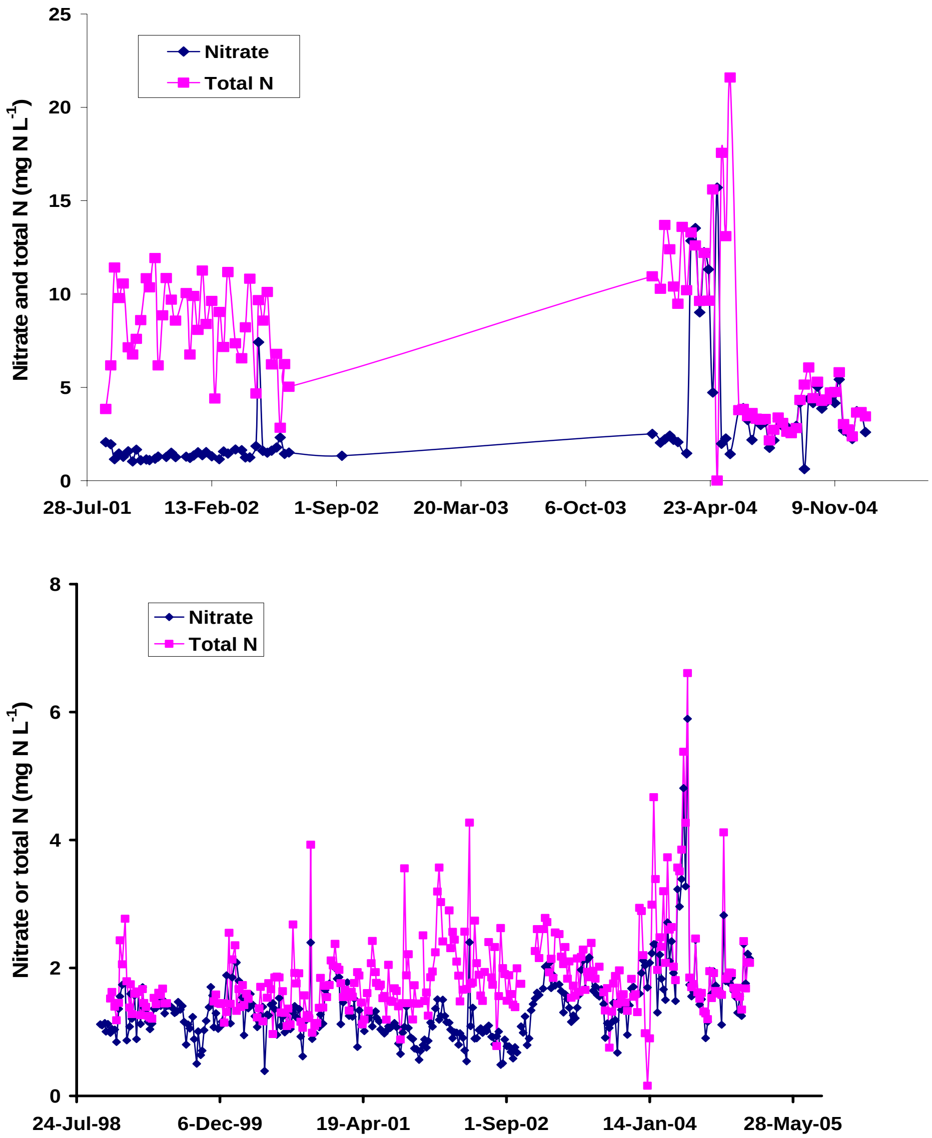

Figure 6. Nitrate (NO_3^-) and total nitrogen at the Gwynns Run (top) and Carroll Park long-term BES sampling sites from October 1998 – December 2004.

5. *Influence of Trees on Pedestrian Exposure to UVB.*

The medical community is certain that ultraviolet radiation (UV) has negative impacts on human health by being a causative factor in skin cancers, one of which—melanoma—is often fatal. However, the UVB component of ultraviolet radiation also provides a health benefit by creating vitamin D in people. Some in the medical community suggest that moderate exposure to sun is a benefit because the vitamin D production protects the body from non-cutaneous cancers and vitamin D certainly promotes bone health. More research is needed to provide recommendations for urban planning and design, including tree arrangements, to optimize human exposure to UV radiation.

Average exposure of pedestrians to ultraviolet radiation in different land use categories in Baltimore differs. For example, exposure in neighborhoods of single-family homes is usually less than in neighborhoods of multi-family housing because tree cover is generally higher in the single-family neighborhoods.

6. ***Land Cover Influences on Air Temperature.***

Where tree cover is higher, temperatures are generally lower. In downtown Baltimore, air temperatures at night are often 8 ºC warmer than in a rural forested site. However, topography as well as land cover is important in determining air temperature differences and the differences depend strongly on atmospheric stability.

7. ***Bacteria in Baltimore Streams.***

Approximately 176 bacterial colonies from each of the three streams were identified using sequencing of 1000 - 1200 nt of the 16S rRNA gene. *E coli*, *Aeromonas* spp., *Klebsiella* spp., and pathogens such as *Yersinia* and *Salmonella* were recovered from the streams.

8. ***Surface-Atmospheres Transport at the Cub Hill Eddy Flux Tower.***

LUMPS (Local Scale Urban Meteorological Parameterization Scheme; Grimmond and Oke 2002 J. Appl. Met.) has been tested for four years of data. The NARP (Net All Wave Radiation (Q*) Parameterization) portion of the model works very well. The nighttime fluxes are the least well modeled. The other fluxes (storage, sensible and latent heat) are modeled less well than Q* but are still very reasonable estimates.

Carbon dioxide fluxes - Estimates of total annual NEE (net ecosystem exchange) suggest that the Cub Hill area is acting as a source of C. Detailed sensitivity analyses of numerous calculations and decisions on estimates are being taken into account to determine impact.

9. ***Carbon Storage in Residential Lands.***

The process of residential development is obviously a substantial disturbance, and the topsoil on which new homes are built can be surprisingly infertile. To develop the methods for use in this project, we established a set of study sites on thirteen turfgrass sites (eleven lawns and two sites in a common area) in residential areas of South Burlington VT. The lawns studied ranged in age from one to 25 years. Nine of the lawns and the two common area sites are in the same development (Dorset Farms) and range from one to eight years old. The remaining two lawns are in another development (Butler Farms) roughly four to five miles away, and are sixteen and eighteen years old. Homes in Dorset Farms were built using identical site preparation methods, and filled using topsoil from the same source. The only factors that vary among these homes, therefore, are the age of the home and the management regime applied by the homeowner. The Butler Farms sites are useful as they provide additional older-home datapoints, but site preparation methods are unknown for these older homes.

We found that for the first eight years after development, C density in the top 20 cm of soil seems to vary with the age of residential development, but that this rate of increase seems to slow down between eight and fifteen years (Figure 7). We also found that amount of clippings, one component of annual turfgrass production, varies substantially from home to home, but that this variation does not seem linked to the age of the lawn (Figure 8). Finally, we find that foliar %N of clippings on a per-weight basis is related to total clipping production (Figure 9), which is an interesting result because it suggests that the %N-to-plant productivity relationship is applicable to the urban and suburban landscape as well as the wild landscapes where it was previously tested and confirmed.

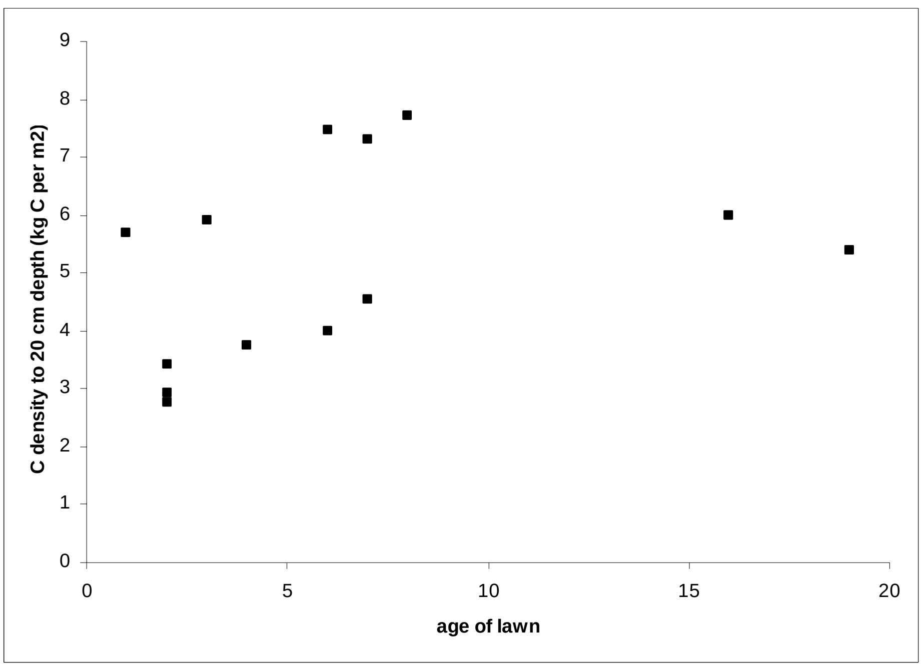

Figure 7. Soil C density (top 20 cm) for a chronosequence of lawns in South Burlington, VT.

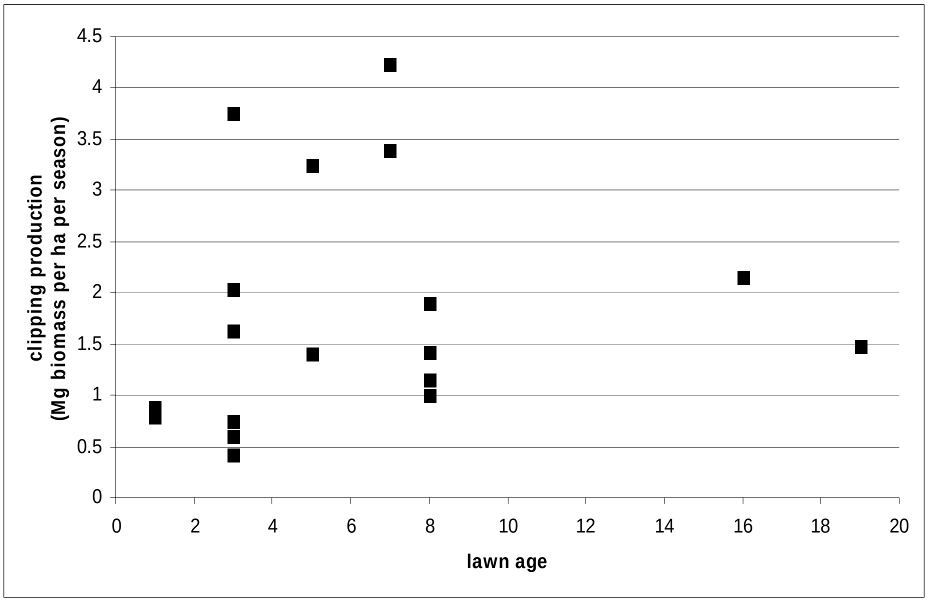

Figure 8. Clipping production related to lawn age for summer 2005, for a chronosequence of lawns in South Burlington, VT. Each point represents one sample plot; some lawns have >1 plot.

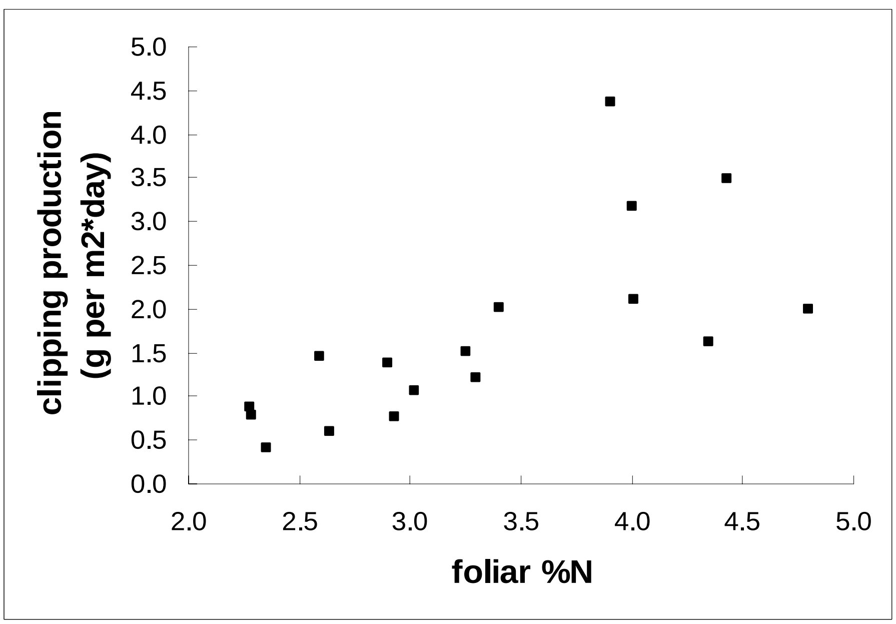

Figure 9. Foliar %N related to daily clipping production for a chronosequence of 13 lawns in South Burlington, VT. Each point represents one sample plot; some lawns have >1 plot.

The first component of the project in Baltimore has accomplished the necessary land classification. The HERCULES land classification system has been applied to the Baisman Run neighborhood, using EMERGE color infrared imagery. Site selection was facilitated by a geodatabase including soil type, parcel boundaries and housing age, land use history (using information from a variety of sources and time periods), and HERCULES class for the three study neighborhoods. Using this information, a set of ten "neighborhood clusters" containing households with identical characteristics (according to our sampling criteria) was identified for sampling. Within each of these candidate neighborhood clusters, we have begun to identify four households for sampling. As of January 2006 we have recruited seventeen households for participation in the project, out of a total of 40. Initial field site characterization visits have been made to the majority of the seventeen participating households.

10. ***Organic Forms and of Nutrients in Relation to Land Use and Air Pollution.***

We have found that organic nitrogen is an important form of nitrogen that is exported from urbanizing coastal watersheds. Up to 40% of organic N can be bioavailable to freshwater organisms, and it can stimulate enzymatic changes in aquatic microbes.

11. ***Restoration of denitrification in coastal watersheds.***

We have found that geomorphic restoration can increase rates of denitrification in urban riparian zones of urbanizing watersheds. Stream restoration may be an important tool for reducing nitrogen pollution to tributaries of the Chesapeake Bay.

12. ***Increased Salinization of Fresh Waters Due to Suburban and Urban Growth.***

Chloride concentrations are increasing at a rate that threatens the availability of fresh water in the northeastern US. We observed chloride concentrations up to 25% the concentration of seawater in streams of Maryland, New York, and New Hampshire during winters, and chloride concentrations remaining up to 100 times greater than forest streams during summers. Our work shows that mean annual chloride concentration increases as a function of impervious surface and can exceed tolerance for freshwater life in suburban and urban watersheds. Widespread increases in roadways and deicer use are now salinizing fresh waters, degrading habitat for aquatic organisms, and impacting large supplies of drinking water for humans. We are investigating the effects of increasing salinity on ecosystem function in waters draining developing landscapes.

13. ***Tracing N sources and transformations along flow paths.***

We have found that stable isotope signatures of nitrogen in autotrophs can be used to detect and quantify nitrogen pollution to streams and rivers, and that small changes in residential development may saturate the ability of headwater ecosystems to attenuate nitrogen pollution. Annual estimates from

N isotope ratios (corrected for natural background variations across seasons) were similar to mass balance estimates obtained from routine measurements of discharge and major N fractions in stream water. This technique is therefore suitable for application in Baltimore. We are now using this technique to delineate N sources and transformations in streams at the Baltimore LTER site affected by differential land use.

14. ***Urban Flooding Dynamics.***

We have developed an envelope curve for floods attaining maximum unit discharge in the region, representing recurrence intervals of 100-500 years. Several floods in our watersheds between 2003 and 2006 were at or near the regional envelope curve. Although one of these (July 7, 2004 in Dead Run) may have been a 100-year flood, other extreme flood peaks (e.g. Moores Run, June 13, 2003 and June 1, 2006) were generated by rainfall events having recurrence intervals of two to five years. Thus urban watersheds can exhibit extraordinary flood response to summer thunderstorms. Hyetographs from radar data and discharge records suggest that Moores Run is as flashy as any stream in the continental U.S. Flood peaks > 28.3 m^3s^{-1} occurred five times in the six-week period between June 1 and July 15, 2006.

We can relate watershed hydrologic response to a dominant duration for intense rainfall; thus, for Moores Run the dominant rainfall duration is approximately 15-30 min, and flood peak magnitudes are not strongly affected by large accumulations over longer periods. For Dead Run, in contrast, the dominant rainfall duration is circa 1-2 hr and the largest floods involve several storm cells moving over the watershed. The drainage network structure diminishes the effect of spatial variability of rainfall on storm response.

Flood response is not necessarily associated with high runoff ratios. The combination of extremely high velocities in storm sewers, and short lag times, minimal dispersion, and low runoff ratios suggest that flood peaks are dominated by the part of the watershed that is hydraulically connected to the storm drain system.

The topographic information for this project is primarily LiDAR data. Using LiDAR data to construct a finite element mesh for 2-d flow modeling, gaps in the data caused only minor variations (typically .03-.08 m) in water levels predicted in large floods.

The hydraulic models exposed patterns of inundation over the course of the hydrograph and illustrated the effect of local topographic features and infrastructure. Bridges and culverts affected both the pattern of inundation and the propagation of the flood wave. Simulating the Moores Run flood of June 13, 2003, the hydraulic model showed that most of the attenuation was attributable to bridges and road embankments, but natural and anthropogenic constrictions and expansions of the valley bottom also played a role. Flood-peak attenuation as much as 50 to 75% has been observed in multiple floods over the study period and is partly attributable to the role of urban infrastructure in accelerating hydrologic response and increasing flood peaks upstream, and to the role of excavated storage areas, flow obstructions and a sharp break in gradient in attenuating flood-wave propagation downstream.

The free water surface and depth-averaged velocity fields for extreme floods in Moores Run, derived from models and comparison with surveyed HWM, exhibit cross-sectional and downstream variations. Spatial variations of the free water surface and velocity field are of primary importance for many applications, including estimation of flood peak magnitudes, floodplain mapping and flood inundation forecasting.

In the Dead Run, modeling focused on the record flood of July 7, 2004. This event exceeded the maximum stage of Tropical Storm Agnes in June 1972, the previous flood of record. We can characterize the spatial and temporal pattern of flood response to a well-specified rainfall field, and explore questions about the meaning of flood frequency across multiple scales and downstream patterns of flood-wave behavior.

One key finding is that stage-discharge relationships for urban stream gages are subject to large errors that are not generally recognized by those who use peak flow records for prediction and planning. We modeled the June 13, 2003 Moores Run flood peak using three different techniques and found that the existing rating curve may be overestimating peak discharge by as much as 100%, i.e. the modeled flood peak is about 50% of the flood peak based on the rating curve. In addition the assumption of a 1-d flow pattern with the same peak stage on opposite sides of the channel is incorrect at several sites where stream gages are located on the downstream side of a bridge. Hysteresis in the stage-discharge relationship has been observed at several locations as described above, raising the possibility that a single-valued rating curve may not be appropriate for many urban sites. The nature of the urban channel-floodplain system, with frequent blockages caused by bridges, culverts, road embankments and floodplain fill, tends to exacerbate this effect in urban and suburban watersheds. For large floods these backwater effects may extend from one bridge or culvert to the next.

Using LiDAR for hydraulic modeling has allowed us to visualize the interaction between geomorphic features and flood behavior. For example, a road built in the mid-1950's upstream of the confluence of Dead Run's two major tributaries raised the level of the floodplain. This project also regraded part of the floodplain to accommodate new businesses and a high-school track on what formerly were riparian wetlands. The original construction plans allowed us to represent the 1953 topography. Hydraulic modeling using both modern and 1953 topography showed how changes in the channel and floodplain might alter the inundation associated with a flood peak like the one of July 2004. Water levels were as much as 0.6 - 1.0 m higher under the modern scenario than for the 1953 scenario.

Dead Run is a watershed that urbanized during the suburban expansion common in postwar America. Trends in monthly minimum discharge and mean annual flow reflect water importation, while trends in peak flow show that urbanization has increased the discharge response during storm events. Yet in contrast to other urbanizing watersheds, the plan form of the Dead Run channel has remained remarkably stable through time, despite decades of urbanization, and the high shear stresses and stream powers experienced by portions of the channel. This stability is likely the result of geologic control by bedrock outcrops and coarse bed and bank material. Proper evaluation of the stability of urban channels requires a good understanding of how hydrologic response and channel form have changed through time, which can lead in turn to insights on the controls of channel form in these changing environments.

15. ***Interpretation of Urban Soil Survey and Heavy Metal Exposure***. Survey, mapping, and interpretation of urban soils have shown that heavy metal contamination in urban soils is fairly ubiquitous at the neighborhood scale, but highest concentrations found in disturbed sites, e.g., vacant lots. Relative to forest soils, urban soils have high potential for sequestering C, especially previously disturbed soils. In arid and semi-arid regions urban soils can store significant amounts of C relative to native soils they replaced. Management strategies to deal with contaminated soils in residential neighborhoods are currently being devised based on these findings.

The fifteen new or extended projects summarized above, address the issues of ecological, social, and physical fluxes in the Baltimore ecosystem. In some cases, the interactions among different kinds of fluxes, as well as the functional interactions between structure investigated under Question 1, and the fluxes investigated in Question 2 have been presented. In the following section, we will address how aspects of the ecological knowledge about the structure and function of the Baltimore ecosystem is made available to students, citizens, and decision makers.

Findings Addressing Question 3: How can people develop and use an understanding of the metropolis as an ecological system to improve the quality of their environment, and to reduce pollution loadings to downstream air- and water-sheds?

The findings and outcomes reported here deal with the feedback between ecological, physical, and social knowledge, and the behaviors and actions of individuals and institutions. This section reviews accomplishments in transferring knowledge that can inform environmental actions and decision makings, including school, non-formal education, and interaction with managers and policy makers. This question also illustrates how BES is engaged with the communities and institutions in Baltimore.

1. ***KidsGrow After School Program.***

This program is viewed as a model in Baltimore. Linking scientific topics to the striking news following Hurricanes Katrina and Rita engaged the students effectively. The second semester focus on nutrition, which engaged the students through gardening, healthy food preparation, and classroom visits by chefs highlighted a topic of concern to the public health community and to community leaders.

2. ***Responsive Teaching Study.***

This research is ongoing, with analyses to come.

3. ***Adopt a School and Curriculum Development.***

The curriculum is currently being implemented in Baltimore schools.

4. ***Urban Environmental Education Inventory.***

The 118 programs represented in the inventory indicate the status of environmental education in Baltimore. Nature and wildlife, and ecosystems are the most commonly covered topics, followed by Water Resources and Natural Resources/Resource Management. Urban ecology, biodiversity, environmental health, and pollution prevention are next most common. Interestingly, several notable environmental topics are covered by less than 15% of the programs - schoolyard ecology, energy, air quality, and sustainable development. The least covered topics are climate change and transportation and, lowest of all, environmental justice (covered by only 2 of the 118 programs). Two thirds of the programs use field activities, and then 45% classroom or workshop instruction. These are by far the most common delivery modes listed. A third of the programs involve a docent- or naturalist-led tour. A smaller number (20-25%) involve in-class presentations, student research activities, hiking and lab experience.

5. ***Research Experience for Teachers (RET)***.

This project has engaged a committed teacher, Ms. Karin Watson of the Doris M. Johnson High School. She has already done innovative work with her students in mapping trees in the surrounding park, planting trees and studying asthma in the community. The entitation project designed through scientific mentoring and field work during the summer of 2006 will be exercised in the school environment during the current academic year.

6. ***School-based Urban Rural Gradient Ecosystem Studies (SURGES).***

This is a new program, and results are not yet available.

7. *Land use and Environmental Justice Curriculum.*

This curriculum has been completed, and is ready for implementation.

8. *Development of Graduate Courses.*

One of the graduate courses developed during the reporting year resulted in factual insights about Baltimore that are useful in advancing understanding the city as a coupled human-natural ecosystem. Each of the three topics researched as part of M.L. Cadenasso's course on Ecology and Urban Morphogenesis at Yale University produced a presentation and paper. The conclusions were:

a. The sports stadia are built on previous B & O land. This area has retained its shape though its function has changed. This "patch" is a barrier, both to flows of people and resources and also a perceptual barrier. Plans for downtown redevelopment do not include this patch in any plan. Neighborhoods on the downtown/inner harbor side of the stadia have undergone successful revitalization, while the neighborhoods to the west of the stadia have not experienced revitalization.
b. The neighborhoods zoned by the Home Owners Lending Corporation as declining (or "redlined") in 1937 remain in a degraded state. Mean vacancy levels of areas categorized as "D," the lowest grade, in the 1937 redline maps averaged 19% in 2000. This is twice any other zoned area and almost three times the level of vacancy as found in areas zoned favorably as "A." D zoned areas in 2000 contained the highest percentage of African-American residents, and the highest percentage of high-density residential land use. D and A zoned areas had the lowest amount of adjacent park lands in 2000.
c. By 1983, 66% of streams were buried. The highest burial occurred in areas zoned D (94%) and the lowest in A zoned areas (81%).
d. The B&O Railroad, while built to facilitate shipping goods west from the port did not take the route that makes sense based on topography. Rather, track placement was driven by political and economic incentives. Within the city of Baltimore, tracks were laid to run to the businesses. The businesses did not reestablish along proposed track lines. Baltimore has transitioned from being a source of goods to the west to being a node on the NE corridor and, in fact, has no contemporary direct west link. Baltimore received more goods from the west than it actually moved west including textiles, paper, lumber, coal, tobacco, and flour.

9. *Neighborhood Restoration and Greening in an Urban Storm Drain Catchment (263).*

Tree planting and removal of sections of pavement from asphalted school grounds has begun. Greening activities in several of the eleven neighborhoods in Watershed 263 are underway with the cooperation of local communities, the Parks and People Foundation, and the Baltimore City

Department of Public Works and the Department of Recreation and Parks. Levels of engagement within the various schools and communities are high.

10. ***Provision of Data to City Government and NGOs.***

Participation is the Mayor's City Stat program is ongoing. The Baltimore Neighborhood Indicators Alliance report "Vital Signs," to which BES contributed has been published.

11. ***Youth Forestry Training and Summer Employment.***

This program trained fifteen young Baltimoreans during 2006. The students learned the significance of greening for quality of life, and were exposed to various environmental career options.

12. ***Informed Congressional Staff on Urban Watershed Forestry.***

We judged this to be an important opportunity to communicate scientific insights and needs for knowledge and application. The recognition that the forest component of urban areas is crucial to environmental and human health, and that city watersheds are an effective management framework for quality and sustainability of both water and vegetation is important for decision leaders.

13. ***Analysis of Barriers and Opportunities for Community Involvement in Urban Forestry.***

Information gathered and analyzed in this project have contributed to identifying places where urban forestry is needed, and has identified situations in which neighborhoods are ready or can be better prepared to exploit the opportunities presented by greening.

14. ***Assistance to Baltimore City Department of Recreation and Parks Forest Assessment.***

The 6000 acres of land in the Baltimore parks system provides much opportunity for improving the greenness of the city, and for providing concentrated sources of ecosystem services throughout the city. Understanding the status of tree canopy and vegetation in different parcels will help park managers improve their resource.

15. ***Neighborhood Ecology Center at Harlem Park Elementary School.***

The Harlem Park Neighborhood, part of Watershed 263, is a dense, old urban neighborhood, distant from wildland parks or other traditional opportunities to engage students with natural environments. Providing such neighborhoods with resources to explore ecological patterns and phenomena close to home is an important step. A plan has been developed for the Center, and funding secured.

16. ***Teacher Materials on Urban Birds.***

Our experience in taking inner city school students outside and identifying and observing birds in their own neighborhoods, suggests that these organisms provide a powerful tool for engaging even center city students in the natural world. Therefore, we have compiled curriculum materials to make these organisms more approachable in city and suburban schools in our region.

Contributions

1. ***Within Discipline***

a. ***Stream Gauging Data.***

Streamflow data provided on regular basis and on special request to individual investigators. USGS scientists have participated on a continuing basis in all appropriate BES planning and scientific meetings, including the BES Steering Committee. USGS is providing leadership in general hydrologic investigations in cooperation with other Principal Investigators and Collaborators and is providing particular leadership in ground-water and subsurface geophysical investigations. Surprising spatial patterns in water flow, control of flooding, and water quality in the urban mosaic have appeared, which call for more sophisticated assessment of the biological, physical and social causes of differential flow, input, and mitigation.

b. ***HERCULES Land Cover Classification.***

HERCULES provides a better tool to test the structure function link in urban systems. It can effectively characterize and quantify spatial heterogeneity in urban landscapes. Conceptually, it question the assumptions embodied in widely used land use classifications and demonstrates why they may be limited when used for understanding the ecological function of urban systems.

c. ***Lifestyle Theory Provides a New, Alternative Explanation of Social Differentiation.***

Classical social stratification theory focuses on income, education, and ethnicity and national origin. We have discovered that lifestyle clusters provide a better theoretical explanation for social differentiation across space in urban agglomerations. Because classical social stratification theory underwrites many spatial stratifications for modeling and statistical analysis used to integrate ecology and social science, integrated social-ecological research stands to be improved by employing this new theoretical foundation. The theory of social differentiation is also relevant to such practical actions as the deployment of management strategies across the metropolis.

d. ***Soil C Storage.***

The potential that the vegetation component of urban systems may contribute to mitigation in the global carbon cycle is relevant to regional and larger scale understanding of C sequestration. The investigation of residential lands in this regard is a new frontier.

e. ***Soil Invertebrates and Ecosystem Function.***

Soil invertebrates are an important but relatively neglected component of many ecosystems. Because they may in fact be a large component of the effective biota in urban systems, understanding their composition, the role of exotics, and their functional role in ecosystem processes are important issues.

2. ***To Other Disciplines***

a. ***Sensor Networks.***

As inexpensive computing devices become pervasive, scientific experiments increasingly use on-line data acquisition and monitoring. Multiple sensors collect densely sampled data streams, making data acquisition easy; but, it requires a substantial effort to turn the raw data into a scientifically meaningful, calibrated data set. To build and end-to-end system that collects real data, and to test the system in several domain sciences is an interest for computer scientists and engineers.

Wireless sensor networks will revolutionize environmental monitoring. This topic was discussed in the April 2006 issue of Nature (http://www.nature.com/news/2006/060320/pdf/440402a.pdf), where our experiment is also featured.

b. ***HERCULES and Other Disciplines.***

This new urban classification provides a tool for urban designers and planners. The classification can operationalize the concern for heterogeneity in designed systems and understanding the link between the structure of the systems they are designing and building and the function of those systems. The integration of biogeophysical heterogeneity captured by HERCULES and the social heterogeneity captured by census and consumer data has been useful for integrating social and biophysical ecology.

c. ***Announced Move of USGS to UMBC Campus***.

USGS has been actively planning a physical move of its facilities and staff to the UMBC campus in 2007, including a new building in the UMBC Research Park. Opportunities for collaboration in hydrologic research and direct involvement of faculty and students are being actively pursued. The interdisciplinary boost afforded by this move for both BES and its campus host, the Center for Urban Environmental Research and Education (CUERE) is potentially great. The presence of BES on the UMBC campus and its close interaction with CUERE have proven successful in leveraging the interest of other disciplines, and additional funding for interdisciplinary research.

3. ***Education and Human Resources***

a. ***HERCULES Training***.

Working on HERCULES has provided training in basic ecological concepts such as landscape ecology, urban ecology, and spatial heterogeneity as well as basic GIS skills for several post-baccalaureate technicians (K. Schwarz, Ph.D. candidate, Rutgers University, A. Holland, M.S. candidate, University of Vermont, C. Hicks, M.S. candidate, University of Florida, and E. Cook, current).

HERCULES plays a central role in the doctoral research of K. Schwarz, Rutgers University. She has helped to develop HERCULES which has increased her skills in GIS and air photo interpretation. It has also helped in getting a clear grasp of ecological concepts such as frameworks in landscape ecology, and spatial heterogeneity. It has provided fodder for W. Zhou (University of Vermont) to develop skills using object oriented classification software and developing algorithms to automate HERCULES using eCognition. It was used by C. Carlson in her thesis research at the University of Georgia on bird use of remnant forest patches embedded in an urban matrix.

b. ***Brooklyn Academy of Science and the Environment.***
Brooklyn Academy of Science and the Environment (BASE), Brooklyn, New York. BASE is the first public high school in Brooklyn that weaves connections between academic subjects and the environment (in conjunction with the Brooklyn Botanic Garden and Prospect Park Alliance) that is funded in part by the city-wide New Century High School Initiative, the Carnegie Foundation, the Bill and Melinda Gates Foundation, and the Open Society Institute. The program is administered by New Visions for Public Schools in collaboration with the New York City Department of Education (DOE). Dr. Quintaniay Holifield served as an educational consultant to provided soil science curriculum in the subject of Soil Microbiology for Grades 9-12. The curriculum and information provided was immediately put to use in the classroom during the fall of 2005. Approximately 125 students benefited from the soil science curriculum at BASE.

c. ***Teacher Training.***
Professional development has been provided at meetings of the Responsive Teaching Study. Jenny Harvey, teacher and developer of the *Investigations in Urban Soils* unit and Martin Schmidt, teacher and developer of the *Investigations in Exploring Watersheds in Baltimore* unit led these sessions with the help of the BES Education Coordinator. Monthly, one hour professional development sessions were also provided to the five KidsGrow teachers during the reporting period.

During this period we have continued to work, through the BES Ecology Education Fellowship program, with three educators who are learning about the local environment and about BES research, developing lesson plans for their own use and then crafting these into instructional support materials for others.

The Ecology Education Internship Program engaged two young educators/ ecologists in projects through the Urban Resources Initiative program at Parks and People.

d. ***Staff Field Safety and Community Awareness Training.***
Mary Cox, URI Coordinator, planned, coordinated and hosted the BES Annual Staff Field Safety and Community Awareness Training Workshop, held in June 2006 at Sandtown Winchester Community Center; approximately 20 people trained from the Institute of Ecosystem Studies (IES), US Forest Service, and Parks and People.

e. ***Parks & People Foundation Interns.***
Eight undergraduate and graduate student interns were supervised and trained in the following projects: 1) Developing and leading Watershed Ecology Education enrichment program with Parks and People's SuperKids Camp. 2) Developing

educational materials and resources for the Neighborhood Ecology Center. 3) Materials for schoolyard greening program. 4) Developing curriculum and leading Watershed 263 Environmental Justice summer youth program. 5) Developing outreach plan and interpretive materials for Gwynns Falls Trail and Watershed 263 Greenway. 6) Developing marketing plan and materials to attract users to Baltimore parks and trails. 7) BRANCHES summer youth forestry training and employment program.

f. ***GIS and Historical Methods.***

Graduate and undergraduate students were trained in GIS and historical methods. The combination of a cutting edge technology with archival research has great potential to improve the integration of that discipline into larger teams.

g. ***Adopt a School Workshops and Curriculum Development.***

Co-PI Quintaniay Holifield, and Education Coordinator Janie Gordon conducted a teacher development workshop for the implementation of the USDA Forest Service Adopt-A-School Program at Franklin Square Elementary School. Subjects of soil science and ecology were presented at the workshop to enhance curriculum development in the Baltimore County and Baltimore City School Systems.

h. ***Student Overview.***

Elsewhere in this report, the sheer numbers of students at various levels are laid out. Here, a sense of the one-on-one mentorship and commitments of advisors and educators can be given. The project has trained one MS student, Ms. Carolyn Klocker, through University of Maryland, and she expects to receive an MS degree from the Marine Estuarine Environmental Sciences Program at the in spring of 2006.

The program has led to the training of an REU student, Tamara Newcomer, who is graduating from the University of Maryland, Baltimore County in spring of 2006. Tamara is interested in applying to graduate schools and pursuing a graduate degree in stream restoration ecology.

At Fordham University, there are current interactions with three graduate students (Kevin Cox, Shannon Morath and Evelyn Fetridge) and three undergraduate students (Caitlin Bell, Rosaly Fernandez and Peter Werrell). The Fordham University REU Program was enriched by interactions with BES in 2006, including a keynote address by the BES Project Director at the Fordham REU Symposium.

Over the duration of the urban flood project, several graduate students and a large cohort of undergraduate students worked together in collaborative teams. During the summer the crew of flood research assistants were based in Baltimore and worked together on field data collection, data reduction and analysis, and modeling. Students gained considerable skill and learned to work independently. Two of the students who worked on the project have gone on to graduate school, others to professional careers involving environmental science and water resources, and others have not yet graduated but have expressed interest in continuing their education with graduate degrees in related fields. The majority of both graduate and undergraduate students involved in the project were female. Students have been coauthors on research presentation and posters and, in one case, senior author on a journal article.

University of Missouri students Parker (Ph.D.) and Denison (M.S.) were graduate students affiliated with BES. Parker completed his dissertation in July 2006. Denison is in the first year of his M.S. research. Both benefited from their involvement in this long term urban ecosystem/urban ecology research project. Cole, Denison, and Nelson, were technicians on the bird monitoring project in 2005 and/or 2006 and were trained in bird census methods.

As part of his employment with the US Forest Service and BES, Bryant Smith will complete his B.A. in social science and aviation. Bryant Smith's participation in this project furthers his goal of becoming a full-time employee of USFS.

Recruitment and hiring of one University of Vermont graduate student, Paul Lilly, occurred this year. He began his Ph.D. program in fall 2005 and plans to continue through spring 2008.

Graduate student Karla Hyde gained experience in working with meteorological data, computer spreadsheets, data quality assurance, and GIS. Technicians Caplan and Quinn received training in meteorological instrumentation, use of data loggers, and quality control in research.

i. ***Summer Employment and Training.***

Fifteen Baltimore City high school students, including a large proportion of persons of color who are underrepresented in science, were trained through in environmental jobs.

Additional contributions to training and human resources include the following:

- *Metropolitan Transition Center for Job Training and Certification for Ex-offenders.*
- *Green Jobs Initiative for the Urban Ecology Collaborative*.
- *Environmental Justice Summer Program for Youth in Watershed 263*
- *Participated in Green Schoolyard Task Force with Baltimore City Public Schools*.
- *Parks & People Foundation Certified as Green Center for Environmental Education Support*.
- *USGS Development Opportunities Through National Training Center Are Available to BES Investigators on a Space Available Basis*.

4. *Research and Higher Education*

a. *Redesign and Development of the Open Research System – a Component of the BES Metadata Management System.*

Connected to the BES website, is an option called "ORS Metadata System", with "ORS" standing for "Open Research System." This is a web-based metadata entry system that BES has used for five years to allow researchers to enter their metadata and upload relevant datasets. This system resides at the University of Massachusetts (UMass), Amherst. In the current design, there are ways for the BES Information Manager, Jonathan Walsh, to extract the metadata from this system and compile it in EML format and also create complementary "static pages" listing BES data which also reside on the BES LTER website.

Over the last year, we have been developing what we call "ORS-lite" or ORS release 4.0, which is a fundamental change in the ORS architecture. At the heart of this change is the use of web "data services" and we have streamlined or made more efficient the design of the relational database it uses. An additional change is an upgrade of the underlying database engine from Microsoft Access to Microsoft SQL server. The new release is not yet operational on the BES website, but most of the functionality is developed and we expect it to be in production in the early fall.

Benefits to this new release are several. First, BES LTER website visitors will no longer experience a "redirect" to the ORS website to get to the search metadata mechanism. Rather, there will be two new options on the BES LTER "Products" menu: 1) search for data and 2) post metadata. Both of these will invoke the server at UMass, but will operate seamlessly – that is, the end user will experience no redirect to the UMass hosting server. To the end user, the search and post pages will look like they reside on the BES LTER web site.

The search mechanism is being designed such that a page residing on the BES LTER server invokes a "web service" to the UMass server. This service is a database query based on the parameters the end user puts in (e.g., a keyword search). The UMass data server will receive this query and respond back to the BES LTER client machine with a stream of the requested data. The BES LTER client page will then interpret and reformat this data to provide the results page to the end user.

The post metadata option works in a similar fashion as the search. After logging in, a BES LTER researcher can complete an online form with their metadata manually, or an option is available to upload metadata that is stored in the ArcGIS metadata format. Upon pressing the "submit" button, transparent to the user, a webservice is invoked that sends a "post data" request to the UMass server asking to post a new record to the metadata database. The end user has the option to upload or attach files associated with this metadata as well.

The main reasons for this change in architecture are: 1) to make the underlying relational database storing the metadata more efficient; 2) to upgrade to the MS SQL server database platform; and 3) to make the end user experience getting to the search and post metadata options on the BES LTER website seamless and easy. An additional benefit is that by utilizing web data service technology, BES is positioned, should we want to do this, to receive automated metadata from environmental data sensors out in the field. In other words, the ORS system is designed to be a potential web interface between automated data collectors and the potential users of this data.

b. ***HERCULES in Research and Higher Education.***

HERCULES has been presented and used by four years of urban design studios at the Graduate School of Architecture, Preservation and Planning at Columbia University.

c. ***BES Data Sets Used in University of Vermont Advanced Spatial Statistics.***

Databases from BES are used as core instructional materials in Co-PI Troy and Grove's course in Advanced Spatial Statistics at the Rubenstein School of Environment and Natural Resources at the University of Vermont.

d. ***Yale Urban Morphogenesis Course Benefits.***

The Ecology and Urban Morphogenesis course taught at Yale provided the students with opportunities to conduct independent research that was interdisciplinary in nature. They also were engaged with urban designers, ecologists, and social scientists.

e. ***Wireless Sensor Development.***

The utility of wireless sensor networks for environmental research is currently a topic of wide interest. Given the development of NEON, a field tested soil sensor network is of great interest to the wider field of environmental science.

f. ***To the LTER Network.***

In the summer of 2005, a workshop was organized and co-hosted in Burlington VT by Dr. Wilson and Dr. Childers from the Florida Coastal LTER, on the topic of "Performing Network-level Synthesis by Quantifying Ecosystem Goods and Services at LTER Sites Representing a Range of Engineered and Designed Ecosystems." This workshop was the result of collaboration initiated at the ASM meeting in Seattle, 2003 and represents a synthesis of two workshops summarized and reported to the LTER executive committee by Matt Wilson and Dan Childers in 2003. A formal report of the workshop was submitted to the LTER network office: Matthew Wilson, Dan Childers, Ted Gragson, Morgan Grove, John Roach, Dave Rudnick, Fred Sklar, Scott Swinton, Austin Troy, and Paige Warren 2005. An Integrative Framework for Ecosystem Services Research and Education across the LTER Network. Report submitted to the National Science Foundation, Long Term Ecological Research program office June 1, 2005.

5. ***Beyond Science and Engineering***

a. ***Stream Data.***

USGS data and products are widely used in the geosciences and natural-resources management communities. BES stream data have been used by local governments and educators.

b. ***Preparation for Flood Warning.***
USGS is striving to add real-time capabilities to all stream-gaging stations to provide flood warning and a regular data stream for recreation, education, and water-resources management applications.

c. ***Soil and Invasive Species.***
Species invasion is a global environmental problem, and cities are not only 'hotspots' for species introduction, the urban environment facilitate colonization and spread of non-native species. Understanding the ecology of non-native species and their behavior and population characteristics is essential for understanding the mechanisms of species invasion and management of invasive species.

d. ***Urban Vegetation Management Mitigation.***
Results from our research have been useful for examining and understanding variations in vegetation cover (tree, shrub, and grass) and management behaviors in terms of fertilizer applications.

e. ***Community Training.***
Conducted community training sessions on: 1) community Grants program opportunities, 2) capacity building and leadership development in Watershed 263, and 3) community greening trainings in planning and carrying out community restoration projects. These skills can influence environmental decision making and capacity in urban communities that otherwise lack access to resources.

f. ***Training City Staff and Students in Exotic Species Control.***
Research Assistant Janelle Burke participated in the City's Weed Warriors by instructing volunteers how to recognize exotics and how to remove them.

g. ***Research on Environmental Justice.***
The research on environmental justice makes theoretical and methodological contributions to geography, sociology, and urban ecology. It shows the utility of using dasymetric methods for improving spatial resolution of historical and present-day geographic data, especially in areas with sparse or heterogeneous land use.

The methods and results from the environmental equity study will inform new initiatives within and beyond BES to analyze the relationship between environmental justice and ecology. These ideas will be addressed at the upcoming ESA meeting and in an NCEAS working group proposal.

h. ***Developed Neighborhood Ecology Center at Harlem Park Middle School.***

i. ***Serve as a model for cities in UEC*.**
Our results and interactions with agencies and communities beyond our project have served as models for similar initiatives in Burlington, Vt., and cities associated with the Urban Ecology Collaborative (UEC), which include Boston, New Haven, New York City, Pittsburgh, and Washington, DC.

j. *The "Ecology of Prestige" Has Influenced Policies for Private Vegetation Management and Restoration.*

Our findings related to an Ecology of Prestige have been influential in developing policies and plans for increasing private landowner conservation of existing vegetation cover and rehabilitation of areas that do not have vegetation cover.

k. *Forest Opportunity Spectrum.*

The Forestry Opportunity Spectrum (FOS), a framework and open source GIS tool for identifying urban and community forestry opportunities, has been completed and employed by municipalities in the Baltimore region for developing strategic and action plans for urban foresters and planners.

Publications and Products

Journal Publications

Bain, D.J. and G.S. Brush. 2005. Early chromite mining and agricultural clearance: opportunities for the investigation of agricultural sediment dynamics in the Eastern Piedmont (USA). American Journal of Science. 305:957-981.

Cadenasso, M.L., S.T.A. Pickett and J.M. Grove. 2006. Dimensions of ecosystem complexity: heterogeneity, connectivity, and history. Ecological Complexity. 3:1-12.

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Grove, J.M., A.B. Cumming, M.F. Galvin, G.W. Hager, J.P.M. O'Neil-Dunne, A.R. Troy, F. Rodgers, F. Spero, E. Svendsen and A.E. Draddy. *Submitted.* Integrating urban forestry research and applications: a forest opportunity spectrum framework and its application to Baltimore, Maryland. Journal of Forestry.

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Higgins, J.A., K.T. Belt, J. Russell-Anelli, J.S. Karns and D.R. Shelton. *Submitted.* Prevalence and molecular characterization of Enteropathic *Escherichia coli* in stream waters in a metropolitan area. Proceedings of the National Academy of Science.

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Pouyat, R.V., I. Yesilonis, D.J. Nowak and J. Russell-Anelli. *Submitted.* Soil chemical and physical properties in an urban landscape. Journal of Environmental Quality.

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Shelton, D.R., J.S. Karns, J.A. Higgins, J.S. Van Kessel, M.L. Perdue, K.T. Belt, J. Russell-Anelli and C. Debroy. *Submitted.* Prevalence and diversity of water-borne *Escherichia coli* 0157 in an urban/suburban watershed. Science.

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Zipperer, W. *Submitted.* Ecological consequences of fragmentation and deforestation in an urban landscape. Urban Forestry and Urban Greening.

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