Baltimore Ecosystem Study

Annual Report

2009

Covering

August 2008—August 2009

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 2007-2008. 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 nine 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 focused on an urban environment, we want to know the ecological interactions in the whole range of habitats—from the center city of Baltimore, to 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 city, 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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"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, suburban, and exurban 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. 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. Developing and making the most of a broad range of educational opportunities satisfies the responsibility to share ecological knowledge with the widest audience. The community engagement component of BES recognizes the responsibilities and opportunities of conducting research where people live. Applying ecological knowledge to management, environmental quality, and environmental equity acknowledges society's needs. Successful application requires dialog rather than outreach or one way delivery of scientific information. Using new ecological knowledge about urban systems in planning, design, and restoration provides important opportunities 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?

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 exploit a variety of research and demonstration sites, including 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 (WS 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 400 sample points for soils, vegetation, and surfaces, spread throughout Baltimore City, Baltimore County, and parts of adjacent counties in the metropolitan area. Social science and historical data expand our scope into Carroll and Harford Counties. 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. Additional detail appears in the research section of the BES web page at http://beslter.org

New and Continuing Activities Addressing Question 1:

1. ***Analysis of the Social Dynamics of Environmental Equity in Baltimore, MD.***

We continued to develop long-term datasets for tracking the spatio-temporal dynamics of environmental amenities, disamenities, and population and housing characteristics of Baltimore. To this end, we completed six GIS databases that provide detailed information on the location and attributes of parks (1928, 1965, and 2008) and heavy polluting industries (1960, 1970, and 1980) that are similar in screening criteria (Standard Industrial Classification codes) as the EPA's Toxics Release Inventory (TRI). Some of these data were used to prepare a publication authored by Co-PIs Boone, Buckley, Grove and Post-doc Sister. Sister and Boone are working on a paper that examines changing park equity patterns over time, and Boone has begun a longitudinal analysis of the TRI and heavy polluting industry data. We have also continued to analyze planning documents, meetings of neighborhood improvement associations, federal agency documentation (especially the Home Owners Loan Corporation), and zoning ordinances and variances to

explore the dynamics of environmental process equity. Some of these materials were incorporated into the Boone et. al. publication.

2. ***Woody Vegetation.***
Woody vegetation species were enumerated and trees measured in 10 x 10 meter plots collected through the riparian part of Baisman's Run. Twenty-five species were enumerated. Of these, the dominant, largest trees included tulip poplar and beech. Tree ring cores were collected from three of these trees in order to determine the history of growth. REU student Rachel Myriski worked along with Co-PI Grace Brush on this project.

3. ***Forest Successional Studies.***
Co-PI's Grace Brush and Dan Bain are studying forest successional sequence on the uplands of the Gwynns Falls Watershed and comparing this with pioneer forests in the riparian areas.

4. ***Vacant Lots Plant Communities***.
The vegetation and surface features of vacant lots in the Harlem Park neighborhood in west Baltimore were assessed. REU student Erica Tauzer performed a geographic and botanical analysis of the herbaceous and woody composition of more than 40 vacant lots in a circumscribed study area. Graduate student Yvette Williams conducted social and biological surveys of unmanaged vacant lots, lots subjected to a "clean and green" management regime, and community gardens to determine the role of management in socio-ecological characteristics of open lands in west Baltimore.

5. ***Urban Forestry.***
During the summer of 2009, 200 field plots in the city of Baltimore were remeasured for analysis by the UFORE model on urban forest structure and function, and changes through time. The field plots were established in 1999 and remeasured in 2001, 2004 and 2009. In addition, 200 field plots in the city of Syracuse, NY are also being remeasured in 2009. Similar to Baltimore, these plots were established in 1999 and remeasured in 2001, 2004, and 2009. Data collected on the plots relate to number of trees and physical parameters of these trees, as well as measures on associated vegetation types (e.g., shrubs, grass) and impervious surfaces.

6. ***Historical Activities of Neighborhood Improvement Associations regarding Urban Parks and Trees.***
Over the course of the past year, grad student Andrew Giguere indexed the Baltimore Enoch Pratt Public Library's entire collection of *The Afro-American,* the newspaper of record of the black community in Baltimore, which spans the period from 1895 to the 1950s. He also began work indexing later editions, specifically from the 1970s. He searched for and tagged articles dealing with parks, urban trees, segregation, neighborhood improvement associations, and, from the 1970s, articles dealing with Hurricane Agnes.

7. ***Environmental Justice.***
Co-PI Geoff Buckley continued his research on asphalt, street trees and environmental justice. Research focuses on the access to recreational and environmental amenities by African-Americans in Baltimore. Co-PI Kirstin Dow is researching environmental justice issues associated with flooding in Baltimore.

8. ***Land Cover Analysis and Modeling.***
The HERCULES land cover system (Cadenasso et al. 2007) has been evaluated to assess the agreement between the visual interpretation and object-based approaches to estimating within patch land cover estimates.

The urban heat island is being investigated. The spatial variation in land surface temperature in the Gwynns Falls watershed was mapped. Research on the urban heat island effect generally has focused on the coarse-scale effect of urban areas being warmer than surrounding non-urban areas. In this work we are quantifying finer scale heterogeneity in land surface temperature. We are also exploring how temperature variation within cities relates to social factors on the scale of census block groups.

Quantified forest cover change in the Gwynns Falls watershed over the 100 years between 1904–2004, using historic forest maps and air photos from six time slices: 1914, 1938, 1957, 1971, 1999, and 2004. The size, shape, and spatial distribution of the patches was analyzed at two scales—the whole Gwynns Falls watershed and within 3 km distance bands from the downtown base of the watershed.

We are adapting the HERCULES land cover model, developed for the Gwynns Falls watershed, to the more arid, grassland-derived urban system of Sacramento, California.

The HERCULES model is being used to organize a new collaborative interdisciplinary team based in Fresno, California working to evaluate home owner water use in terms of landscape structure and social factors, given the installation of water meters for the first time.

The University of Vermont Spatial Analysis Laboratory focused on generating high resolution land cover data for the Baltimore Metropolitan Region. This undertaking involved analyzing a vast amount of data, equivalent in storage size to the 30m USGS National Land Cover Database (NLCD) for the eastern United States. These datasets will give BES researchers an unprecedented understanding of land cover dynamics.

9. ***Land Cover Assessments—Shadowed Land.***
We have collaborated on an analysis comparing object-based methods for detecting shadows and classifying shadowed land cover for high resolution remotely sensed imagery, using Baltimore data.

10. ***Land Cover Assessments and Urban Tree Canopy.***
We continue to work with Baltimore City, and Baltimore, Howard, and Anne Arundel Counties to develop high-resolution landcover assessments. In the case of

Baltimore City and County, these data have been used to establish urban tree canopy goals and prioritization strategies for tree planting by these two jurisdictions.

11. ***Economic Welfare and the Genuine Progress Indicator (GPI).***
We have investigated how sustainable economic welfare in the Baltimore region has changed over the study period 1950-2005 by calculating a Genuine Progress Indicator (GPI) for Baltimore City, Baltimore County, and the state of Maryland. Comparisons of time trends have been made between GPI and Gross Domestic Product (or the appropriate local-scale equivalent) in order to explore the extent to which Gross Domestic Product (GDP) accurately reflects changes in the Baltimore region's true welfare.

12. ***Spatial Patterns of Urbanization.***
Data collection: We have acquired tax assessment records from the 2007 MD PropertyView records that provide detailed information on land parcels, including their land use and year in which any structure that sits on the parcel was built, and merged these data with parcel boundary maps. This generates a parcel-level map of current land uses by county. We have used the information on land use and year built to construct a microscale, time-series of urban land development over a 107-year time period (1900-2007). We have generated a series of maps that illustrate the residential, commercial and undeveloped pattern of land use by decade. To date we have created these historical maps for three counties within the BES metropolitan study region: Baltimore, Harford and Carroll Counties. We have also acquired the MD PropertyView data for Baltimore City and linked these data with a parcel boundary map and are currently generating the historical time series maps of urban development. Once completed, we will merge the three county area with the City to generate a comprehensive representation of the spatial pattern of urbanization in the northern portion of the Baltimore metro region from 1900-2007. Finally, we are using data from the Maryland State Archives (www.plats.net) on residential subdivision activity to develop a history of land subdivision development. We are currently working on residential subdivision history of Carroll County from 1970-2007.

In addition, we have gathered the following time series data:

- Population by sub-county (districts in Baltimore, Harford, Carroll, and Montgomery Counties) and sub-city (Baltimore City wards) by decade from 1900 to 2000.
- Employment by district from 1960-present; business establishments in the four county study area, by sector type, with a subset study of the spatial location of business by major category and exceeding 100 employees.
- Transportation data, including detailed roads network in GIS format; basic commuting data, and traffic volumes for major roads; traffic volume in the major water and airports; historical information on trolleys and early bus systems; recent information on light rail ridership.
- Zoning and sewer data: Collecting data on the service areas of municipal water and sanitation districts, and the thousands of water wells and septic tanks distributed throughout the rural portions of the study area, which account for about 15% of housing units in the four county study area.

- Historic agricultural census data: data has been collected for the metro region on farm structure, including farm size, farm sales, commodities grown, etc., back to 1900.
- Current business data: We have obtained data from InfoUSA, a private market research company that compiles estimates of retail sales data, and geocoded these data using ESRI's (Environmental Systems Research Institute) Business Analyst. These data are estimated for 2008, using 4th quarter 2008 data. Several variables are available, including six-digit NAICS (North American Industry Classification System) codes, sales volume and employee size.

13. ***Analysis of Land Use Patterns at Multiple Spatial and Temporal Scales: Patterns and Processes of Urbanization in the Baltimore Region.***

We have pursued initial multi-scale spatial data analysis of historical land use patterns in Carroll, Baltimore and Harford Counties using a battery of landscape metrics. Based on this initial exploration, we have selected several metrics to measure the pattern of scattered, fragmented, leapfrog development and of infilling over time. An analysis of fragmentation and infill dynamics over time and space is currently being conducted for Carroll County to assess the question of how persistent or transient is exurban "sprawl," as defined by fragmented development and a lack of infill development. Once this analysis is complete, a similar analysis will be performed for the entire study region (three counties and Baltimore City) to examine the pattern dynamics of central city development, suburbanization, exurbanization and the emergence of subcenters in this region.

We are currently examining a variety of data on population, employment, land use and other key urban variables at multiple spatial scales and over a long time period (1900-2008) to examine the potential relationships between development processes and patterns over time across the urban-rural continuum.

14. ***Develop Process-based Models that Link Micro-level Individual Behavior to the Emergence of the Observed Macro Scale Patterns and Dynamics.***

Microsimulation model of urban land development: We have developed a structural model of land development that begins with a model of household location demand. Households optimally allocate their income between the consumption of a numeraire good and spatially heterogeneous land distinguished by non-marketable natural amenities and travel distance to local urban centers. Given households' bids for residential location, agricultural landowners choose the optimal time to irreversibly convert their land to residential use such that the present value of future cash flows from the land is maximized. Land developers determine the actual location of residential development in each period by choosing the site that maximizes profits. The model encompasses three types of land heterogeneity: the commuting cost, which affects the budget of residents; the agricultural yield, which affects the threshold rent of the farmers; and the conversion cost, which affects the site choice of developers. The land development decision rule derived from this structural model is then applied to the evolution of land use patterns in Carroll County from 1970-2008. Using parcel data from MD PropertyView on land use and the timing of development, we are able to reconstruct the evolution of land

development at the parcel level from 1970 to 2008. Other sources of spatial heterogeneity, including the topological structure imposed by the road network in the county, the agricultural productivity and the conversion cost associated with each parcel of land, are accounted for using ArcGIS and the land conversion rules derived from the structural model are applied to the Carroll County landscape. All model simulations are performed using NetLogo, an agent-based modeling software. Spatial measures of fragmentation and clustering, including the contrasting edge ratio and measures of the local spatial correlation of development concentration and density, are used to assess the likelihood that the simulated landscape replicates the changes in clustering and fragmentation over time exhibited by the observed landscape.

15. ***Urban Crime and Social Cohesion.***

Co-PI Austin Troy continued working on research relating the level of yard care and maintenance to crime, using a dataset collected by our team in 2007. We statistically analyzed the relationship between tree cover and crime.

16. ***Effects of Urban Parks on Property Values.***

We conducted an analysis in which property data were analyzed using hierarchical linear models to determine the effects of environmental factors on property values at different scales.

17. ***Watershed 263.***

We have developed a dynamic, spatially explicit modeling tool to facilitate learning about the interactions among the biophysical and socio-economic components of Baltimore's Watershed 263 and quantitatively assess landscape restoration activities within the watershed. We focus on individual and neighborhood measures of quality of life, how these metrics are expected to change over time as the city of Baltimore strives to achieve their urban forestry goals, and how perceived quality of life affects residential location decisions.

18. ***Bird Monitoring Project.***

Co-PIs Nilon and Warren continued collaboration on the BES Bird Monitoring Project. They collaborate with colleagues at the University of Missouri on developing spatial models for bird species and bird communities; and with colleagues at the University of Massachusetts on understanding the relationship between tree health and bird species composition in Baltimore neighborhoods.

19. ***US-France Urban Ecology Workshop.***

The Second US-France Workshop on Urban Ecology: Urban Ecology and Sustainable Management, was held in mid-October 2008. The workshop included French scientists associated with Les Zones Ateliers and US scientists associated with the two urban LTER sites: BES and CAP. Meeting participants also attended the BES Annual Meeting to experience results of current and ongoing BES research. Follow-up activities have been identified and are being pursued at this time.

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.

New and Continuing Activities Addressing Question 2:

1. ***Legacies in Material Fluxes.***

In collaboration with Mark Green, City University of New York (CUNY), we procured funding from the Long Term Ecological Research Network Office to convene a working group meeting on "Legacy Effects on Material Fluxes." The meeting was held February 9-11, 2009 at the New England Center, Durham, NH. This meeting marks the beginning of a larger, long-term effort to outline fundamental theories on legacy effects of human activities, particularly geophysical changes and ramifications of these changes. A review article arising from this meeting should be complete within the next year.

2. ***Exotics and Dissolved Organic Carbon (DOC).***

Co-PI Dan Bain and Brian Pellerin (USGS) have procured a small amount of supplemental funding to build a dataset of DOC characteristics of native and exotic plant materials. Plant collection is ongoing and results/findings should be available for next year's annual report.

3. ***Organic Matter.***

We are exploring two related concepts to facilitate study of the role of organic matter in the waters draining urban lands. One is the phenomenon of "urban karst." In non-urban systems, karst is a landscape type dominated by layers of intact but soluble bedrock punctuated by eroded fissures through which water enters subterranean streams and groundwater. Such landscapes, like cities, are characterized by expanses of impervious surface with extensive networks of

subsurface water flow. Urban areas are engineered karst, in which impervious surfaces result from paving and building, and the underground flow is determined by engineered infrastructure and its interaction with ground water. The second is the Urban Engineered Stream Continuum (UESC) concept, which extends and modifies the influential and provocative stream continuum concept to urban systems. However, the UESC hypothesizes that karstic transport, and subsidies in gutters that replace low order, tributary streams are crucial for understanding and managing the flow of organic matter (OM) in urban ecosystems.

OM transport and breakdown in urban stream and engineered karst ecosystems. A concept-data paper is being prepared to put into perspective the complete hydrological picture of how organic matter (and coincidentally, other constituents) moves to urban streams from locations in the landscape distant from traditional riparian patches. It will synthesize literature and data from BES and Baltimore City Department of Public Works (DPW) sampling programs. It will also include results of a leaf load model, focusing on three of the LTER stream catchments, that examines the expected leaf fall into and near gutters and small urban streams. Elements will include: the urban landscape and its streams; connectivity of urban drainage networks, streams and groundwater; the gutter subsidy and leaf load estimates of course particulate organic matter (CPOM) from stream samples and remotely sensed ISC data; and the urban engineered stream continuum.

Stream litter breakdown along an urban-rural land use gradient. This work examines stream leaf litter breakdown rates in riparian/upland and urban/rural. We measured the in-situ leaf litter breakdown rates (Winter-Spring of 2005) in an urban (Gwynns Falls at Gwynnbrook) and a forested (Baisman Run) stream, using Sycamore (native riparian) and Planetree (the hybrid "urban" counterpart) leaf litter. A paper is being prepared that will feature a comparison of Sycamore tree litter breakdown of leaves taken from along the urban rural gradient. Elements will include: Sycamore vs. Planetree breakdown rates in urban and rural streams; Sycamore breakdown rates along an urban-rural gradient; gutter effects of Planetree breakdown; leaf moisture characteristics of urban vs. suburban Planetree litter; and leaf loads in the urban landscape.

Fine particulate (FPOM) and dissolved organic matter (DOC): concentrations, size fractions and fluxes in the urban landscape. This work draws on grab and focused sampling that included total suspended solids (TSS) and FPOM (=VSS) from the thirteen BES LTER stream networks. This network covers urbanization gradients, from 2005-2007, and a variety of hydrologic contexts, even though focused storm sampling is not included. The TSS and FPOM data can be parsed by size fraction—0.7 µm, 250 µm, 500 µm and 1mm—and this will be done for all analyses. A useful derived variable will be percent organic matter (i.e. FPOM/TSS), since this relates to the "food" quality of seston. A paper being prepared on this topic will examine various contexts and drivers for FPOM and DOC concentrations and fluxes, land use, season and drainage network density and baseflow hydrologic interactions. These will be put into an ecological context and discussed in terms of the urban engineered stream continuum (UESC).

Fine particulate (FPOM) and dissolved organic matter (DOC): stormwater concentrations, size fractions and fluxes in the urban landscape. This work draws on the focused stormwater hydrograph sampling (ISCOs) from three intensive sites (Dead Run, Baisman Run, Gwynns Falls at Gwynnbrook), and Gwynns Falls at Villa Nova, for the fall of 2007. The same constituent parameters were done as above, but without fractioning by size. Many of the DOC samples are still to be analyzed. A paper being prepared will examine various contexts and drivers for FPOM and DOC concentrations and fluxes, land use, season and drainage network density and baseflow hydrologic interactions. These will be put into an ecological context and discussed in terms of the urban engineered stream continuum (UESC). This paper, will, however, focus on smaller time scales and examine stormwater runoff dynamics in terms of flow rate and hydrograph position; baseflow and seasonal hydrologic interactions; and potential effects on annual loads.

These papers are being prepared using synthesized information from the literature, and from data collected the last three years during baseflow and storm runoff in LTER streams, including FPOM (fine POM, various particulate organic matter types and fractions), CPOM (Coarse POM), DOC, C, and N. All data is being analyzed in a hydrologic context and is being integrated with unit value and daily value US Geological Survey (USGS) flow data.

4. ***Pathogens: E. coli.***

Work continues on two papers utilizing data already collected from sampling in BES-US Forest Service (USFS) streams for *E. coli* that continued until May 2008. For one paper, these data are being analyzed in the context of the temperature data collected by USFS, the flow data collected by USGS and ancillary nutrient and cation data produced by the Cary Institute of Ecosystem Studies. The second paper underway is an *E. coli* survival paper describing the long periods *E. coli* 0157 can survive in urban stream waters. This data needs further statistical analysis due to data design change mid-way through the collection process.

5. ***Stream Temperature.***

These almost continuous measurements of stream temperature in ca 20 BES-USFS streams have continued (but with about half the stations being dropped in May 2008 due to USFS budget cutbacks). These data are currently being reviewed and will be analyzed in the context of the flow data collected by USGS and ancillary nutrient and cation data produced by the Cary Institute of Ecosystem Studies. Papers being prepared will examine various contexts and drivers for temperatures and fluxes, land use, season and drainage network density and baseflow hydrologic interactions, put these into an ecological context and discuss them in terms of the urban engineered stream continuum (UESC). It will, however, also focus on smaller time scales and examine stormwater runoff dynamics in terms of flow rate and hydrograph position; baseflow and seasonal hydrologic interactions; and potential effects on annual loads. The final analysis of this data (affecting QC process, programming) has been delayed due to budget constraints.

6. ***Stream Gaging.***

Since 1998, the US Geological Survey (USGS) has operated six stream-gaging stations using full or partial NSF funding that provides part of the base

infrastructure for physical investigations by the Baltimore Ecosystem Study. In addition, USGS operates five additional full-service stream gages in the Gwynns Falls watershed, and thirty other stations in the Baltimore region through funding from USGS and local cooperators.

Under a separate NSF grant, USGS has conducted field investigations to determine flood peaks and selected peak discharges in five small urban, sub-watersheds in the Gwynns Falls watershed. Continuous stage recorders have been operated and maintained at the five stations, and indirect peak discharges were determined at two stations, by survey of high-water marks and cross sections, and computation of flows by use of a step-backwater slope-area computation program.

USGS, in cooperation with US Environmental Protection Agency (US EPA), has continued with an investigation of 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 atmospheric flux monitoring tower. One additional stream-gaging station and a precipitation station are in operation as part of this study. Water levels in 71 wells and piezometers are being measured monthly in two study reaches as part of this work.

USGS also continued to collaborate with the US EPA and Montgomery County, MD to investigate impacts of urbanization on stream ecology in the Clarksburg Special Protection Area in Montgomery County, Maryland. A unique element of this work includes partial operation of three stream-gaging stations by County staff using USGS protocols. BES scientific staff and students are mentored by USGS field experts in standard operating procedures to ensure data quality to meet USGS standards.

7. ***Climate Change.***

Co-PI, Ken Belt, representing BES LTER, is involved in several efforts to establish stream site networks for monitoring climate change. These include 1) a Maryland effort by the Maryland Water Monitoring Council (MWMC), 2) USGS climate change monitoring, and 3) the USFS experimental forest and ranges network. The MWMC Monitoring and Assessment committee is conducting a workshop in September 2009 to establish a network of stream sites (from existing resources) to detect climate change in Maryland streams (and possibly other states.) Ken Belt is communicating with the USGS in conjunction with their efforts to establish a national network (Peter Murdock-lead), and hopefully, to name the Chesapeake Bay watershed as a CORE site. We would like to have urban and, of course, the BES sites included these networks. Ken Belt will be exploring the feasibility of integrating the USFS experimental forests and range networks into these processes so that long term data sets can be used in conjunction with any Maryland data collection and as sites for various kinds of experimental stream work in cross-site comparisons. Although there currently are no "pots" of money available, hopefully these contacts/contexts can be used to revive our long term USFS stream temperature and related work (*E. coli*, litter processing, denitrification, etc.) in grant proposals. In particular, the stream temperature data has potential for supporting in-stream BGC process work and in quantifying the effects of trees in

both upland and riparian on temperature regimes in streams and shallow groundwater. Belt hopes the Maryland network will adopt the idea of getting beyond the "typical" parameters currently being used and add in-stream process and functions to any effort to do long term monitoring of climate change effects on streams (i.e. denitrification, litter breakdown).

8. ***Watershed 263: Ultra Urban Headwater Catchments.***
This work, done in partnership with Baltimore City Department of Public Works, continues with the objective of measuring change in runoff quantity and quality as the watershed restoration activities increase in the WS 263 catchment. Monitoring at the two small urban headwater catchments continues and data is being analyzed to produce a paper which discusses the water quality characteristics of these two ultra urban sites and how they are being used to place into context old, highly impervious sites such as these in terms of other urban and suburban sites and in terms of management issues. In particular the repeated damage by surcharging pipe flows to the ISCo samplers has necessitated that these be withdrawn from the field, and has temporarily ended storm composite sampling. The sites also suffer from inadequate flow ratings and primary devices (flumes). It is hoped that these sites can be included in a grant proposal to allow these activities to resume. A US Forest Service general technical report and a data paper are being planned that will serve as a summary of the methods and hydrology research so far in this catchment. In the meantime the data will be used for various purposes such as for the urban stream work mentioned above, and for modeling purposes. We are also looking for resources to resume the Storm Water Management Model (SWMM).

9. ***Urban Water Cycle.***
Research on urban water cycle includes comparisons of watershed hydrologic response associated with varying patterns of urban development and stormwater management; geomorphology and hydraulics of the urban riparian zone, and the influence of urban infrastructure on flow patterns and residence times in urban streams.

10. ***Methane Uptake in Urban Forests and Lawns.***
We measured CH_4 fluxes monthly from four urban forest, four rural forest and four urban lawn plots in the Baltimore, MD metropolitan area from 2001–2005. Our objectives were to evaluate the effects of urban atmospheric and land use change on CH_4 uptake and the importance of these changes relative to other greenhouse forcings in the urban landscape.

11. ***Urban to Rural Gradients—Comparing Baltimore and Pittsburgh.***
We are characterizing N deposition gradients in urban to rural gradients in Baltimore and Pittsburgh. This involves characterizing the isotopic composition and concentrations of multiple gaseous N species and uptake by vegetation.

Finer scale measurements are characterizing deposition and uptake of gaseous N along a gradient perpendicular to a major highway. This work measures the isotopic composition and concentrations of multiple gaseous N species and uptake by vegetation. Measurements are coupled with CALPUFF modeling of dispersion of vehicular N emissions, atmospheric transformations, and deposition.

In addition, we are characterizing spatial patterns in CO_2 concentrations and isotopic composition of CO_2 and concentrations along urban to rural gradients in Pittsburgh and Baltimore.

12. ***Ecohydrology of Forest and Suburban Catchments.***

This work was co-funded by the BES grant from DEB, an EPA Star Graduate Fellowship, an EPA/Forest Service contract, and an NSF Biocomplexity grant. The topics break down as follows:

- The hydrologic and biogeochemical characteristics and management of parcels, with an emphasis on lawns,
- Distributed hydrologic modeling of forest and suburban catchments, with an emphasis on spatial patterns of land cover, impervious surface and vegetation on runoff production (completed master's thesis),
- Measurement and analysis of nitrogen export from nested, small catchments relative to spatial distribution of land cover, sanitary infrastructure and landscape position.

Distributed modeling of catchment hydrologic behavior was carried out with Pond Branch, the gauged forest control watershed, and a nearby suburban catchment. Two hypotheses were tested:

- Calibrated parameters from the gauged Pond Branch site describing soil and substrate hydraulic properties could be successfully transferred to the ungauged suburban catchment.
- Conversion of lawn to forest leads to a significant decrease of total runoff, and conversion of downslope lawn area to forest will produce greater decreases of runoff than conversion of upslope areas.

13. ***Urban Stormwater Ponds.***

Graduate student Robin Van Meter, with the guidance of Co-PI Chris Swan, is studying pond food webs for her dissertation. In her experiments she is looking at the effect of road deicer/road salt on life in the ponds.

14. ***Ecology of Invasive Species.***

The focus of this research is the three-way interactions among earthworms, soil fungi, and trees. We are testing several hypotheses about how non-native earthworms might alter soil microbial communities and thus plant growth. This year we have collected extensive data on earthworm community composition from experimental plots with different leaf litter treatment. We have also been collecting biweekly data on soil respiration on earthworm exclusion and inclusion plots.

15. ***Wireless Sensor Networks for Soil Monitoring.***

We have expanded our Cub Hill deployment: currently we have 53 motes operating in forest and grass sites. The CO_2 sensors were operating until February 2009, when we had to pull them out due to massive construction at the site. We have redeployed them at our Smithsonian Environmental Research Center study site, where they have been collecting data since April 2009. Summer REU intern Yun Chen analyzed both data sets and presented her results in the August MIRTHE All-Hands Workshop in New York. Another summer REU was involved in developing a

web-based visualization tool for these datasets. This tool is user friendly and can be used by scientists, science classes in middle or high schools and by the public. Co-PI Szlavecz along with collaborators A. Szalay and A. Terzis organized a workshop: "Environmental Sensor Networks" at the Johns Hopkins University in August 2008.

16. ***Soil CO_2 Efflux Measurements.***

Graduate student Lijun Xia has been working on comparing the more traditional chamber method to the continuous gas well method in the lab as well as in the field.

17. ***Response of Forest Soil Properties to Urbanization Gradients in Three Metropolitan Areas.***

We investigated the effects of urban environments on the chemical properties of forest soils in the metropolitan areas of Baltimore, New York, and Budapest. We hypothesized that soils in forest patches in each city will exhibit changes in chemistry corresponding to urbanization gradients, but more strongly with various urban metrics than distance to the urban core. Moreover, differences in parent material and development patterns would differentially affect the soil chemical response in each metropolitan area.

18. ***Long-term Soil Temperature Data.***

Postdoctoral Fellow Julia Savva has compiled and analyzed the soil temperature data collected at the BES permanent plots. She built a model that included land cover type in addition to the traditional air temperature.

19. ***Urban Temperature Patterns.***

BES climate scientists are measuring and modeling the pattern of urban temperatures in Baltimore and surrounding areas.

20. ***BES Host Partnership.***

The Center for Urban Environmental Research and Education (CUERE) serves as host to the field operations of the Baltimore Ecosystem Study, providing lab, office, and meeting space to BES PIs and students as a subcontractor to the Cary Institute of Ecosystem Studies. CUERE's GIS Laboratory provides spatial data analysis services to BES researchers as needed. In addition, CUERE provides BES with an academic link to UMBC, whereby several of the BES PIs serve as adjunct faculty at UMBC, and UMBC faculty and students work on BES-related projects.

CUERE has continued to be instrumental in leveraging the presence of the BES on campus to increase related research activities. In the past year CUERE has received preliminary notification of a new award entitled "Integrating Real-Time Chemical Sensors into Understanding of Groundwater Contributions to Surface Water in a Model Urban Observatory." PI: C. Welty, Co-PIs: S. Kaushal, M. Maxwell, L. Band, P. Groffman, K. Belt, A. Miller, M. McGuire, and J. Duncan. We await the final award letter.

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 the 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.

New and Continuing Activities Addressing Question 3:

1. ***KidsGrow.***

We have continued to develop and provide curriculum and teacher professional development to the Parks and People Foundation KidsGrow After-School Program. In the 2008-2009 school year, KidsGrow was located at two sites; Franklin Square Elementary School and William Paca Elementary School. Approximately 130 students participated in the program at these two highly urbanized Baltimore City Public Schools. Six complete modules from the My City's An Ecosystem! curriculum were taught during the school year, plus the students were engaged in field trips and with classroom visitors including BES scientists Drs. Steward Pickett and Peter Groffman. The students took field trips to Port Discovery Children's Museum, Cromwell Valley Farm, the National Aquarium in Baltimore, the Frederick Douglass Isaac Myers Maritime Park museum, and the Maryland Science Center. Students also participated in the Baltimore Harbor Boat Program and in an overnight experience at Patapsco State Park and Echo Hill Outdoor Science Center. The fall

semester was spent on a rich exploration of urban ecosystems, hurricanes and the urban climate. Students developed an understanding of urban ecosystems by studying their schoolyard and neighborhood ecosystems, investigating the causes and consequences of Atlantic hurricanes and understanding the impact of urban centers on local and regional climates. During the spring semester, students learned about urban habitats, the ecological history of their communities and were engaged in the Ecology of Food, Agriculture and Nutrition module. Through this module, students began to understand where our food comes from before it gets to the grocery or corner store. Students at both schools planted their own schoolyard vegetable gardens and held a Salad Extravaganza at the end of the school year.

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

With the support of the new NSF MSP grant for the Baltimore Partnership for Environmental Science Literacy, we were able to offer four teachers an intensive 6-week research experience during the summer of 2009. Each worked closely with a scientific mentor, developing and carrying out an independent research project. In some cases, the research will continue into the coming school year. The RET Fellows also participated in a 6-week summer graduate course at Towson University. Each Fellow will be participating in school year workshops, and working closely with BES scientists and educators to develop and test teaching activities that build on their research experiences. The four Fellows for 2009 and their projects are listed below:

- Richard Foot, Dundalk High School

Mr. Foot, a science teacher at Dundalk High School, conducted research with mentor scientist, Dr. Andrew Miller a BES Co-PI from the University of Maryland, Baltimore County (UMBC). His 6-week research at UMBC focused on comparisons of stream flow data for multiple storm events across selected stations in the BES region, to determine trends in time of rise, peak and drop in water levels. Mr. Foot also assisted Dr. Miller in researching the geology, flora and water chemistry of the Horsehead Branch (HH), to determine whether HH can be considered as a secondary "semi-pristine" site for the BES stream study. Mr. Foot hopes to introduce his students to stream sampling techniques used by BES. From September 2009 to April 2010, selected Baltimore County high school students from Mr. Foot's classes would accompany BES researcher Dan Dillon on a monthly basis for collection of samples at selected BES sites.

- Carla Guarraia, St. Paul School for Girls

Ms. Guarraia, a science teacher at St. Paul School for Girls, conducted research with mentor scientist, Kenneth Belt, a BES Co-PI from the USDA Forest Service (USFS). Her research took place for six weeks of research focused on learning sampling techniques for the Urban Forest Effects Model (UFORE). She worked closely with Ken Belt, Ian Yesilonis (USFS), and UMBC graduate student Yvette Williams to learn how to set up permanent UFORE plots, sample the plots and input and analyze the data in the UFORE model. She then set up UFORE sampling plots at her school with the intention of teaching her students how to sample these plots, and collect data for use in the UFORE model. Additionally, she developed curriculum that incorporates both UFORE sampling and ecology research methods for three courses she plans to teach this fall.

- Tom Keller, Hereford High School

Mr. Keller, a science teacher at Hereford High School, conducted research with mentor scientist, Dr. Chris Swan, a BES Co-PI, from UMBC. Mr. Keller conducted two research projects this summer. The first was a small, manageable laboratory macroinvertebrate feeding study comparing the ash leaf litter eating capacity of two common shredders, amphipoda and trichoptera. Mr. Keller plans to translate this project, designed to be completed within 4-5 weeks, into his classroom, emphasizing both ecological concepts and experimental design. The other project Mr. Keller is conducting is a longer-term field study in which he assists a graduate student in monitoring the benthic macroinvertebrate assemblages at three stream types; reference, disturbed, and restored sites (those which have had habitat improvement restoration at least 5-10 years ago). This study is intended to provide useful information about overall ecosystem function and ultimately indicate the success of the restoration efforts from several years ago.

- Laura Dailey, Deer Park Middle School

Ms. Dailey, a science teacher at Deer Park Middle School, conducted research with mentor scientist Dr. Roland Roberts from Towson University. Ms. Dailey assisted a graduate student studying chocolate varieties from Trinidad. She performed DNA extraction and purification, followed by gel electrophoresis, on each sample. Polymerase Chain Reaction was then used to amplify sections of the DNA that control flavor of the bean or resistance to fungi and disease. Additionally, Ms. Dailey expanded her interest in plant ecology by assisting UMBC graduate student Yvette Williams and Cary Institute of Ecosystem Study summer REU intern Erica Tauzer in sampling vacant plot vegetation. Ms. Dailey learned plant identification, techniques for setting up permanent vegetation plots and extensively studied the geology of the physiographic province in which her school is located. Ms. Dailey plans to use her newfound knowledge to develop her school's courtyard into a native plant garden. She plans to start an environmental science after school club to assist with the design, implementation and long term study of the native plant courtyard.

3. ***Towson University Summer Course, Investigating Urban Ecosystems: Research and Teaching Applications.***

In addition to conducting 6-week research projects, the four RET Fellows participated in a 3-credit graduate course called Investing Urban Ecosystems: Research and Teaching Applications. This graduate course, developed specifically for participants in the Baltimore Partnership for Environmental Science Literacy project, met twice weekly for six weeks beginning in late June 2009. The Tuesday session of each week focused on cutting edge science content from BES and related urban ecosystem research. The Thursday session of each week was presented by a science educator and included insights from research into teaching and learning about that week's topic and included examples of effective pedagogy and instructional materials for use in middle and high school classrooms. The four RETs will continue to participate in the Baltimore Partnership by joining the fourteen teachers from the Summer Teachers' Institute for five one-day professional development sessions to be held during the 2009-2010 school year.

4. ***Teachers' Institute.***

Fourteen teachers participated in a summer workshop that represents the first portion of a year-long Baltimore Ecosystem Study Teachers' Institute. The workshop, an 8-day professional development program focusing on urban ecology and placed-based teaching methods, was designed specifically for participants in the Baltimore Partnership for Environmental Science Literacy funded by the National Science Foundation. These middle and high school science teachers received training in environmental science research and teaching techniques. They also learned about the project's education research into student thinking and learning. Three days overlapped with the Towson University Summer Course, Investigating Urban Ecosystems: Research and Teaching Applications. On those days, Institute participants joined the four Research Experience for Teachers (RET) Fellows for afternoon lectures by BES scientists and Towson University professors. Overall teacher goals of the Summer Institute included:

- Gaining deeper content knowledge about the key dimensions of environmental science literacy.
- Developing strong ecosystem thinking skills – the ability to apply systems thinking, evidence-based (scientific) thinking, spatial and temporal thinking, quantitative reasoning, trans-disciplinary thinking, and creativity to understand any place as an ecosystem.
- Learning about patterns and challenges in student thinking and learning about environmental science in general, and urban ecosystems in particular.
- Learning about effective pedagogies and teaching resources.
- Gaining an appreciation for the nature of environmental science and inquiry, with specific reference to understanding urban ecosystems.
- Viewing, teaching and learning of environmental science in the context of learning progressions.
- Having increased confidence to teach about urban ecosystems.
- Understanding the benefits and costs of various approaches to teaching environmental science.

These fourteen teachers along with the four RETs will continue to participate in this Partnership during the 2009-2010 school year by attending five one-day professional development sessions. The teachers will develop concrete plans for teaching about the Baltimore ecosystem in the upcoming school year, provide students the abilities to attain positive outcomes in terms of content knowledge, skills, citizenship practices and attitudes towards science and become part of a learning community of students, scientists, teachers, and education researchers in Baltimore and across the nation, that is interested in defining and fostering environmental science literacy.

5. ***Communicating Climate Change (C3).***

In the fall of 2008, BES began a partnership with the Maryland Science Center and eleven other science centers around the country. This collaborative partnership, entitled, "Communicating Climate Change" (C3), is supported by an NSF Informal Science Education grant and uses current research and citizen participation to illustrate local signs of climate change. The C3 project in the Baltimore region will use citizen scientists to gather local temperature data and observe and record the timing of important plant life cycle events such as the bloom times of Black Eyed

Susans. BES scientists, including Co-PI Gordon Heisler (USDA Forest Service), were active in developing protocols for the collection of this data. Co-PI John Hom (USDA Forest Service) gave a presentation on local climate change at the Maryland Science Center on April 25th for the launch event of the C3 project. Additionally on May 9th, BES participated in a community training session for growing and monitoring Black Eyed Susans.

6. ***Education Research: Investigations in Student Thinking and Learning.***

BES is a partner in an NSF MSP-supported project that is developing a comprehensive framework for environmental science literacy. The project is a collaboration headed by John Moore (Colorado State University) at the Short Grass Steppe LTER Site, and includes Andy Anderson (Michigan State University) at the Kellogg Biological Station LTER site, Allison Whitmer (Georgetown University) at the Santa Barbara Coastal Ecosystem LTER site, and a number of other colleagues at colleges and universities across the nation. This project is allowing us to conduct significant, long-term and large scale (across sites) research about how students think and learn along key strands of an environmental literacy learning progression.

7. ***From Yardstick to Gyroscope: Interdisciplinary Methods for the Long-Term Study of Social-Ecological Systems.***

We taught a distributed course in collaboration with CWT LTER (University of Georgia), FCE LTER (Florida International University), and CAP LTER (Arizona State University).
http://coweeta.ecology.uga.edu/ecology/web_learning/intro2009.html

We have received funding from NSF to convene a week-long meeting this October at Harvard Forest to convert the presentations and discussions into book chapters. We have funding for ~40 participants, divided between academics and students who took the course. Students will be included as authors.

8. ***Project BLUE (Baltimore Lessons in Urban Ecosystems).***

Project BLUE (Baltimore Lessons in Urban Ecosystems) is an urban environmental education program that focuses on Baltimore City from an ecological perspective. Collaborating to create an urban environmental curriculum for Baltimore City middle school students are partners including the Parks and People Foundation, Inc., the BES Education Program, the US Geological Survey MD-DE-DC Water Science Center, and the US Forest Service.

Project BLUE provides enriching experiences for middle school students to connect them to the natural world and help them understand how communities depend on natural resources such as clean water, healthy soil and clean air. Lessons are grounded in science and make cross curricular connections to math, reading, social studies, arts, and community service. Project BLUE has a pre-career focus where students are exposed to career possibilities in the natural resource management field. Students engage in hands-on lessons pertaining concepts such as tree planting and maintenance, soil and water testing for key nutrients and pH levels, the health of the Chesapeake Bay, bed gardening, and public speaking skills.

Additionally, the students are exposed to green careers by working alongside soil scientists, water quality engineers, and community organizers.

During January-May 2009, Project BLUE After-school Environmental Science Education Program was implemented at Franklin Square Middle School and Bluford Drew Jemison STEM Academy. Urban Ecology learning modules focused on hydrology, the atmosphere and soils. Prior to and after each module the students were given assessments to gauge the attitudes in learning. The mode of instruction included lectures, art projects, service learning projects and hands-on activities, which included field trips to different landscapes and museums within the city of Baltimore.

Each school hosted an "open house" in which the community was invited to view the various presentations on soil and water experiments that were conducted by the students during the course of the school year. The presentation included service activities, such as planting trees in the school yard, the effect of pollution in urban watersheds, soil texture, soil fertility and the Earth Day Activity in which the Project BLUE scholars helped the elementary grade students at Franklin Square Elementary School plant seeds using recycled milk cartons and compost.

The open house held at Bluford Drew Jemison STEM Academy (BDJ) included parents, students, teachers and staff. Presentations included posters and demonstrations about the various activities that were conducted during the course of the school year. The activities included investigations about soil texture, soil fertility, soil biodiversity and the water cycle. Several students were recruited to participate in Project BLUE for the 2009-2010 school year.

On May 23, Parks and People Foundation, Inc. and the USDA Forest Service, NRS-8 sponsored a Saturday field trip for the Project BLUE Scholars of Franklin Square Middle School and Bluford Drew Jemison STEM Academy. The group visited the Smithsonian Institution's Museum of Natural History. The main focus of this field trip was to observe the exhibit, *"Dig It! The Secrets of Soil."* The students observed the world of fungi, bacteria, worms, and countless other organisms that were on display. They discovered the connections between soils and everyday life and learned to think about this hidden world in a whole new way.

The Project BLUE scholars also explored other exhibits, including "Written in the Bone," which examines history through 17th-century bone biographies, including those of colonists teetering on the edge of survival at Jamestown, Virginia, and those living in the wealthy and well-established settlement of St. Mary's City, Maryland. The highlight of this exhibit was the all new Forensic Anthropology Lab which is part of the temporary exhibition. In this Lab, the students learned that forensic science is far more mysterious and engaging than forensic fiction seen in television shows such as the CBS "CSI: Crime Scene Investigation." They used real human bones to identify and describe the gender and status of people from the past and draw conclusions about their lives. The focus of the Lab is to help students use the tools and problem solving skills of forensic anthropology to collect and analyze data the way that forensic anthropologists do.

USGS activities in Project BLUE to date have included gathering and sharing urban hydrologic information and education materials (K-12) with other collaborators, reviewing the ongoing Project BLUE curriculum on the hydrologic component, providing recommendations for modifications to that curriculum, and arranging forums to discuss modifications to the curriculum. In particular, the recommendations focus on climate change and the impact it could have on water availability in large metropolitan urban areas in the future, and the need to have citizenry that can make educated decisions regarding water availability and use. Thus, the emphasis of these recommendations is to modify the current hydrologic component of the curriculum to engage inner city and outlying suburban middle school students with an "in-my-back-yard" fundamental understanding of the urban hydrological cycle and its relationship to water use in their homes and local neighborhoods, as well as recognize that their conditions could differ from fellow middle school students in the Greater Metropolitan Baltimore Area.

As a student appointment for the USGS, undergrad student Fawn-Marie Golden facilitates the outreach and education efforts of the USGS MD-DE-DC Water Science Center to the local community. In working on Project BLUE, she has gathered and shared urban hydrologic information and education materials (K-12) with the BES LTER program. The USGS contributes its expertise on the hydrology of the Baltimore region and Fawn is developing ways to implement that expertise into the Project BLUE urban education curriculum. She currently is assisting through FY2010 in the development of middle school curriculum designed to engage inner city and outlying suburban middle school students in the development of an "in-my-back-yard" fundamental understanding of the urban hydrological cycle, and its relationship to water use in their homes and local neighborhoods, as well as that of their fellow middle school students in the Greater Metropolitan Baltimore Area. Fawn-Marie hopes to continue with the USGS on this effort when she graduates with a Bachelor of Science degree in Environmental Science from the University of Maryland, Baltimore County (UMBC).

9. ***Research and Community Engagement.***

Much of our community engagement is facilitated by one of the key BES partner organizations, Parks and People Foundation Inc. They participated in the following projects on behalf of BES LTER:

- Parks and People Foundation, Inc. (PPF) initiated technology transfer to Harris Creek Watershed (Stormdrain 246) with the Baltimore Harbor Watershed Association, Center for Watershed Protection, local government and existing community-based organizations to develop and implement a community survey and restoration plan for 1,100-acre storm drain watershed (Watershed 263) incorporating twenty neighborhoods in Northeast Baltimore.
- PPF worked with the Watershed 263 Stakeholder Council to apply for a grant from the Chesapeake Bay Trust to conduct education and outreach activities including the production of a video. They continue to work with local government and community-based organizations to develop and implement the restoration plan for 900-acre storm drain watershed (Watershed 263) incorporating eleven neighborhoods in Southwest Baltimore to demonstrate

impact of greening strategies on quality and quantity of storm water runoff and quality of life.
- An "Experimental Forest" of 150 trees was planted at Cherry Hill/Reedbird Park by PPF's youth forestry and natural resource training employment program. Middle school youth participating in PPF's Project BLUE (Baltimore Lessons in Urban Ecosystems) maintained, measured growth and took soil samples. High school youth participating in the BRANCHES (Building Resources and Nurturing Community Health and Environmental Stewardship) program were also involved.
- PPF strengthened our relationship with Baltimore City Public Schools System to provide field research experiences to middle school aged youth through Project BLUE (Baltimore Lessons in Urban Ecosystem) in collaboration with US-Forest Service and US Geological Survey (see #8 above).
- PPF continued their involvement with the BES Education Team through the development of assessment tools and curriculum for the KidsGrow and Project BLUE environmental education and science enrichment programs and provided opportunities for BES, CUERE and Forest Service scientists to interact with program participants.
- PPF provided environmental education enrichment for 400 Baltimore City 2nd and 3rd graders participating in the Parks and People Foundation's SuperKids Camp, a 6-week reading enrichment summer program through Project BLUE.
- Co-PI Mary Washington of PPF participated in the 2009 Cary Conference on Effective Communication of Science in Environmental Controversies.

10. ***Building Resources and Nurturing Community Health & Environmental Stewardship (BRANCHES)***.

The BRANCHES program is a 6-week youth force training and educational experience in park forestry management and maintenance for thirty youth ages 14-21. Core activities included work in Baltimore City Parks to remove invasive species, plant and maintain trees, and improve Baltimore's parks and watersheds. A strong emphasis was placed on green career development, providing a resume writing workshop and discuss of available green jobs in Baltimore.

11. ***Maryland Civil Justice Corps***.

This is a 6-week, non-residential summer program for 200 Baltimore City youth ages 14-17 providing job-skill and stewardship opportunities in outdoor conservation projects and recreational opportunities in Maryland State Parks. Crews learned skills related to reforestation, trail maintenance, invasive species removal and outdoor carpentry. Environmental education was provided to offer hands-on lessons on soil science, biodiversity, stream study and tree identification. The program also focuses on career development, with a "Career Day" which provided crew members the opportunity to tour local colleges and universities with traditionally strong science, math and environmental science programs and participate in a career awareness workshop led by local BES scientists and local environmental and community organizers.

12. ***Additional Educational Activities***.

- Spring 2008 - Nine students from Barclay's Gardening Class and their teacher assessed the condition of the recently installed schoolyard trees and garden. The Parks and People Foundation's Environmental Education staff conducted a

two hour workshop including a habitat survey using a map and key developed by the students. Students assessed the health of trees and recorded conditions and resources.

- Parks and People Foundation Environmental Education staff partnered with BES scientists, US Forest Service, URBANtells (http://urbantells.net) at the University of Maryland, Baltimore County and Hooked on Nature to review Schoolyard Habitat & Education Program (SHEP) lessons, participate in activities and assess student achievement as it related to relevant Maryland Voluntary State Science Curriculum.
- Fall 2008 - The Parks and People Foundation's Environmental Education staff and a US Forest Service soil scientist conducted a workshop at an all Barclay EMS faculty meeting. The workshop focused on the importance of using the schoolyard as an outdoor classroom. Part of the workshop took place in the schoolyard where teachers visited stations that offered ideas for using the natural environment to teach across the curriculum.

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/Greening Celebration***.

Formal public outreach is 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. Attendance at the Annual Meeting and Open House has been approximately 100-150 people in the last several years. The evening Open House is held annually in conjunction with the Parks and People Foundation's Annual Greening Celebration. Over time, the number of attendees at these functions has grown. At the 2008 Greening Celebration and Open House, the Parks and People Foundation and the Baltimore Ecosystem Study were personally recognized by Mayor Sheila Dixon, who also presented awards to individuals and groups for their local community gardens.

Additional Research Meetings held during the year focused on the upcoming BES renewal. The topics covered were: Environmental Change & Environmental Inequity; Land Change Scenarios and Locational Choice Modeling; New Hydro-Ecological-Social Theory; and Integrated Sampling Strategy.

2. ***Educational Outreach.***

Many of the educational items previously covered in this report can also be considered outreach, as they bring urban ecology perspectives to important and

often underserved audiences. Beyond our formal work with participating teachers and their students, and the KidsGrow after school program we engage in informal outreach on a regular basis, often in conjunction with Parks and People Foundation programs. During the current reporting period, the Education Coordinator participated in many Parks and People events, sometimes wearing a combined volunteer/BES education hat.

3. ***Field Trips and Tours***.

- Co-PI R. Pouyat organized a field trip with others of the Baltimore-based US Forest Service staff—K. Belt, Q. Holifield and students—to Washington, DC to Senator B. Cardin's office where grad students and techs were able to explain their research and interact with the senator's staff. The group also visited the new soils exhibit at the Natural History Museum where Dr. Holifield explained the various components of the exhibit "Dig It! The Secrets of Soil."
- Co-PIs K. Belt and R. Pouyat participated in a Parks and People Foundation meeting with National Fish and Wildlife, Baltimore City officials, and the WS263 Community Stakeholder Council representative. This meeting included a field visit to the Lanvale storm drain monitoring site and discussion of how urban runoff research can be integrated into environmental improvements in an ultra urban community in Baltimore.
- Field Tour led by Co-PI Ken Belt as part of the June 23rd BES LTER Planning Meeting, "New Hydro-Ecological-Social Theory." It was an "urban hydrology walk and talk" event to various points near Herbert Run that illustrate hydrologic pathways on an urban microscale.
- Co-PI Ken Belt toured Harris Creek watershed outfall areas in Canton (East Baltimore City) with Dr. Ray Bahr, Harris Creek Watershed Association, to discuss potential watershed restoration and educational opportunities in the context of storm drains and underground streams.
- A BES site tour and meeting was held for a group of seven researchers led by Jim Gosz of the University of Idaho. The group was seeking information on the BES experience as an integrated long term research project.
- Maryland Science Center Career Day with the Maryland Science Center, Baltimore. SciGirls Campers, twenty-five girls (ages 11-15), participated. Guest Speakers Day included a panel of female scientists: 1) Marcia Segura, Saturn Mission Specialist of NASA Goddard Space Flight Center; Shubah Barriga, Marine Biologist with NOAA; and Quin Holifield, Soil Scientist with the USDA Forest Service-NRS 8.
- Thirty high school students attended an event at the Civic Justice Corps, Winan's Meadow, Baltimore, MD. This event provided a hands-on learning activity station with emphasis on soil characteristics and the importance of soil testing, soil texture and soil quality.
- A field trip was conducted for high school teachers 24 June, 2009 as part of the CoastLines Project.

4. ***Humane Metropolis Baltimore***.

- Co-hosted the Humane Metropolis-Baltimore Workshop Conference with the Lincoln Institute on June 11, 2009 at the Maryland Historical Society. The workshop provided a means of gathering researchers, graduate students and community leaders in Baltimore for a networking opportunity with natural

resource managers. There was a great deal of discussion that tied into the Baltimore Sustainability Plan and Baltimore City's Tree Canopy goals. There was also a panel on the work of the Baltimore Ecosystem Study. BES members included Co-PIs Buckley, Kaushal, Pickett, and Washington. BES graduate student, Yvette Williams was also on the program. Information about the Humane Metropolis can be found at http://humanemetropolis.org/

5. ***Other Outreach***.

- Co-PI Ken Belt serves on the board of directors of the Maryland Water Monitoring Council (MWMC). His activities with the MWMC are in the context of providing a link to the scientific community to resource managers, in particular as a representative of the USDA Forest Service and the BES LTER. He also serves on the Monitoring and Assessment Committee with respect to initiating a network of stream sites designed to measure the effects of climate change.
- Co-PI Grace Brush participated in the Central Baltimore Partnership which is a coalition of neighborhood, private and public institutions with the objective of increasing investment and improving the quality of life in a section of the city bounded by several institutions of higher learning. Her involvement is to organize projects where undergraduates can be involved in improving the quality of life of the people who live in this area from planting gardens to building playgrounds, to reducing urban runoff, etc.
- Co-PI Grace Brush is on the Advisory Board of the Center for a Livable Future and the Henry Spira/Grace Project of the Johns Hopkins University School of Public Health.
- Co-PI Grace Brush is on the Advisory Board of the Urban Resources Initiative, Baltimore.
- BES members have worked with city, county, and state agencies to provide critical data and analysis for their sustainability efforts.
- Journalist Dan Rather did investigative report entitled "Conquering the Concrete." He interviewed Co-PI Dr. Sujay Kaushal. As part of the report they conducted field trips in upland watersheds affected by impervious surfaces and cruised along Chesapeake Bay. The episode is available on I-tunes and information regarding schedules for airing can be found at http://www.hd.net/danrather.html. The episode was made available to various environmental organizations in Maryland through University of Maryland Center for Environmental Science. It is also available for environmental groups and outreach efforts.
- Co-PI Larry Band was interviewed on Public Television in North Carolina (North Carolina People, hosted by Bill Friday on Friday, June 12, at 9 PM, and Sunday, June 14, at 5:30 PM http://www.unctv.org/ncpeople/watch_people.html) on water resources and management in North Carolina and the Chesapeake Bay area.
- The high resolution land cover products generated through this year's activities are being used by counties and municipalities in the Baltimore metropolitan region. To assist these community partners we have written reports and conducted webinars in an effort to translate data developed for research activities into information that is useful to decision makers.

- Parks and People Foundation, Inc. aided BES scientists and staff in developing relationships with local public agencies, non-profits, community groups and residents in series of meetings with heads, elected officials and managers.
- Four hundred 2nd and 3rd graders planted trees as part of the SuperKids Camp 2008 at locations across Baltimore City. Students learned about the Chesapeake Bay Watershed water quality and the importance of tree canopy to a healthy environment.
- Parks and People Foundation staff participated in the Urban Ecology Collaborative Third Annual Meeting Working Group, Leadership roles in Restoration Tools.
- Participated in the Working Group and Community Outreach portions of the development of the Baltimore City Sustainability Plan.
- Senior Parks and People Foundation staff, Dr. Mary Washington, serves on the Baltimore Sustainability Commission.
- BES Project Director Pickett testified before the Baltimore City Council committee responsible for recommending the Sustainability Plan for vote by the full Council.
- The Parks and People Foundation conducted community trainings on: Community Grants program opportunities, Capacity building and leadership development in Watershed 263, Rain barrel Construction, and Community Greening trainings in planning and carrying out community restoration projects.
- Co-PI Kathy Szlavecz was the Soil Invertebrates team leader for the Patuxent River Park Bioblitz.
- Co-PI Sujay Kaushal is a member of the Baltimore Mayor's Sustainability Committee Water Working Group. He was also an organizer for the Chesapeake Bay Ecosystem Based Management Session, "Past, Present, Future of Chesapeake Bay Tributaries." He was also a speaker at the Maryland Department of Natural Resources MANTA seminar and Project BLUE Career Day program for urban youths.
- Co-PI Richard Pouyat has participated in teacher training as well as on several local steering committees including: Tree Baltimore, Revitalizing Baltimore Technical Committee, Baltimore County Sustainable Forestry Initiative.
- Co-PI Ken Belt gave a presentation on the development of the organic matter research questions and approaches to the Urban Experimental Design graduate class (GES 622 Research Design for the Urban Environment) at the University of Maryland, Baltimore County on October 4, 2008.
- BES Information Manager Jonathan Walsh participated in several LTER groups:
  2006-2009 – LTER GIS database group: To provide methods of visualizing LTER spatial data online; Theresa Valentine, Chair.
  2008-2009 – ProjectDB: Collaborative programming project to make a synthetic database of LTER projects underway and historic; Margaret O'Brien, Chair.
  2007-2008 – Unit Dictionary Project: To provide a standard dictionary of units for the LTER; Inigo San Gil, Chair.
  2008 – LTER IM Extensible Markup Language (XML) Workshop: To develop the use of XML for data and metadata synthesis and sharing; Kristen Vanderbilt, Chair.
  2007-2008 – Controlled Vocabulary Committee: To develop a standard vocabulary to facilitate a set of accepted keywords for LTER metadata; John Porter, Chair.

Presentations, Posters and Websites Considered Outreach Activities

Presentations

Bain, D.J. 2008. Property and people in proto Baltimore – how do we evaluate the murky past? CUAHSI Summer Synthesis Institute, Massachusetts Institute of Technology, Boston, MA. June 25.

Bain, D.J. 2008. Synthetic historic hydrology: putting the long in long-term catchment research. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD, October 15.

Bain, D.J., J. Bergman, L. Sieple, and M. Bartko. 2008. Rain barrels: understanding urban best management practices at the gutter. Ohio River Basin Consortium for Research and Education Annual Meeting, Pittsburgh, PA. October 30.

Belt, K.T., W.P. Stack, C. Welty, S.S. Kaushal, and P.M. Groffman. 2008. The engineered "karst" of urban landscapes and their constraints on water quality and urban stream ecosystems. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Boone, C.G. 2008. Socioecological Science. Design Challenges and Solutions for Establishing a Network of Socio-Ecological Research Sites, LTER Network Office Workshop. San Juan, PR. December.

Brush, G.S. 2008. Historical land use, nitrogen and coastal eutrophication: a paleoecological perspective. Weekly Seminar Series. Virginia Institute of Marine Sciences, Gloucester Point, VA. November 14.

Brush, G.S. 2008. Historical land use, nitrogen and coastal eutrophication: a paleoecological perspective. Weekly Seminar Series. University of Maryland Center for Environmental and Estuarine Studies. Cambridge, MD. November 19.

Brush, G.S. 2009. Nitrogen from land to water. First Annual Roland Park Lecture Series, Roland Park Presbyterian Church, Baltimore, MD. March 11.

Brush, G.S. 2009. Historical land use and coastal eutrophication: nitrogen matters. Henry Darwin Rogers Lecture and Awards Ceremony. University of Pennsylvania Philadelphia, PA. May 1.

Brush, G.S. 2009. What is Biodiversity? Lecture for BES RET program. University of Maryland, Baltimore County, Baltimore, MD. July 7.

Buckley, G.L. 2008. Baltimore's urban forest: a century of change. Miami University, Oxford, OH. October.

Buckley, G.L. 2008. Neighborhood improvement associations in Baltimore, Maryland, 1900-1945. Baltimore Ecosystem Study Annual Meeting. Baltimore, MD. October 15.

Buckley, G.L. 2009. Race, class and environmental justice: the role of neighborhood improvement associations in Baltimore, Maryland, 1900-1945. Center for Environmental History, University of Stirling, Stirling, Scotland. May.

Buckley, G.L. 2009. Why study past places and events? Lincoln Institute of Land Policy and the Humane Metropolis. Maryland Historical Society, Baltimore, MD. June 11.

Cadenasso, M.L. 2008. Understanding heterogeneity of complex urban landscapes: opportunities for improving ecological and social resilience. Cornell University, Ithaca, NY. October 21.

Chen, Y., C. Jayaprakash, and E.G. Irwin. 2009. A microfoundation model of exurban land development patterns. Selected paper. Regional Science Association International Annual Meeting, San Francisco, CA. November 18-20.

Costanza, R. 2008. Understanding, modeling and valuing ecosystem services. Invited plenary speaker. EPA Ecosystem Services Science Workshop, Portland, OR. August 12-14.

Fisher, K.R., and D.J. Bain. 2009. Metal dynamics in a restored Pittsburgh stream. National Conference on Undergraduate Research, LaCrosse, WI. April 16.

Grove, J.M., K. Dow, S. Murdoch and C.G. Boone. 2008. Why am I in this basket and where are we floating? A longitudinal analysis of household characteristics in Baltimore's floodplains: 1950-2000. Baltimore Ecosystem Study Annual Meeting. Baltimore, MD. October 15.

Heisler, G.M. 2009. Urban air temperatures and C3 (communicating climate change). Association of Science Technology Centers. Webinar. May 18.

Irwin, E.G. 2008. Urban-rural land use change in the US. Invited presentation. Tough Choices-Land Use under a Changing Climate, joint German-US Conference on Climate Change, sponsored by the National Science Foundation and the Deutsche Forschungsgemeinschaft (German Research Foundation), Berlin, Germany October 3-4.

Irwin, E.G. 2009. New directions for urban economic models of land use change: incorporating spatial heterogeneity and transitional dynamics. Invited presentation. 50th Anniversary Journal of Regional Science symposium, sponsored by the Journal of Regional Science and the Federal Reserve Bank of New York, New York, NY. April 23-24.

Irwin, E.G. 2009. New directions for urban economic models of land use change: incorporating spatial heterogeneity and transitional dynamics. Invited seminar.

Smart Growth Center, University of Maryland, College Park, MD. April 25.

Irwin, E.G. 2009. Spatial dynamics and economic models of land use change. Invited presentation. Economics of Land Use Change: Advancing the Frontiers, workshop sponsored by the US Environmental Protection Agency, Washington, DC. June 25-26.

Jayaprakash, C., E.G. Irwin, Y. Chen, J.K. Clark, R. McChesney, C. Wang, and D. Wrenn. 2009. Quantifying and explaining spatio-temporal patterns of fragmentation in the Baltimore region. Selected paper. European Regional Science Association Annual Meeting, Lodz, Poland. August 25-29.

Jenkins, J.J., P. Groffman, J. Butnor, A. Holland, M. Cadenasso, J.M. Grove, M. Washington, S. Pickett, R. Pouyat. 2008. Residential carbon: C and N dynamics in a chronosequence of suburban lawns. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Johnson, A.L. and D.J. Bain. 2008. Pittsburgh metal concentrations in annual tree rings. Ohio River Basin Consortium for Research and Education Annual Meeting, Pittsburgh, PA. October 30.

Kaushal, S.S., P.M. Groffman, L.E. Band, and K.T. Belt. 2009. Hydrologic connectivity, climate change, and nutrient delivery to receiving waters. LTER Mini-Symposium, Washington, DC. February 2.

McConaghie, J., M. Lipscomb-Smith, W. Zhou, P. Groffman, L. Band, and M. Cadenasso. 2008. The influence of land cover elements on nitrogen and water flux in small urban watersheds. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

McCormick, M.K., T. Morcol, J. Saunders, K. Szlavecz, and D.F. Whigham. 2009. Direct and indirect effects of non-native earthworms on mycorrhizal fungi. Botany and Mycology, Snowbird, UT. July 25-29.

McGuire, M.P., C. Welty, and M. Sibug. 2008. Using the CUAHSI HIS system for data management: examples and lessons learned from an urban hydrologic observatory. Maryland Water Monitoring Council Annual Conference, Baltimore, MD. December 4.

Miller, A.J. 2009. Lidar applications in urban flood hydrology. NSF Workshop on Studying Earth Surface Processes with High-Res Topographic Data, Boulder, CO. June 15-18.

O'Neil-Dunne, J.P.M. 2009. Object-based image analysis. LTER Network, Phoenix, AZ. February 17.

O'Neil-Dunne, J.P.M., S. MacFaden, K. Pelletier, J.M. Grove, and A.R. Troy 2009. Object-based high resolution land cover mapping: operational considerations. 17th International Conference on Geoinformatics 2009, Fairfax, VA. August 12.

Pickett, S.T.A. 2009. Advances in Urban Ecology: Questions and Lessons from the Baltimore Ecosystem Study LTER. Juanita Greer White Distinguished Lecturer Series, School of Life Sciences, University of Nevada, Las Vegas, NV. February.

Pickett, S.T.A. 2009. Introduction to the Baltimore Ecosystem Study. From Compass to Gyroscope: Interdisciplinary Methods for the Long-Term Study of Social-Ecological Systems. An Internet Course at the University of Georgia, University of Vermont, Florida International University, and Arizona State University. March 9.

Pickett, S.T.A. 2009. Urban ecology and the Baltimore green map. First Annual Roland Park Lecture Series, Roland Park Presbyterian Church, Baltimore, MD. March 11.

Pickett, S.T.A. 2009. Introduction to the Baltimore Ecosystem Study, Long-Term Ecological Research. Lincoln Institute of Land Policy and the Humane Metropolis. Maryland Historical Society, Baltimore, MD. June 11.

Pouyat, R.V. 2008. Biogeochemistry of urban ecosystems. Department of Forestry and Wildlife Resources, Auburn University, Auburn, AL. November.

Pouyat, R.V. 2008. Urban ecosystem services: the good, the bad, and the ugly. Webinar presentation session on Ecosystem Services, Ecological Society of America. Broadcast December 2.

Pouyat, R.V. 2009. Urban ecosystem services: the good, the bad, and the ugly. Department of Biology, University of Louisville, Louisville, KY. January.

Pouyat, R.V. 2009. Long-term studies of urban ecosystems. 4th Annual New York City Restoration Practitioners Meeting, Wave Hill, New York, NY. February 18.

Pouyat, R.V. 2009. Environmental science and public policy. Center for Urban Environmental Research and Education, University of Maryland, Baltimore County, Baltimore, MD. February.

Raddick, J. 2009. Macroscopes: wireless sensor networks for soil ecology activity. National Science Teachers Association (NSTA) National Conference, New Orleans, LA. March 20.

Savva, Y., K. Szlavecz, R.V. Pouyat, P.M. Groffman, G. Heisler. Effects of land use and vegetation cover on soil temperature in the Baltimore metropolitan area. 2008. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 16.

Schwarz, K., S.T.A. Pickett, M.L. Cadenasso, K.C. Weathers, R.V. Pouyat, and I.D. Yesilonis. 2008. Lead in urban residential soils: first steps toward a predictive model. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 16.

Sikora, M.T., E.M. Elliott, and D.J. Bain. 2008. Nutrient input and dynamics in a restored urban stream impacted by mixed sewer systems. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Sikora, M.T., E.M. Elliott, and D.J. Bain. 2008. Nutrient input and dynamics in Nine Mile Run, a restored urban stream. Ohio River Basin Consortium for Research and Education Annual Meeting, Pittsburgh, PA. October 30.

Smith, K. and M. Avins. 2008. Focus on: community-managed open spaces. Parks & People Foundation and Baltimore City Department of Recreation & Parks, Baltimore, MD. June 18.

Smith, K. 2009. Are the public health benefits of community gardens being offset by nutrient (fertilizer) runoff into the Chesapeake Bay? Johns Hopkins University, "Reverse Research Day," Baltimore, MD. March 13.

Smith, K. and J. Nash. 2009. Tree surveying. Parks & People Foundation, Baltimore, MD. May 4.

Szlavecz, K. and A. Terzis. 2008. Life under your feet: a wireless soil ecology network. MIRTHE Summer All-Hands Workshop, Baltimore, MD. August 1-8.

Szlavecz, K., E. Hornung, C. Csuzdi, Z. Korsos, F. Vilisics, P. Solymos, and R. Pouyat. Patterns in urban soil biodiversity: biotic homogenization and urban vicariance. 2008. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 16.

Szlavecz, K. and D. Whigham. 2008. Invasive species effects in the Mid-Atlantic deciduous forest. 2008. Maryland Department of Natural Resources, Annapolis MD. December 12.

Szlavecz, K. 2009. Urban soil fauna and ecosystem services: examples from the Baltimore Ecosystem Study. Invited. Soil Ecology Society Biennial Meeting, Burlington, VT. July 12-15.

Troy, A. 2009. Integrating spatial methods and social research to address watershed processes. Baltimore Ecosystems Study Quarterly Research Meeting, Baltimore, MD. June 23.

Twery, M.J. 2008. The CarbonPlus calculator: a web-based tool for individuals to evaluate and reduce their CO_2 emissions. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Washington, M.L. 2008. Research opportunities in afterschool environmental education and career development. Baltimore Ecosystem Study Quarterly Research Meeting, Baltimore, MD. June 24.

Washington, M. 2009. Community-based service learning in afterschool and summer settings. The After School Institute Network Meeting, Baltimore, MD. March 31.

Welty, C., A.J. Miller, J. Smith, L. Band, K. Belt, R. Ryan, R. Maxwell, R. Shedlock, T. Scanlon, P. Groffman, M. McGuire, N. Crook, P. Larson, and C. Runyan. 2008. Lessons learned in establishing an environmental observatory - the Baltimore experience. CUAHSI Biennial Science Meeting: Resilience & Vulnerability of Natural and Managed Systems, Boulder, CO. July 14-16.

Welty, C., A.J. Miller, J. Smith, R. Maxwell, R. Shedlock, E. Doheny, T. Kerchkof, C. Runyan (presenter), K. Belt, M. McGuire, P. Larson, R. Ryan, N. Crook, M.L. Baeck, S. Kaushal, T. Scanlon, L. Band, and P. Groffman. 2008. The Baltimore WATERS Testbed, 1st International Conference on Hydropedology, Penn State, State College, PA. July 28-31.

Welty, C., P. Larson, C. Runyan, M. McGuire, R. Ryan, N. Crook, A. Bhaskar, A. Miller, J. Dillow, E. Doheny, D. Soeder, and K. Belt. 2008. Subsurface characterization of an urban watershed at multiple spatial scales. 14th Annual Meeting of the Maryland Water Monitoring Council, Linthicum, MD. December 4.

Zhou, W., K. Schwarz, and M. Cadenasso. 2008. Agreement assessment of visual interpretation and digital classification for mapping urban landscape heterogeneity. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Xia, L., K. Szlavecz, A. Szalay, R. Musaloiu-E, J. Cogan, A. Terzis. 2008. Assessing soil CO_2 effluxes using measurements of CO_2 profiles with solid state sensors MIRTHE (Mid-Infrared Technologies for Health and Environment) Summer All-Hands Workshop, Baltimore, MD. August 1-8.

Posters

Heisler, G., I. Yesilonis, K. Belt, R. Pouyat, K. Szlavecz, Y. Savva, P. Groffman, D. Nowak, C. Welty, E. Noonan, H. Ryeol Na, A. Lee, D. Dillon, and B. Caplan. 2008. Center City Baltimore weather observations: opportunities and challenges. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Bayne, E., M. McGuire, and K. Belt. 2008. The gutter subsidy: tree cover proximal to impervious surfaces in the Gwynns Falls catchment. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Belt, K.T., S.S. Kaushal, C.M. Swan, R.V. Pouyat, and P.M. Groffman. 2008. Dissolved organic carbon in streams: fluxes, impervious surfaces, and hydrologic drivers along an urban stream continuum. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Higgins, J.A. and K.T. Belt. 2008. Survival of *Escherichia coli* in stream water. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Lapa-Lilly, P., S. Poole, and C. Welty. 2008. Quantification of hydraulic conductivity of streambeds throughout the Gwynns Falls watershed and surrounding area. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Mayer, P., P.M. Groffman, S.S. Kaushal, and E. Striz. 2008. Hydrology and hyporheic nitrogen biogeochemistry in a geomorphically degraded urban stream. 93rd Ecological Society of America Annual Meeting, Milwaukee, WI. August 6.

Middlecamp, K., E.M. Elliott, and J. Hom. 2008. Isotopic investigations of anthropogenic sources of carbon and nitrogen to vegetation along a road gradient. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Middlecamp, K., E.M. Elliott, and J. Hom. 2008. Isotopic investigations of anthropogenic sources of carbon and nitrogen to vegetation along a road gradient. Ohio River Basin Consortium for Research and Education (ORBCRE) Annual Symposium, Carnegie Mellon University, Pittsburgh, PA. October 29-31.

Middlecamp, K., E.M. Elliott, and J. Hom. 2009. Isotopic investigations of anthropogenic sources of carbon and nitrogen to vegetation along a road gradient. Graduate Student Expo, University of Pittsburgh, Pittsburgh, PA. March 16.

Nilon, C.H. and P.S. Warren. 2008. Modeling bird species distribution and abundance in urban areas: an example from Baltimore. Annual Meeting of the Wildlife Society. November 12.

Poole, S., P. Lapa-Lilly, C. Welty. 2008. Determining values of soil hydraulic conductivity in and around the Gwynns Falls watershed using automated mini-disk tension infiltrometers. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Runyan, C., P. Larson, C. Welty, J. Dillow, E. Doheny, J. Kvech, A. Miller. 2008. Lessons learned from the Baltimore WATERS test bed. Baltimore Ecosystem Study Annual Meeting, Baltimore, MD. October 15.

Websites

www.beslter.org – Main website for the Baltimore Ecosystem Study.

http://beslter.org/perspective/perspective.aspx?action=all-pages&collection=Education – Repository of curricula and other instructional support materials, education-related report and other resources for educators. The BES education webpages were updated in the spring of 2009. An education newsletter was established and is disseminated to the Baltimore education community. Additionally, two Google Groups were established to support the Baltimore Partnership for Environmental Science Literacy, including participants in the BES Teacher Institute and Research Experiences for Teachers Fellows who participated in the Investigating Urban Ecosystems: Research and Teaching

Applications course. These two Google Groups are used for discussion forums and to post resources for the teachers.

http://www.beslter.org/frame5-page_8.html – BES Education newsletter.

http://www.beslter.org/frame5-page_10.html – Provides information for participants of the Baltimore Partnership for Environmental Science Literacy project.

http://beslter.org/biocomplexity-and-habitable-planet.html – Repository of curriculum and instructional support materials for the BioComplexity and the Habitable Planet project.

http://www.besdata.org – The ORS system provides partnering research groups and the broader environmental research community a mechanism to share research and data products on the web.

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

http://his09.umbc.edu/dash/ – In cooperation with the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI), CUERE has also utilized some of the long-term BES data to demonstrate the capabilities of the CUAHSI Hydrologic Information System. CUERE has continued to maintain the Data Access System for Hydrology which provides a map-based data discovery and dissemination system where BES data can be visualized and downloaded. In 2008 the BES stream chemistry and long term study plot soil data were added to this system.

http://his09.umbc.edu/BESOD/cuahsi_1_0.asmx?WSDL – CUAHSI WaterML (http://his.cuahsi.org/wofws.html) web service featuring the BES stream chemistry dataset.

http://his09.umbc.edu/BESoil/cuahsi_1_0.asmx?WSDL – CUAHSI WaterML (http://his.cuahsi.org/wofws.html) web service featuring the BES long term study plot soil data.

http://cuereims.umbc.edu/website/bes – This is a clickable Arc-GIS map which includes BES data collection points. A number of features have been added to the map such as the capability to link directly to monitoring site information and directly download stream chemistry data.

www.lifeunderyourfeet.org – This website is dedicated to various aspects of soil research, primarily to developing sensor networks for soil monitoring. We have been collecting data from several sites, among them from urban forests in the Baltimore Ecosystem Study. The data are downloadable from the web. We are currently working on a section usable for high school science projects.

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/climdb/ – Daily weather data from the BES primary weather station since April of 2000 are posted for free public access on the National LTER database, ClimDB. For comparison, we also post data from two National Weather Service stations, the Baltimore Washington International Airport (BWI) and the Baltimore Downtown station (DMH) at the Maryland Science Center.

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://waterdata.usgs.gov/nwis – Historical data for six stream gaging stations supported by BES and many other stations in or near the study area.

http://waterdata.usgs.gov/md/nwis/current?type=flow – Near real-time streamflow data for five stream-gaging stations supported by BES and many other stations in or near the study.

http://ida.water.usgs.gov/ida/ – Approved instantaneous discharge data for six stream-gaging stations supported by BES and many other stations in or near the study reach are available for downloading at this site.

http://wdr.water.usgs.gov/ – Annual summary of data for six stream-gaging stations supported by BES and many other stations in or near the study area.

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. Note: Website was mentioned on NPR in a radio interview.

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

http://nrs.fs.fed.us/urban/utc/ – Description: Urban Tree Canopy (UTC). First UTC prototype was developed for Baltimore and has now been applied to numerous cities in the U.S. Many of the associated publications focus on Baltimore. The website 1) describes the UTC, 2) addresses frequently asked questions; 3) identifies current UTC cities; 4) lists data requirements; and 5) includes relevant publications and products.

ftp://bcftp:bacounty@towson4.co.ba.md.us/deprm – The Oregon Ridge Park Forest Health Assessment and Forest Management Plan. User name=bcftp, PW=bacounty. The Oregon Ridge Park Forest Health Assessment and Forest Management Plan prepared by Mar-Len Environmental Consultants, with assistance from Co-PI Mark Twery. This report is the result of a DEPRM initiative, in collaboration with the

Department of Recreation and Parks, to address forest sustainability of large forested County-owned lands, using the UDSA Forest Service NED method.

http://www.dnr.state.md.us/forests/programs/urban/urbantreecanopygoals.asp Description of needs and methods for assessing existing and potential Urban Tree Canopy; resources describing general and various specific assessments and UTC goals.

www.parksandpeople.org – Section of the website is devoted to the Baltimore Ecosystem Study and the Urban Resources Initiative.

www.beslter.org/biocomplexity – Used to disseminate curricula and study materials including GIS files and software for the BES Biocomplexity K-12 education program.

www.ecotope.org/projects/global_frag/ – This is a project page for BES REU-supported research on global patterns of landscape fragmentation in anthropogenic landscapes.

http://letters-sal.blogspot.com/ – *Letters from SAL*. This site reports on GIS advances from the UVM Spatial Analysis Laboratory, focused primarily on the Baltimore Ecosystem Study. It includes commentary, preliminary results, and software tutorials.

http://weblogs.baltimoresun.com/news/local/bay_environment/blog/2009/03/icy_dilemma_road_salt_taints_s.html – Baltimore Sun's environmental blog: "Icy dilemma: Road salt taints streams, reservoirs."

http://www.itreetools.org/carboncalculator/entry.cfm – The CarbonPlus calculator is a web-based application for informing the public about their carbon emissions and promoting action to reduce those emissions. See additional detail in the "Contributions Beyond Science and Engineering" Section.

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. ***Park Equity in Baltimore, MD.***

In addition to established methods for measuring distribution of and access to parks, we employed a novel park service area approach that uses Thiessen polygons and dasymetric reapportioning of census data to measure potential park congestion as an equity outcome measure. We found that a higher proportion of African Americans have access to parks within walking distance, defined as 400 meters or less, than whites, but whites have access to more acreage of parks within walking distance than blacks. A needs-based assessment shows that areas with the highest need have the best access to parks but also have access to less acreage of parks compared to low-need areas. Park service areas that are predominantly black have higher park congestion than areas that are predominantly white, although differences are less apparent at the city level than at the metropolitan level. We examined how segregation ordinances, racial covenants, improvement associations, the Home Owners Loan Corporation, and the Parks and Recreation Board created separate black spaces historically underserved with parks. These mechanisms ultimately fueled middle class flight and suburbanization and black inheritance of much of Baltimore's space, including its parks.

2. ***Woody Vegetation.***

The preliminary data from Baisman Run indicates that more water was available for trees from about 1990 to about 2005. The dominant trees for all size classes were tulip poplar and beech.

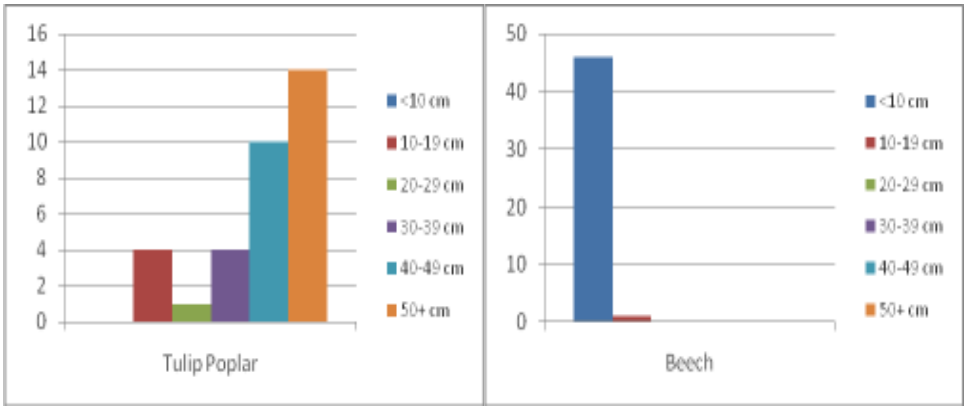


Figure 1. Histograms of the size classes are shown above, where the *y* axis is number of stems.

Below are time series of the patterns of tree growth for both species obtained from tree rings.

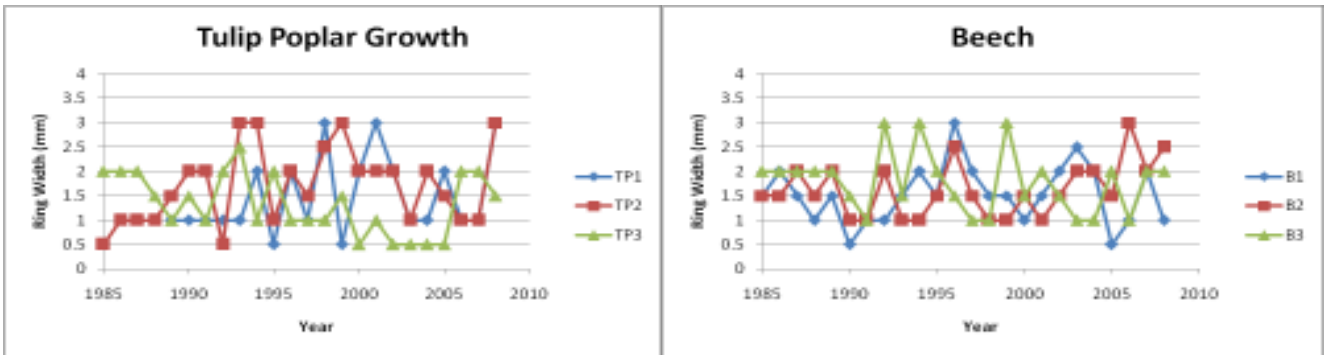


Figure 2. The tree ring cores show 15 years of growth and indicate in both cases, that tree ring growth was greatest in both cases from 1992 to 2000, indicating that during this period more water was available for tree growth. One tree of each species also showed very high growth between 2005 and 2007.

3. ***Forest Successional Studies.***

Summary of studies on forest succession (by Co-PI's Grace Brush and Dan Bain): Random sampling of vegetation in the Gwynns Falls uplands shows that water availability is the predominant factor determining tree species distributions. While some species grow on a variety of soil types, many species are restricted by high or low water availability. Based on regional pollen profiles, the present species composition is similar to that occurring on this landscape over the past 6000 years. However, land use has altered the disturbance regime, affecting the landscape successional mosaic. We propose that as agricultural activity declined in the Baltimore region, beginning about 1900, the first fields abandoned were marginal lands on erodible, steep slopes. In contrast, the flatter less erodible fields would have remained in agriculture for a longer period of time, with afforestation, where it occurred, beginning later. The data summarized in the accompanying table show the relation of successional stage of species with erodibility (the product of slope and soil k factor) and 1992 forest cover within a 0.5 km radius. On average, late successional species occur in plots with higher erodibility and more forest cover, indicating that these areas have been undergoing afforestation for a longer period of time than areas dominated by early successional species which tend to occupy areas of low erodibility and less forest cover.

successional stage (no.spp)	mean (range) erodibility	mean (range) percent forest cover
early (6)	1.05 (0.4-2.1)	0.3 (0.2-0.4)
early to intermediate (5)	1.35 (0.5-1.9)	0.4 (0.3-0.6)
intermediate (6)	1.5 (0.8-2.3)	0.4 (0.2-0.5)
late (18)	2 (0.9-4.4)	0.5 (0.1-0.8)

4. ***Land Cover Analysis and Modeling.***

We found that estimates through the visual approach are fairly accurate. But this accuracy decreases in areas of the Gwynns Falls watershed that are structurally complex. We also found that shape complexity and the spatial arrangement of land cover elements within the patch also make it more difficult for the user to visually assess cover.

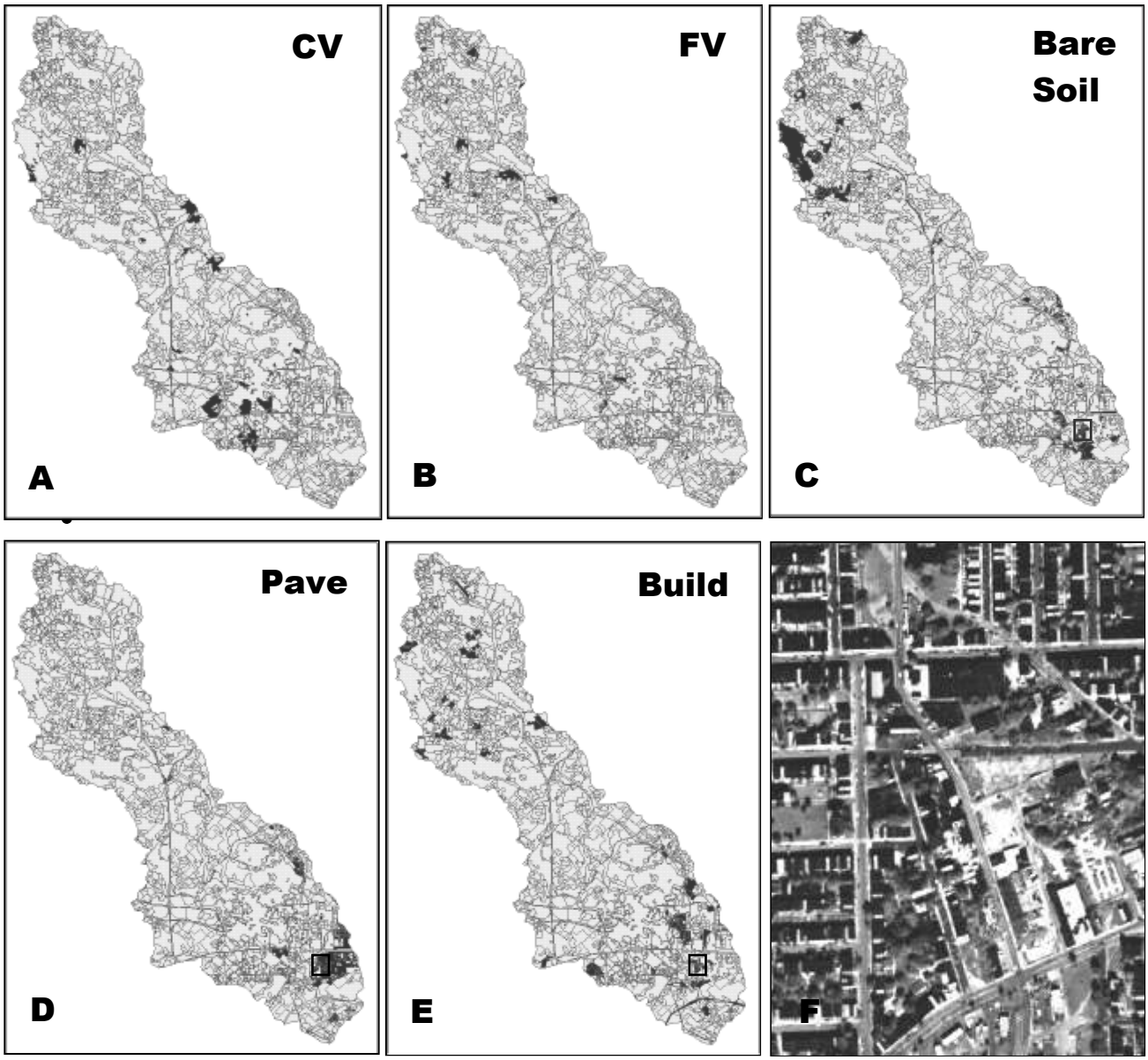


Figure 3. Panel A-E: the "hotspots" of large disagreement that were detected by the local Moran's I index at the 5% significant level for each of the five landscape features. The spatial cluster of patches with large disagreement for bare soil, pavement and building is outlined by the square on the bottom right of the watershed in Panels C, D and E. Panel F shows the striking heterogeneity of the landscape within this box. (Zhou et al. submitted, Landscape Ecology)

The urban climate is a significant factor in the quality of life and health. We found that land surface temperature is high in block groups that have low income, high poverty, less education, more ethnical minority, more elderly people and high crime risk.

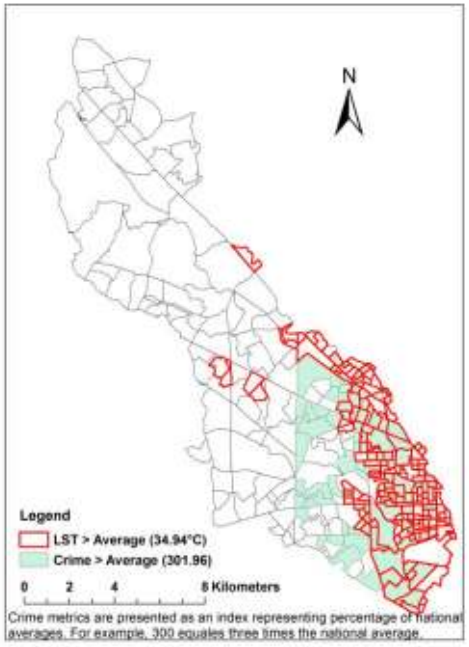


Figure 4. Hotspots and crime risk (Huang et al. in prep).

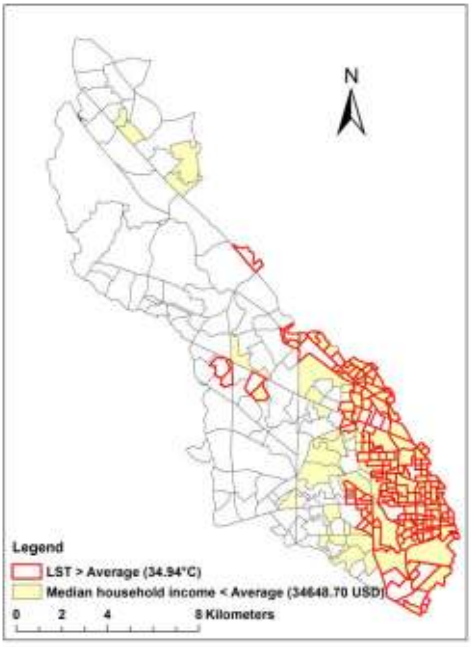


Figure 5. Hotspots and income (Huang et al. in prep).

Forest cover within the Gwynns Falls watershed is dynamic, both temporally and spatially, from 1914 to 2004. The number, size, shape, and spatial distribution of forest patches within the watershed greatly changed over the 100 years. Forest cover became increasingly fragmented even though the total area of forest cover remained largely unchanged. In addition, results from the analysis of change in different distance bands shows an outward shift over time in the location of high rates of forest cover change. Forest cover tends to be more stable in and near urban centers that have been largely developed, whereas forest cover is more dynamic in areas where urbanization is still in process.

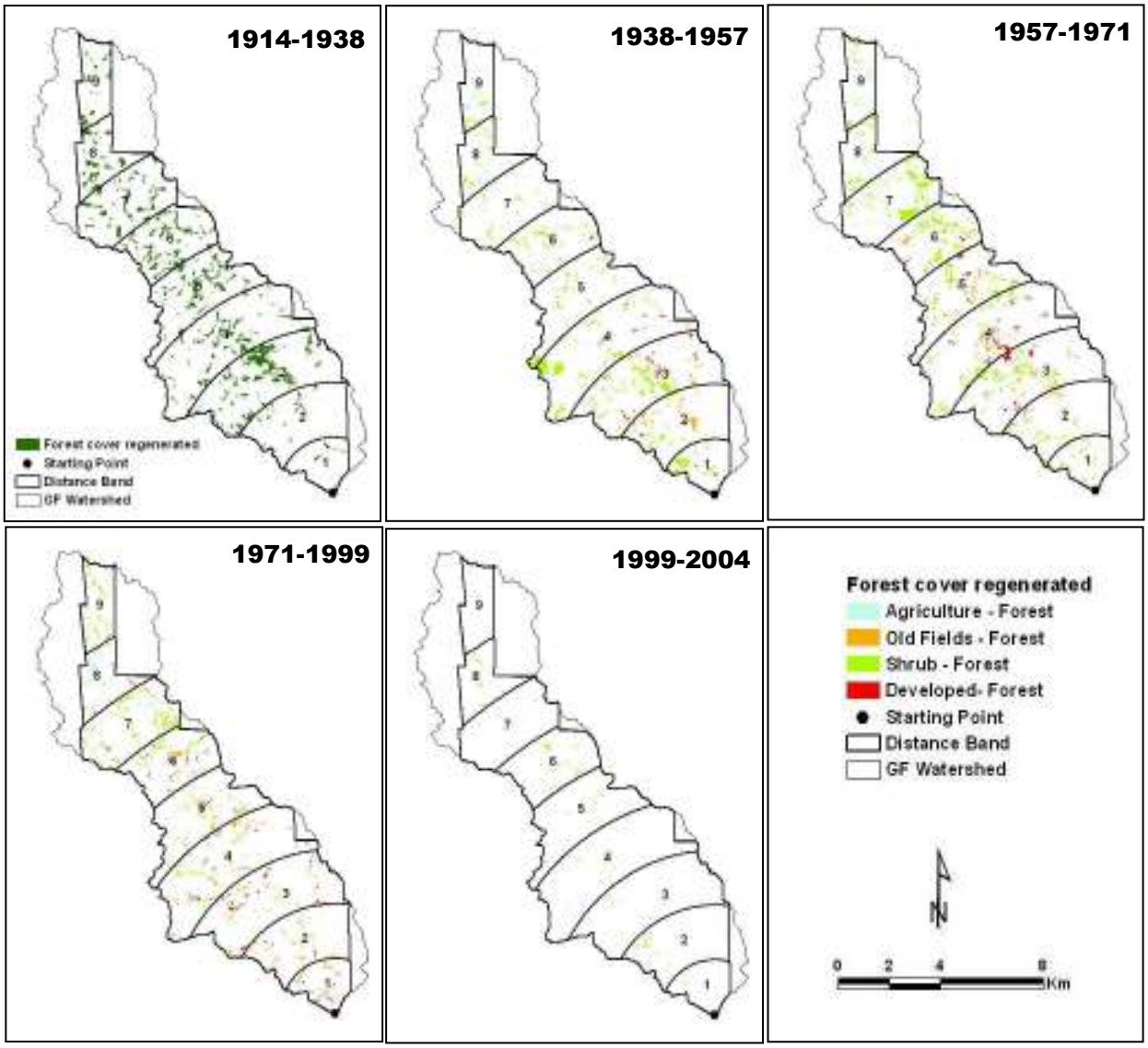


Figure 6. Maps of forest cover regenerated from other types of land cover/use between two time slices from 1914 to 2004 in the Gwynns Falls watershed. Note that the origins of regenerated forest cover between 1914 and 1938 were not identified, since no aerial photos were available before 1938. (Zhou et al. in prep)

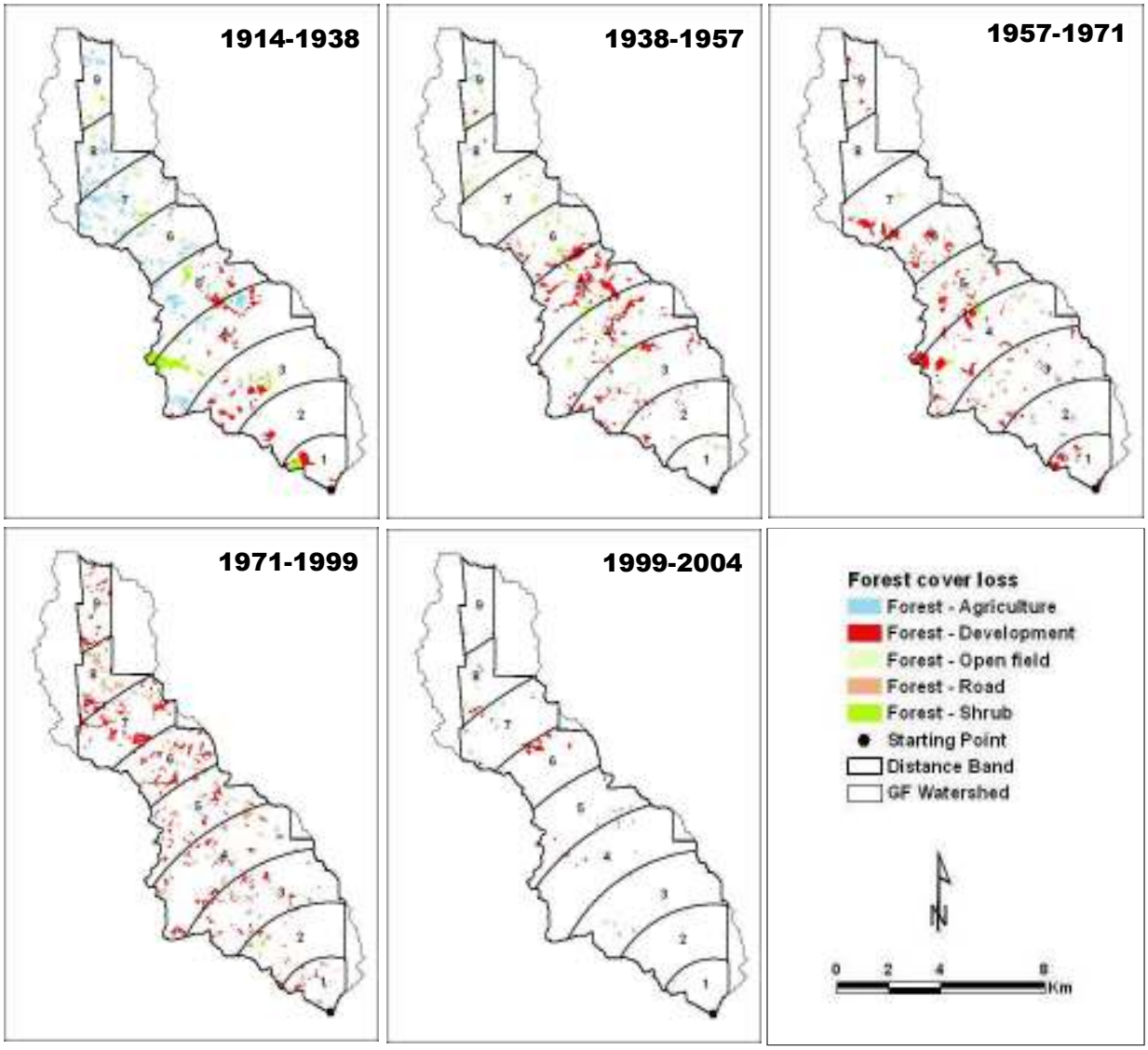
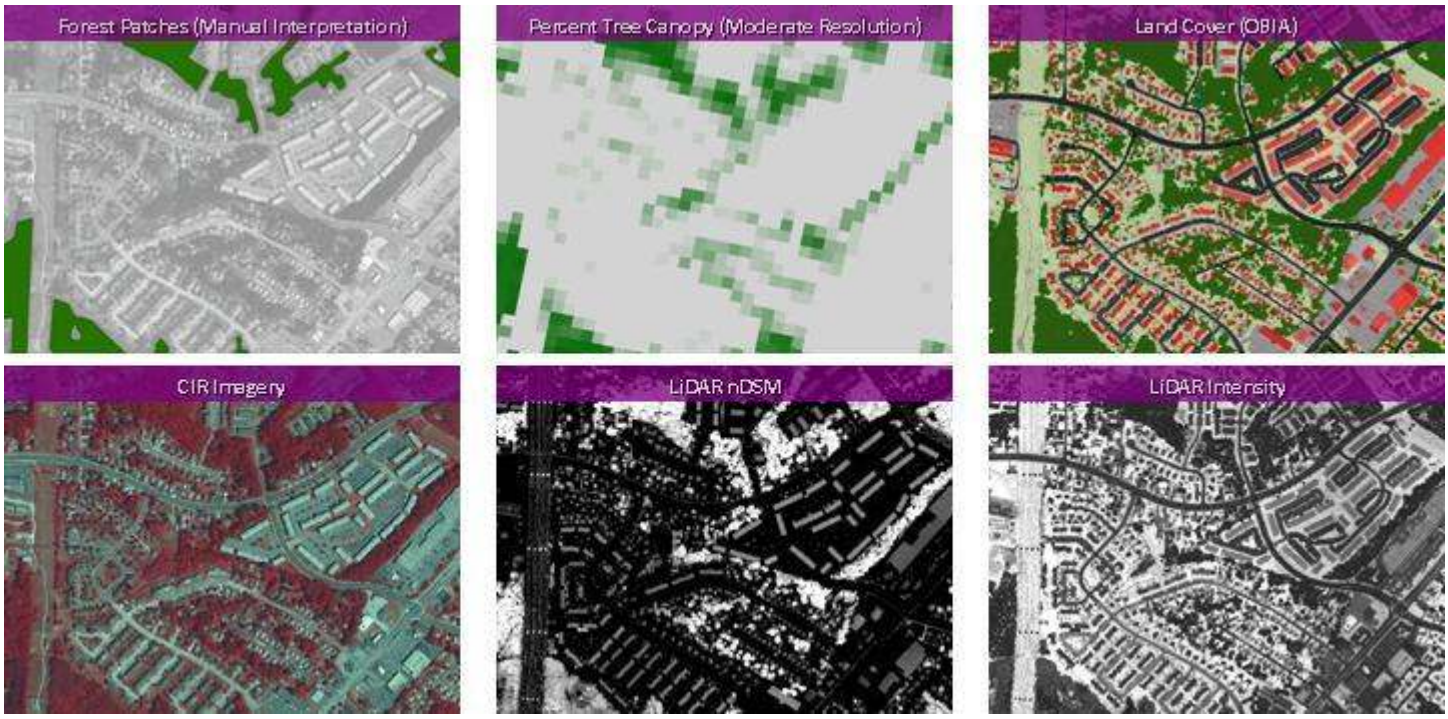


Figure 7. Maps of conversions of forest cover to other types of land cover/use between two time slices from 1914 to 2004 in the Gwynns Falls watershed. (Zhou et al. in prep)

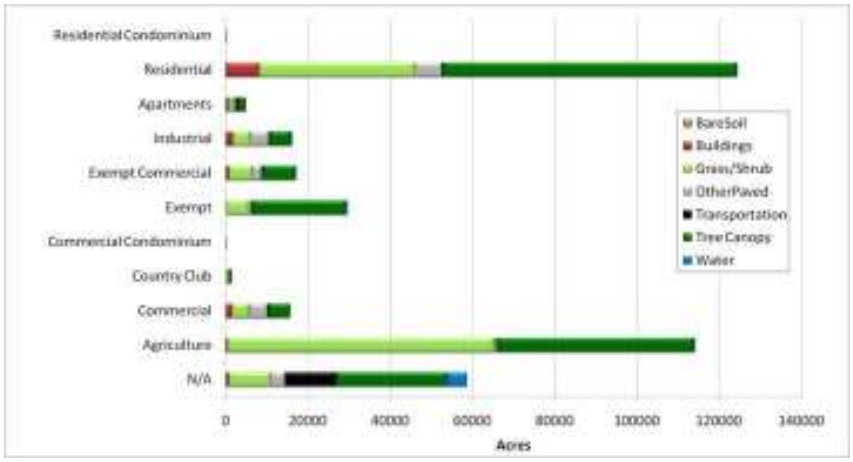
The development of high resolution land cover datasets has brought into question the conclusions drawn using previous lower quality datasets.

Figure 8 below presents examples of the various land cover products and sources of remotely sensed data for Baltimore County. Forest patches derived by manual interpretation (upper left), per-pixel percent tree canopy from NLCD 2001 (upper center), land cover generated by BES (upper right), CIR aerial imagery (lower right), LiDAR normalized Digital Surface Model (nDSM) (lower middle), and LiDAR intensity image (lower right). It is quite clear that the object-based image analysis (OBIA) land cover product generated to support BES research offers the most accurate depiction of the landscape.



These new land cover datasets allow researchers to examine the relationship between land cover and land use.

In Figure 9, below it is the residents in Baltimore County that control the largest percentage of the county's forest resources.



5. ***Land Use Change and Streams.***

- We have documented rising stream and river temperature in the U.S. due to interactive effects of climate change and urbanization (Kaushal et al., in press).
- Land-use change is contributing to increasing sodium and chloride concentrations in suburban and urban streams (Kaushal 2009).
- Interactive effects of land-use change and climate variability amplify nitrogen loads in streams in Baltimore, Maryland and regional changes in N concentrations due to land-use change (Kaushal et al. 2008).
- Watershed restoration efforts focusing on increasing hydrologic "connectivity" between streams and floodplain wetlands influence denitrification rates (Kaushal et al. 2008, Klocker et al. in press).
- Land-use change has contributed to extensive alteration of headwater areas due to stream burial by urbanization in the Gunpowder-Patapsco watershed potentially influencing biogeochemical fluxes of materials and energy from the land surface to receiving waters (Elmore and Kaushal 2008).

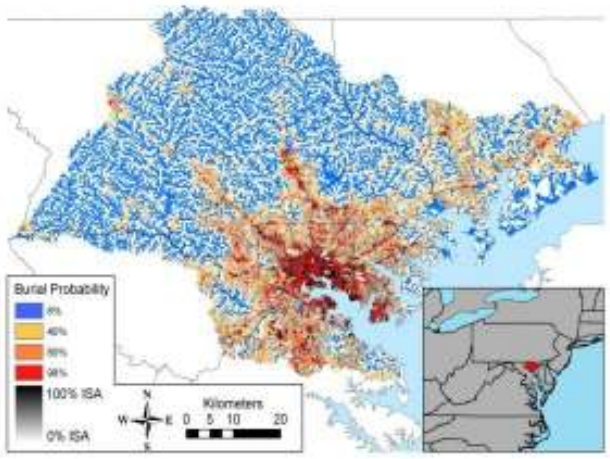


Figure 10. Increases in downstream headwater stream burial due to urbanization may have effects on DOM sources and quality in the Gunpowder-Patapsco watershed of Baltimore, Maryland. (Elmore and Kaushal 2008).

6. ***Descriptive Space-time Analysis of Exurban Development Patterns in Carroll County.***

Adding Carroll County to our detailed research extends our ability to understand dynamics at the urban fringe. Analysis of Carroll County exurbanization patterns illustrate exponential population growth and urbanization since 1970 (Figure 11). Initial investigations of pattern dynamics provide evidence of pervasive "leapfrog" development, i.e., a pattern of development in which new development skips over available areas closer to cities, leaving intervening undeveloped areas and leading to an increased scattered pattern of development. Figure 12 illustrates the timing and location of new development around the central city of Westminster by decade from 1980 to 2009. We find that the largest proportion of new development occurred at intermediate distances during the 1980s and 1990s, but that the innermost ring grew the most proportionately in the 2000s. This provides clear evidence of leapfrogging, i.e., outer areas being developed earlier and inner areas being developed later. We also explored the implications of leapfrog development

for fragmentation patterns. We find that new developed land in inner rings has reduced fragmentation over time, but increased fragmentation in the outer rings (Figure 13). This appears to be largely a function of development "filling up" within a local area over time and thus leading to a more compact pattern. In fact, we find a very strong correspondence between the proportion of total developed land within a local area (as defined by a 210m x 210m cell size) and the proportionate change in the fragmentation of development within that same area. Our findings suggest a fragmentation threshold of about 20% developed land within a local area (again based on a 210m x 210m cell size): on average, areas with less than 20% developed land are growing in fragmentation whereas areas with a developed land base greater than this are declining in fragmentation. In examining the proportion of cells that contain 20% developed land or less in any given time period, we find that this proportion has changed relatively slowly over time. Between 1975-2009, this proportion declined by 32.6% or almost 1% annually. In 2009 the proportion of cells within the Westminster region with 20% developed land or less was 51%. If current trends continue, this suggests that roughly by 2058 fragmentation will no longer be increasing in the region around Westminster. Of course, this ignores price effects and other economic, demographic or institutional changes that should be taken into account when making such a prediction, but nonetheless provides a ballpark estimate of the persistence of fragmentation patterns over time.

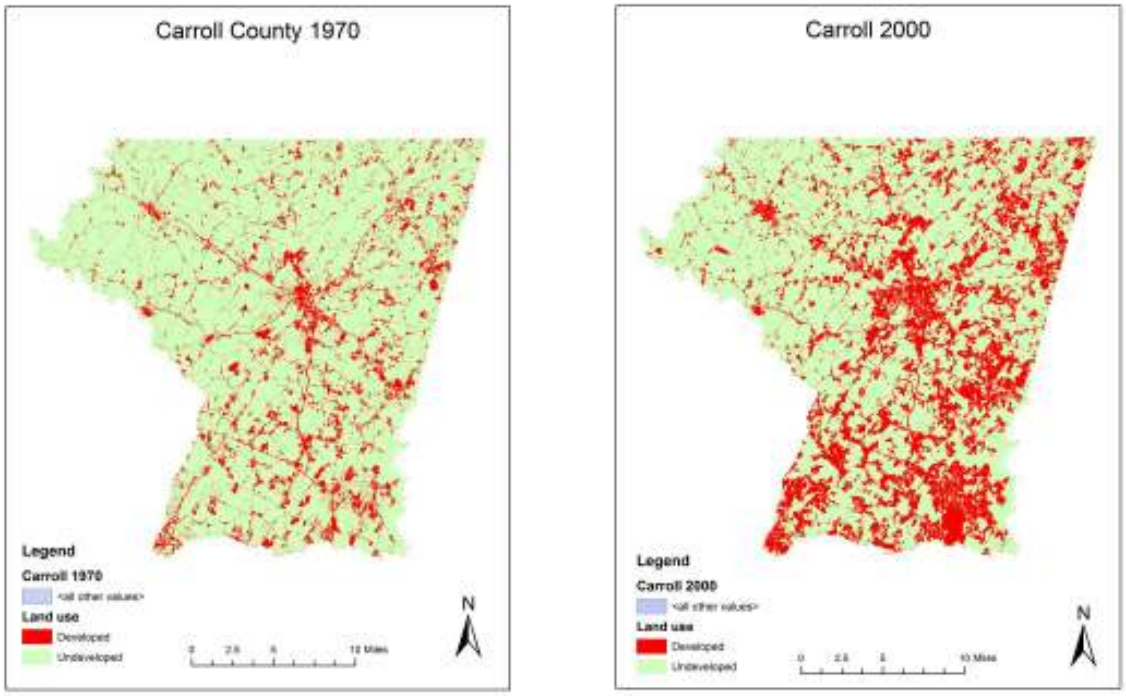


Figure 11: Carroll County urban land use patterns, 1970 and 2000.

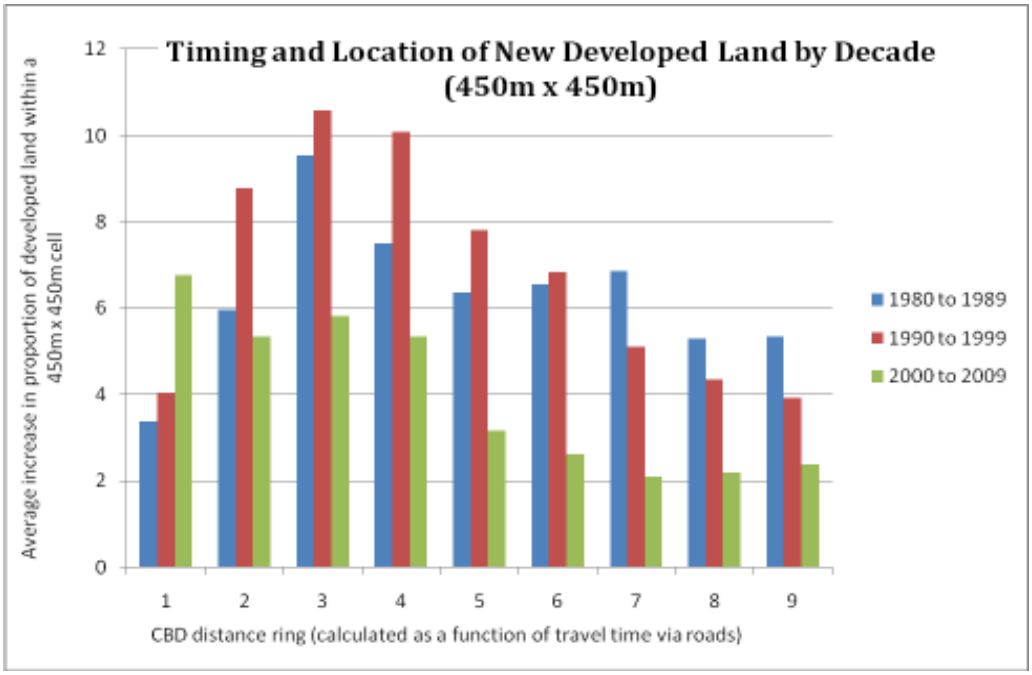


Figure 12: Average proportion of new development across the Westminster urban gradient.

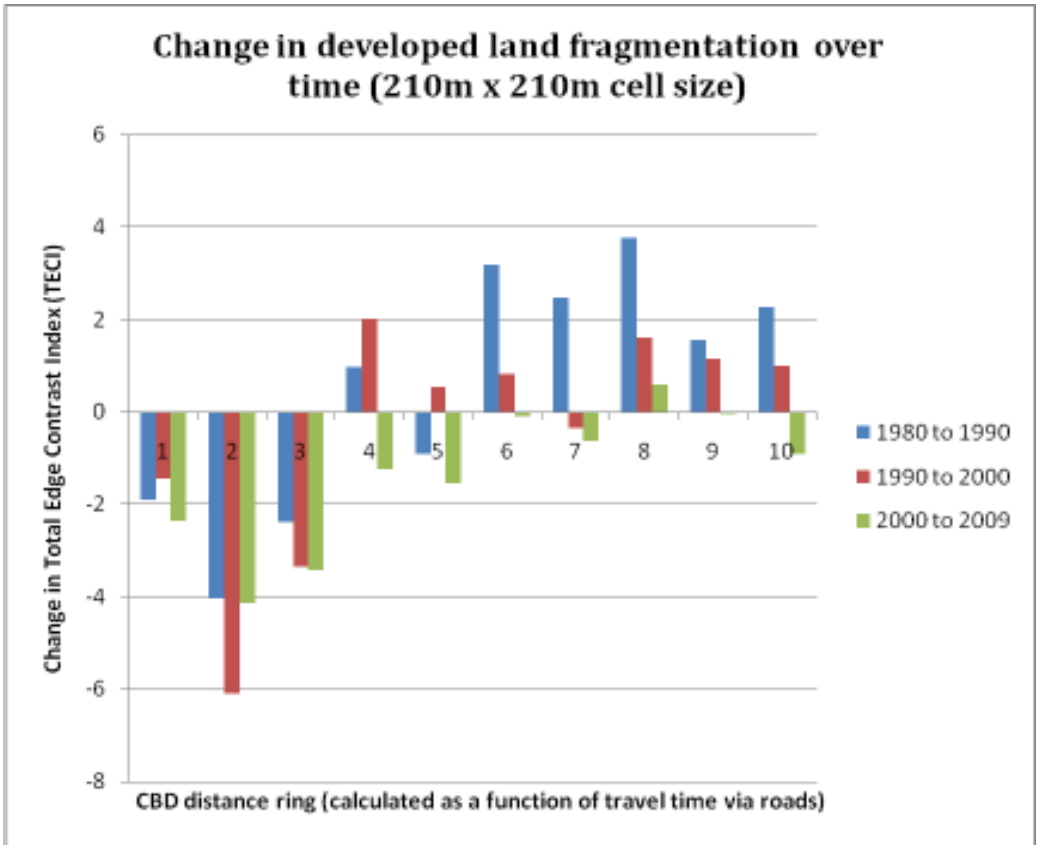


Figure 13: Average change in the developed land fragmentation over time and across the Westminster urban gradient.

7. ***Patterns and Processes of Urbanization in the Baltimore Region.***
Researching the first few decades of the 20th century has suggested processes that may not have been revealed had the study been more contemporary. Current efforts are to obtain early data on transportation, well water and septic systems, and employment type and distribution, and automobile usage to gain insight into how the metropolitan landscape was essentially 'pre-wired' for future development. Spatial data analysis of population indicates early signs of decay in parts of Baltimore City as early as 1910, predating by 50 years the city's 1960 population peak. This also reveals population loss from 1900-1940 in the outer parts of the metropolitan area. Time series of employment data from 1960 to present reveals the evolution of employment centers from a monocentric downtown Baltimore to a polycentric distribution containing over thirty employment nodes exceeding 10,000 employees. Exurbanization began early in the century and grew at an increasingly rapid rate from 1950-2008 (Figures 14-16). Preliminary data analysis suggests that technological process not only resulted in the city influencing its hinterland, but also in the "hinterland" playing a role in the resulting development patterns of the entire region from 1900 to today. For example, we have documented evidence that farmers played an early and key role in purchasing cars and trucks, advocating road improvement investments, and utilizing increased access to the central city to reorganize rural space in such a way as to be receptive to a wave of exurban residential development over fifty years later. This pre-wiring of the landscape, along with a preponderance of obtaining water from wells and providing sanitation from septic tanks, created conditions from which extensive exurban fragmented development could occur.

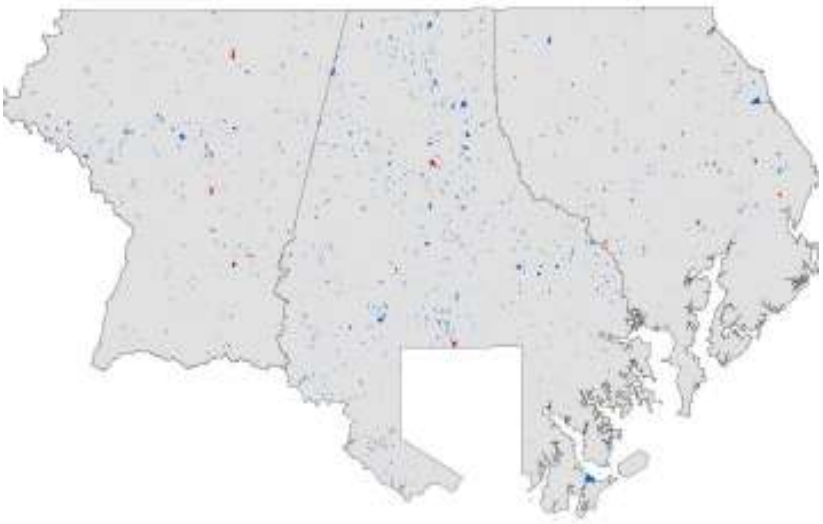


Figure 14: 1900 land development pattern in the northern Baltimore metropolitan region (Carroll, Baltimore and Harford counties) (blue indicates existing residential; red indicates existing commercial).

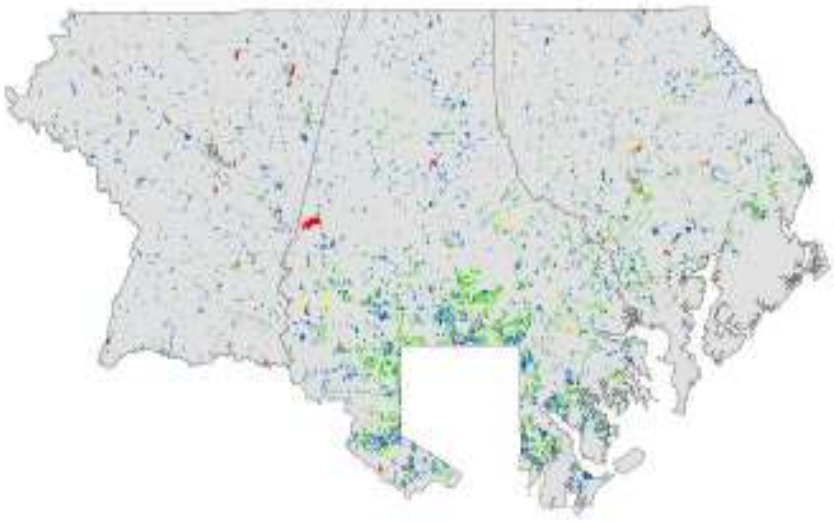


Figure 15: 1960 land development pattern in the northern Baltimore metropolitan region (Carroll, Baltimore and Harford counties) (blue indicates existing residential in 1950; red indicates existing commercial in 1950; green indicates new residential 1950-1959; yellow indicates new commercial 1950-1959).

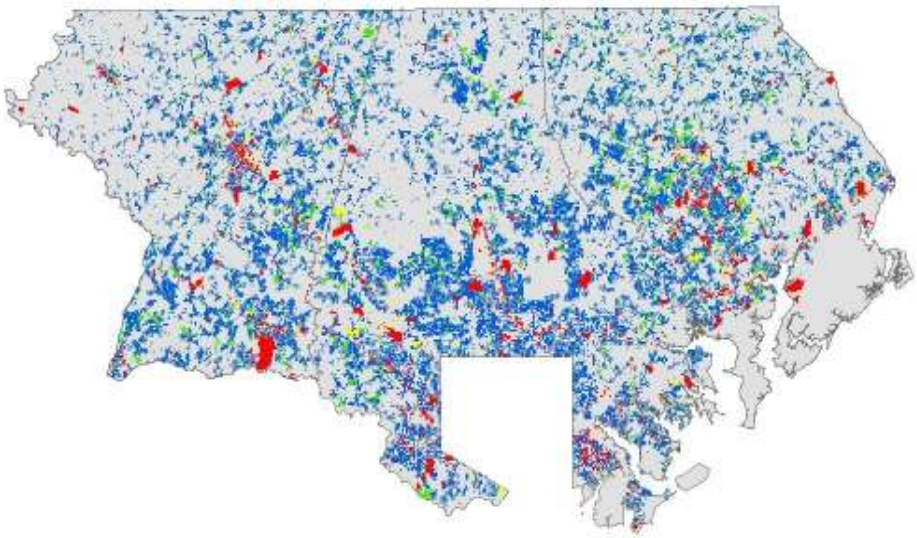


Figure 16: 2008 land development pattern in the northern Baltimore metropolitan region (Carroll, Baltimore and Harford counties) (blue indicates existing residential in 2000; red indicates existing commercial in 2000; green indicates new residential 2000-2008; yellow indicates new commercial 2000-2008).

8. *Microsimulation Economic Model of Land Development with Land Heterogeneity.*

Preliminary modeling shows that the canonical urban economic model is unable to fully explain the observed pattern of land use change, despite the incorporation of preferences for locally varying natural amenities into households' demand for location. The results show that, while our simulation model performs well in predicting the location of exurban development, it is unable to generate the observed land-use patterns (Figures 17-18). On average, 80% of the parcels that were actually developed in 2000 had at least one neighboring parcel that was predicted to be developed by the simulation model at an aggregate scale of analysis (1 km^2 cell size). This is a reasonable model result if we are only interested in the location of development. However, visual comparison shows that the simulated land-use pattern is not as clustered as the real land-use pattern around urban areas and not as scattered in rural areas. Comparison of selected landscape metrics reveal that the simulated land-use pattern differs significantly from the observed land-use pattern in reality (Table 1) and thus, statistically, it is very unlikely that the simulation model can generate the land-use pattern. In general, the simulation model generates too many patches and the patch sizes on average are too small. Extensions of the model will explore alternative mechanisms that have been commonly hypothesized in the literature to explain scattered or leapfrog development, including competing land uses, heterogeneous expectations and preference heterogeneity. In addition, the model will be simulated at a much finer scale of analysis so that local interactions and spatial heterogeneity may be represented.

Real Landscape in 2000

Figure 17: 2000 Carroll County observed urban land use pattern aggregated to 1 km^2 scale (dark indicates location of predominantly developed land).

Simulated Landscape

Figure 18: 2000 Carroll County simulated urban land use pattern aggregated to 1 km^2 scale (red indicates location of predicted developed land).

Pattern of the developed land use				
	NP	Mean area	Total edges	
Data 2000	38	458	353000	
Simulation	47	306	426750	
(std)	(4.4)	(32.1)	(15197)	
	Fractal	PA ratio	Shape index	CE
Data 2000	1.02	33.6	1.18	91.5
Simulation	1.02	36.0	1.23	96.5
(std)	(0.004)	(0.67)	(0.04)	(1.08)

Note:
NP = Number of patches
Fractal = Fractal dimension
PA ratio = Perimeter-area ratio
CE = Contrast edges

Table 1: Spatial pattern metrics comparing the observed and simulated 2000 development pattern in Carroll County, MD.

9. ***Land Cover Assessments—Shadowed Land.***
We have found that a multisource data-fusion technique was the most accurate among three potential methods for classifying land within shadows in remotely sensed imagery.

10. ***Urban Crime Study.***
We found a significant relationship between certain indicators of yard care and neighborhood level crime for parts of Baltimore City and County. We also found a statistically significant relationship between robbery rate and tree canopy cover at the neighborhood scale for parts of Baltimore City and County.

11. ***Effects of Urban Parks on Property Values.***
We found that property values do vary with proximity to parks, but a property's land area and house size provide a strong substitution effect to the beneficial impact of park proximity on property price. Park size and land cover interact with park proximity such that open and large parks increase the benefits to nearby properties (compared to smaller or wooded parks). Neighborhood socio-economic characteristics were not found to affect the park-price relationship.

12. ***Bird Monitoring Project.***
A subset of environmental and social variables, varied at different scales are predictors of bird species composition and abundance.

13. ***Economic Welfare and the Genuine Progress Indicator (GPI).***
Preliminary results are included below in graphs of GPI versus GDP at each of the three scales. The preliminary results indicate that for Baltimore City, Baltimore County, and Maryland, genuine progress has increased across the entire study period, though at decreasing rates since 1980. This is in contrast to a generally steady increase in GDP, suggesting that around the 1980s the environmental and social costs of further economic growth began to outweigh the benefits. This application of the Genuine Progress Indicator provides evidence of diminishing welfare returns to increases in GDP at the sub-national scale. The GPI's inclusion of social and environmental impacts associated with GDP growth provides a more useful measure of overall well-being than GDP itself. The results of this GPI study could stimulate debate at the city, county, and state levels about the nature of the economic development process and how to monitor progress towards sustainability goals.

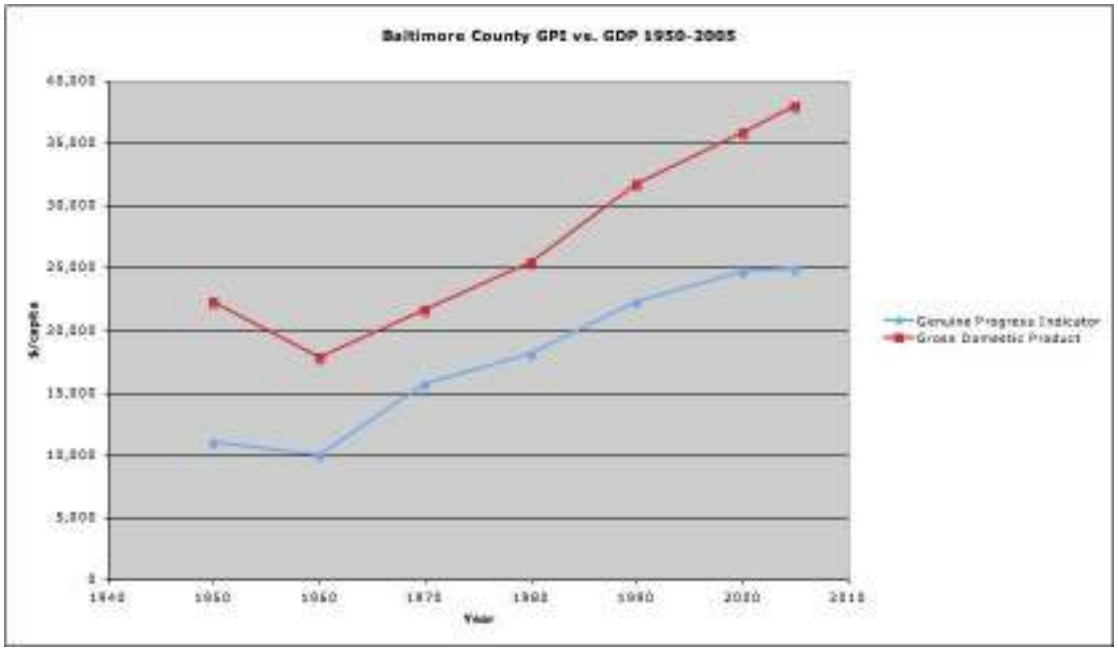


Figure 19. Baltimore County GPI vs. GDP 1950-2005.

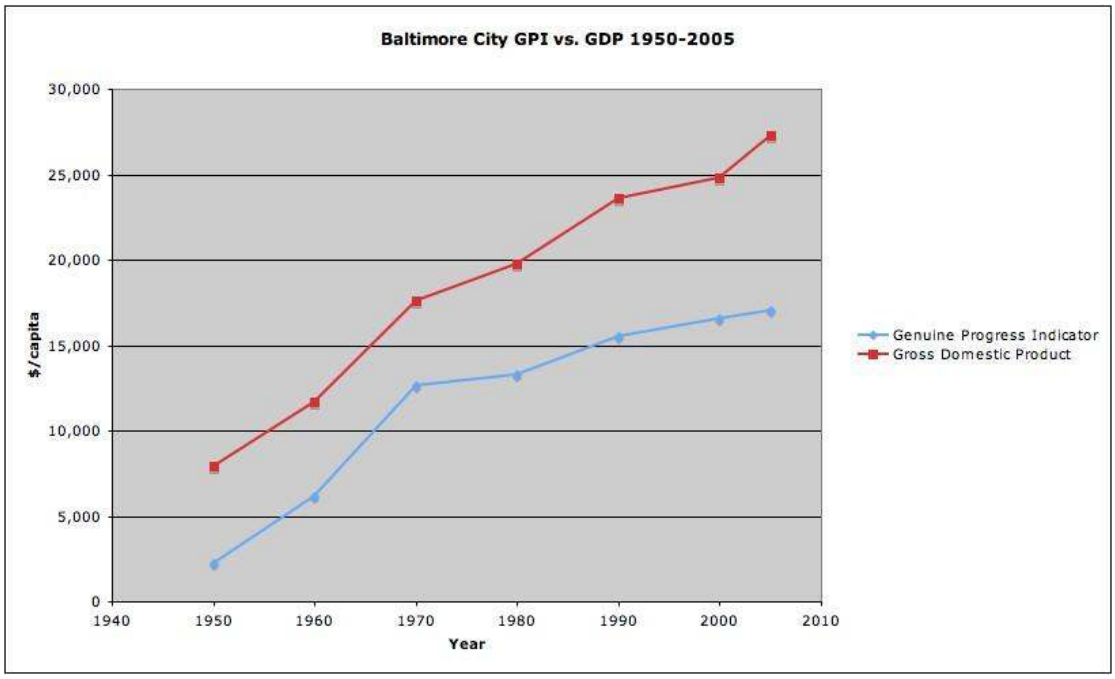


Figure 20. Baltimore City GPI vs. GDP 1950-2005.

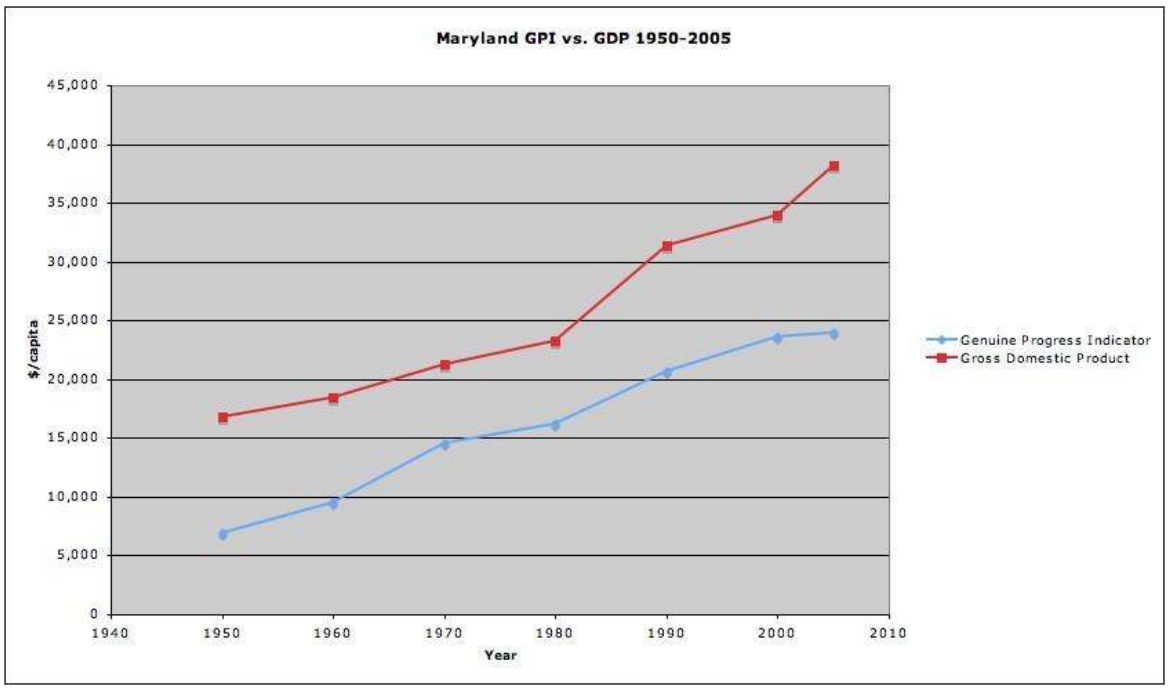


Figure 21. Maryland GPI vs. GDP 1950-2005.

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

1. ***Legacies in Material Fluxes.***

Material flux legacies can be categorized into two types: Signal, e.g., contamination traveling through a very long flow path, and Structural, e.g., one that changes the structure of the watershed, subsequently altering process. Separating a legacy effect from simply the tail of a distribution through time requires a comparison of disturbance duration and effect duration. Simple batch reactor theory can be used to understand legacy theory.

2. ***Organic Matter*.**

DOC and FPOM concentrations in streams were greater in more urbanized catchments and in elevated flows and especially during stormwater runoff events. Urbanized streams export huge quantities of dissolved and particulate organic matter, far in excess of natural catchments. These are likely from multiple sources, as the three component network of urban water systems (water, sewer, and storm drains, i.e. "urban karst") all have different effects on organic matter fluxes. In particular though, the organic matter fluxes deriving from greatly expanded upland drainage networks (gutters etc.) provide very large subsidies (the gutter subsidy) which, through stormwater flows, provide organic matter subsidies to urban streams.

3. ***Stream Temperature*.**

Water temperatures in summer were higher in more urbanized streams; small catchments exhibited a large spike in temperature that did not immediately decline with the cessation of surface runoff, indicating that shallow groundwaters may also be higher in temperature. A significant portion of the summer stream temperature distribution fell outside the tolerance limits of a number of fish species. Buried streams (carried in storm drainage networks) may provide an ameliorating effect, since they deliver cool waters which reduce the effects of thermal fluxes from storm runoff and heat island effects.

4. ***Stream Gaging.***

The primary product is a continuous data stream, published annually, with most station data available in near real-time.

5. ***Pathogens, E. coli*.**

E. coli concentrations are higher in more urbanized streams, but *E. coli* 0157 also was detected in less urbanized catchments suggesting that sources other than leaky sewers may be important. Longer than expected in-situ survival rates of *E. coli* 0157 also suggest that these pathogens are able to survive outside their host bodies and do not die quickly after spending time in aquatic environments.

6. ***Watershed 263, Ultra Urban Headwater Catchments.***

Ultra urban small catchments may be hotspots for the export of urban runoff pollutants (metals, nutrients, BOD, etc.), with concentrations exceeding background and regulatory levels in both baseflow and stormflows. With both high

concentrations and flows (on a per hectare basis) these watersheds likely have extremely high export rates.

7. ***Urban Water Cycle.***

Preliminary findings of work in progress include:

- a critical assessment of stage-discharge relationships at urban stream gages, which in turn have implications for our understanding of flood frequency relationships;
- development of methods for assessing stage-discharge relationships using LiDAR, supplementary topographic data collected with a total station, and application of 2d hydraulic models;
- observations showing that urban infrastructure has a profound impact on longitudinal profiles of urban streams, in turn causing a stepped pattern that induces extremely long residence times at base flow and long pooled reaches at flood stage, with more complex behavior at intermediate flow stages.

8. ***Urban Stormwater Ponds.***

Work by graduate student, Robin Van Meter, is finding that in pond food webs the experimental addition of road deicer runoff, in the form of road-salt, is:

- Indirectly benefiting the size at and rate of metamorphosis of amphibians;
- Indirectly benefiting the biomass of algae (periphyton, phyotplankton);
- Directly reducing zooplankton abundance.

In addition, a recent survey of urban stormwater ponds along a conductivity gradient supports the negative impact on zooplankton. To summarize, a contaminant of rising concern in the region, road salt deicer, seems to influence pond food webs in complex ways, mainly through indirect effects mediated by a change in zooplankton abundance. This suggests that in urban ecosystems (e.g., stormwater ponds) that support diverse food webs, common stressors, applied at realistic levels, result in novel effects on food web dynamics.

9. ***Ecohydrology of Forest and Suburban Catchments.***

Household surveys and measurement of parcel land cover and lawn management practices revealed a set of conclusions:

- Approximately half of all households fertilize their lawns, with half of the fertilizers hiring commercial groups, and half doing it themselves.
- Fertilization rates range from zero to nearly 1000 kg N/ha.
- Peak fertilization rates occur on small lawns of moderate total parcel value. This may be related to the size of the lawn relative to the size of fertilizer bags marketed.
- Lawn fertilization rates are spatially variable with a detectable drift, with trends that are better explained using geographically weighted regressions.
- Lawn infiltration capacities are very variable but can be surprisingly high, with a large overlap with forest infiltration capacities. Well tended lawns have the potential to absorb significant amounts of precipitation and run-on infiltration.
- There are regular variations in infiltration capacity on most lawns dependent on location (e.g. distance from structure and road).

Distributed modeling of catchment hydrologic behavior: Monte carlo sampling of model parameters for RHESSys (Regional Hydro-Ecological Simulation System) using the GLUE methodology produces a family of parameter values that adequately explain both the catchment runoff and the log of the catchment runoff (to emphasize peak and base flows, respectively) for the Pond Branch site. Transfer of the parameters to a comparably sized nearby catchment in low density suburban development produced results (based on limited discharge measurements) similar or better than the model fit in Pond Branch. In particular, runoff was better fit in the suburban catchment as the limited impervious area was more dominant, and is simpler to model than distributed water balance and runoff production in the pervious areas. This has important implications for hydrologic modeling of suburban areas that are ungauged as gauged runoff or other measurements are typically required to successfully model pervious area runoff, but the variety of build out strategies and spatial structures of impervious area and infrastructure is large, and typically ungauged. However, calibrated models using a test "proxy" basin can be used to develop behavioral models of developed catchments that can be used to test the efficacy of different development patterns.

Conversion of lawn to forest: Simulated conversion of all lawn to forest showed significant drops in runoff production, consistent with recent work globally on the hydrologic impacts of pasture to forest conversion. However, conversion of downslope lawn areas to forest showed slightly lower declines of runoff compared to the conversion of upslope lawn to forest on an annual basis. This pattern was consistent for the fall and winter seasons, but was reversed in the summer period when simulated runoff from downslope lawn conversions showed lower runoff than upslope conversion (more effective summertime runoff control). These results were for total volume of runoff; downslope conversion of lawn to forest consistently resulted in smaller runoff peaks. Hence the strategy of riparian buffers show differential results depending on seasons, and the emphasis of BMP control for either volume reduction or peak reduction.

10. ***Ecology of Invasive Species.***

We found that 1) soil respiration was significantly and consistently higher at the high earthworm density site compared to the earthworm exclusion plots; 2) earthworm density was significantly higher (on the average two times) under the tulip poplar subplots compared to the beech plots; and 3) the legacy of selective feeding on leaf litter types by soil macrofauna (primarily earthworms) can be found in the soil.

11. ***Methane Uptake in Urban Forests and Lawns.***

The largest natural biological sink for the radiatively active trace gas methane (CH_4) is bacteria in soils that consume CH_4 as an energy and carbon source. This sink has been shown to be sensitive to nitrogen (N) inputs and alterations of soil physical conditions. Given this sensitivity, conversion of native ecosystems to urban, suburban and exurban managed as lawns thus has potential to affect regional CH_4 budgets. Rural forests had a high capacity for CH_4 uptake (1.68 mg m^{-2} d^{-1}). This capacity was reduced in urban forests (0.23 mg m^{-2} d^{-1}) and almost completely eliminated in lawns (Figure 22). Possible mechanisms for these reductions include increases in atmospheric N deposition and CO_2 levels, fertilization of lawns, and

alteration of soil physical conditions that influence diffusion. Although conversion of native forests to lawns had dramatic effects on CH_4 uptake, these effects do not appear to be significant to statewide greenhouse gas forcing.

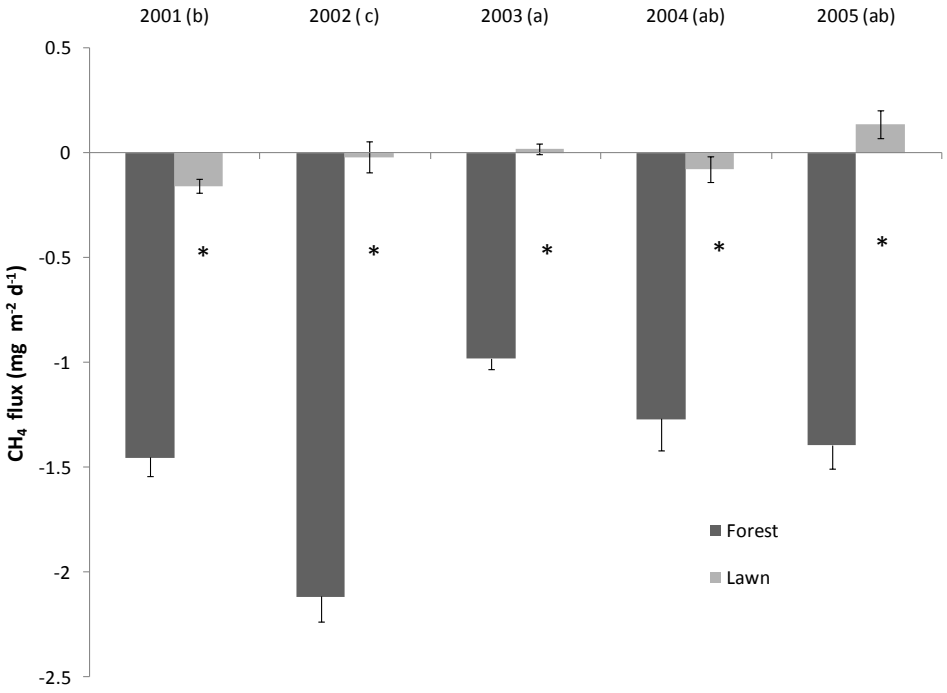


Figure 22. Soil: atmosphere fluxes of CH_4 from forest and lawn plots in the Baltimore metropolitan area from June 2001 to December 2005. Values are means from 3 replicate chambers in 7 undisturbed forest and 4 grass plots. *Indicates significant difference between forest and grass at $p < 0.05$. Years followed by different letters are significantly different at $p < 0.05$, e.g. 2002 is lower than 2001, which is lower than 2003.

12. *Wireless Sensor Networks for Soil Monitoring.*

The second generation mote design performs very well. The installation of the newly developed software, KOALA, allows us to access the data remotely in several sites (JHU campus, Cub Hill, the Smithsonian Environmental Research Center, and, most recently, the Beltsville Agricultural Research Center Farming System Project).

13. *Response of Forest Soil Properties to Urbanization Gradients in Three Metropolitan Areas.*

Results showed that soil chemical properties varied with measures of urban land use in all three cities, including distance to the urban core, which was an unexpected result. Moreover, the results showed that the spatial extent and amount of change was greater in New York than in Baltimore and Budapest for those elements that showed a relationship to the urbanization gradient (Pb, Cu, and to a lesser extent Ca). The spatial relationship of the soil chemical properties to distance varied from city to city. In New York, concentrations of Pb, Cu and Ca

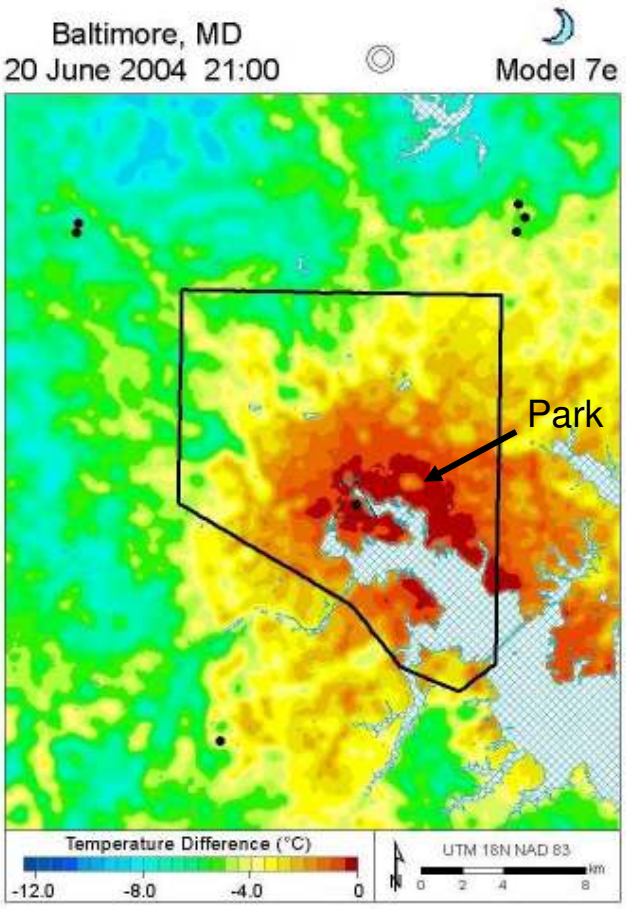
decreased to approximately background concentrations at 75 km from the urban core. By contrast, concentrations of these elements decreased closer to the urban core in Baltimore and Budapest. Moreover, a threshold was reached at about 75% urban land use above which concentrations of Pb and Cu increased by more than twofold relative to concentrations below this threshold. Results of this study suggest that forest soils are responding to urbanization gradients in all three cities, though characteristics of each city (spatial pattern of development, parent material, and pollution sources) influenced the soil chemical response.

14. ***Long-term Soil Temperature Data.***

Average annual soil temperature was higher in urban than rural sites under both turfgrass (15.0°C versus 13.5°C) and forest (12.6°C versus 12.2°C). Application of climate change scenarios predicted by general circulation models (GCMs) to the developed model suggested that the highest increases in mean soil temperature will occur in August, September, February and March and will range from 1.2 – 2.0 °C while the air temperature is predicted to change from 3.4 to 5.6 °C in 2070-2099.

15. ***Urban Temperature Patterns.***

It is well-known that the pattern of air temperature across a city differs throughout a day and with changes in clouds and wind speed. Using regression analysis of temperature differences between weather stations (black dots in figure) as a function impervious cover, tree cover, water cover, elevation, and weather conditions, we were able to map predicted temperature differences in Baltimore. In the figure, temperatures at 9:00PM on a June evening with clear skies and low wind speeds are highest in the center city (dark red) and about 10ºC cooler (blue) in rural areas. The park is about 3ºC cooler than surrounding dense inner-city residential neighborhoods. With cloudy, windy conditions and during the day, temperatures across the area are much more uniform. This methodology is aimed at determining the effects on temperature of landscape changes, such as large scale tree planting.



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 watersheds?

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. ***Education Research: Investigations in Ecology Teaching.***

- Responsive Teaching Study: We now are analyzing the results of two years of intensive professional development with teachers, and research with the teachers and their classrooms.

- The Ecology Teaching Study: Results of the Ecology Teaching Study, described in previous reports, are being included in manuscripts now in preparation.

2. ***Environmental Justice.***

Grad student Andrew Giguere catalogued the role that different citizen organizations—RAM, MAD, SCAR, The Society, etc.—played in opposing the "highway to nowhere." Co-PI Geoff Buckley investigated the origins of Baltimore's asphalt-surfaced playgrounds. Baltimore's Women's Civic League was a key proponent of the use of asphalt to "clean up" derelict lots as early as the 1940s. By the 1960s, neighborhood groups, as well as the city's school superintendent, were voicing their opposition to asphalt playgrounds. The city would not begin replacing asphalt playgrounds until the early 2000s.

3. ***Project BLUE (Baltimore Lessons in Urban Ecosystems).***

The primary product is the development of an urban middle-school curriculum and software training tool for urban middle-school teachers that provides their students an "in-my-back-yard" fundamental understanding of the urban hydrological cycle, and its relationship to water use in their homes and local neighborhoods. The students develop a broader understanding of urban stream ecosystems and how they might vary in the large metropolitan areas.

Contributions

1. ***Within Discipline.***

Research and activities in BES made a number of contributions to the knowledge of urban socio-ecological system structure and function:

- Co-PI Ken Belt introduced and elaborated on 1) the idea of urban stormwater infrastructure drainage density providing a "gutter subsidy" in organic matter and other water quality constituents to urban streams, 2) the idea that older "ultra urban" watersheds contribute even greater pollutant loads than was thought, and that 3) urban hydrologic systems, with their alternate sources of water (potable, sanitary sewage and stormwater) may mimic the function of a "karst" landscape, with dry weather flows contributing to receiving stream impacts as well as stormwater.

- Showed that the transport of organic matter, both dissolved and particulate is highly driven by hydrologic variables and that urban areas may be huge exporters of dissolved and particulate organic matter.

- Showed that older urban catchments may be hotspots for the export of a variety of water pollutants (nutrients, metals, etc) and that many of these may be buried streams that can transport appreciable annual loads during dry weather flows that may exceed those exported during storms (at least in dry years).

- Showed that *E. coli* ecology in urban streams are likely more complicated than previously thought, with these pathogens surviving long periods and possibly being part of a complicated system that not only includes leaky sewers and impervious surface sources as sources for short lived *E. coli* in streams, but likely aquatic refugia where these microorganisms can survive.

- The research on social structures and interactions improved understanding of urbanization dynamics, particularly the role of institutions in shaping human and environmental outcomes in cities. This research will add to urban theory and contribute to the social and natural sciences disciplines represented by this project.

- Forest succession in riparian areas is changing from wetland- to dry-adapted species related to hydrologic changes in those areas, whereas forest succession in the upland areas remains a progression of early successional species to late successional species in abandoned areas. Upland trees growing in riparian areas record dry and wet periods in their tree rings. (Bain and Brush, in preparation and REU 2008 studies.)

- Data collection: The Baltimore metropolitan area of about 2.8 million people comprising multiple counties is studied to model the quantity and quality of urban land expansion. The processes that produce extensive urban development that has a combined pattern of compact central cities, sprawling suburbs, and fragmented exurban patches, are best studied with highly disaggregate data over a long term period of time. However, the vast majority

of land use models use data that is either limited in space (e.g., aggregate data on land use shares at the county level) or time (e.g., spatially disaggregate data that spans a 5-10 year period). We are working to address these traditional data shortcomings by compiling spatially referenced, temporally rich data on land use at the micro scale to study urban development and change.

- Economic Modeling: Most urban economic models of land use abstract from the multiple sources of spatial heterogeneity and local interactions that are known to influence observed land use pattern dynamics. While the assumption of homogeneous land eases the burden of theoretical analysis, it has substantially hindered the development of spatial economic models of land use derived from microfoundations that can incorporate spatial heterogeneity and interactions. On the other hand, empirical models of land use change are able to incorporate any number of spatially heterogeneous variables, but do not provide the needed structural framework for modeling the evolution of land use patterns over time. Empirical agent-based models, in which land use pattern dynamics are explicitly modeled as the result of individual household, developer and landowner decisions, provide a useful modeling approach that can incorporate spatial heterogeneity and interactions. However, economic agent-based models of land markets are still in their infancy and many open challenges to this modeling approach remain. We contribute to this nascent literature by investigating whether the canonical urban economic model of land development, expanded to incorporate household preferences for local natural amenities (e.g., open space), can explain observed evolution of land development patterns in a suburban and exurban region of Maryland. While our model and results are only preliminary at this stage, our work seeks to make a substantive contribution to the development of agent-based land use models that are based on a rigorous treatment of land markets. This is a major methodological challenge that currently separates urban economic models from geographic models of land use and land development.

- The research in characterizing urban-rural N disposition and CO_2 gradients aims to better define discrepancies in spatial patterns of atmospheric N deposition in environments influenced by human activities. Excess N is a critical component in eutrophication of surface water; improving our understanding of deposition patterns is an important frontier for improving water (and air) quality.

- Interdisciplinary contributions to the fields of ecosystems, hydrology, urban environment and human-environment interactions. Development of new methods linking GIS and distributed modeling.

- The bird monitoring work expands knowledge of bird distribution and abundance in cities.

- As a result of the datasets generated this year BES has the most comprehensive, accurate, and highest resolution land cover datasets of any LTER network site.

- The USGS participants in Project BLUE have participated on a continuing basis in the annual scientific meeting, and the appropriate Quarterly BES Science Meetings. USGS participants are also providing leadership in general hydrologic component of Project BLUE development in cooperation with other Co-PIs and collaborators.

- Initiated development of a community ecological perspective of urban ecosystems. This is an important complement to the predominant role of biogeochemical theory in supporting BES.

- Have contributed to knowledge regarding biogeochemistry of urban watersheds and coupled effects of land-use and climate and restoration science.

- Soil Ecology: Species invasion is a global environmental problem, and cities are not only 'hotspots' for species introduction, the urban environment facilitates colonization and spread of non-native species. While there are several studies examining patterns of urban biodiversity in vertebrates and plants, to our knowledge this is the first attempt to synthesize urban soil invertebrate species distribution data. 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. The results of this work highlight the complexity of the biotic interactions between and among species and trophic levels, and the implications for carbon transformations and long term carbon storage in soils. The model based upon the long term soil temperature BES data has the novel element of incorporating land use/land cover information. It can be used for predicting the average daily soil temperature in the Baltimore area for sites with similar hydrological and soil conditions.

- Streamflow data are provided on regular basis and on special request to individual investigators. USGS is providing leadership in general hydrologic investigations in cooperation with other Co-PIs and collaborators.

- A contribution to the discipline of urban meteorology includes the finding that an index of atmospheric stability called the Turner Class is a useful means of categorizing the weather-related factors that determine the intensity of urban island effects.

- Ecological and economic indicators: This work has provided further evidence of the need for better measures of economic, social, and ecological well-being at the national and sub-national scales. The results from the Baltimore GPI study indicate that while GDP has continued to rise over the study period, sustainable economic welfare as measured by the Genuine Progress Indicator has risen more slowly. This builds upon previous studies that have shown economic growth as measured by increases in GDP is subject to diminishing marginal returns on welfare. This local-scale application of the GPI framework contributes to an expanding body of work that uses environmental, social, and economic indicators to explore sustainable development and the often hidden costs of economic growth.

- Development and conservation policy: The GPI study provides information about how changes in environmental, social, and economic conditions have impacted human well-being across a 55 year study period. This information can inform land-use decisions and stimulate political debate about the nature of the economic development process in the Baltimore area. The time-series measure draws attention to critical development and policy issues relevant to the distribution of resources, benefits and costs of production and consumption, and the value of non-market goods and services.

- Ecosystem services and landscape modeling: The development and dissemination of the Multi-scale Integrated Models of Ecosystem Services (MIMES) has contributed to establishing an international standard for ecosystem service assessment, modeling, and evaluation. The workshops offered by Gund Institute experts have provided a foundation for further ecosystem service research in several different countries, while the applications of the modeling methods have revealed opportunities to restore ecological systems and enhance the valuation and protection of ecosystem services in diverse landscapes.

- Human ecology: This work advances the effort to shift human economic activities and decision-making to include a broader ecological perspective. Incorporating human and ecological dimensions into indicators of progress explicitly acknowledges the mutual interactions between the built and natural worlds. Developing and implementing a standardized framework for evaluating ecosystem services (through which humans derive benefits from healthy, functioning landscapes) exposes linkages and opportunities to more closely align human activities with the natural world.

2. ***Contributions To Other Disciplines.***

- The interdisciplinary nature of this work helps to fill data gaps arising from disciplinary focus and tradition. For example, fluvial geomorphologists address total suspended solids and bedload fluxes but do not account for the organic fraction of these. This work seeks to collect both mineral and organic fractions of fine and coarse particulate matter, bridging an important gap. More work in this arena will enable cross fertilization that will enable geomorphologists and stream ecologists to interact more effectively on measuring parameters and processes important to both fields.

- Similarly, the pursuit of the "gutter subsidy" and "urban karst" work provides valuable insight into the complicated nature of engineered urban water systems and their interactions with ecological processes in streams. The melding of traditional stream ecology concepts, such as the stream continuum concept with these complex urban engineered systems (the UESC, or urban engineered stream continuum) provides both insight and opportunity for mutually beneficial collaboration between stream ecologists and engineers and water resource managers.

- Interdisciplinary collaboration is at the heart of BES education work. By integrating education with the BES scientists' work and science with our education work we strengthen both aspects of the project.

- Advances continue to be made in the area of object-based image analysis, specifically overcoming the challenges of integrating very large remotely sensed datasets for automated feature extraction.

- USGS data and products linked to BES are widely used in all disciplines of the geosciences and natural-resources management communities.

- Computer Science: 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 an 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. Our comparative measurements will allow giving more accurate estimates on soil CO_2 fluxes and the effects of land use and land cover on those fluxes.

3. ***Contributions To Education and Human Resources.***

- USFS Web: The USDA Forest Service policy of posting pdf copies of research papers, as well as revamped scientist and unit websites offer increased availability of research results and knowledge to groups which normally do not have access to university or society resources. Similarly the USDA Forest Service's improving and updating of its web based "tree search" feature makes it easy to find publications which have a FS co-author or author, with an immediate link to pdf copies (in most cases).

- Through all of BES education work, from the "My City's An Ecosystem" curriculum for KidsGrow to ecology units for high school students to work with IGERT graduate students, the project contributes to the development of an ecologically literate citizenry in Baltimore, and, potentially, to a new generation of urban ecologists.

- After two years working on Forest Service LTER projects, one research assistant gained sufficient experience in collecting environmental data that she developed the initiative and confidence to pursue a master's degree beginning in fall 2009.

- Developed a 2008 Teacher and Staff "More Kids in the Woods" Workshop and Program Survey.

4. *Contributions To Research and Higher Education*

- Electronic Outreach: Some PowerPoint presentations given by BES researchers are posted on the BES website and this availability provides a resource to researchers, students, community associations and others.

- Co-PI Ken Belt advised and provided data for a Cornell University graduate student, M. McCloud, doing his masters research on a hydrologic model of the Watershed 263 Lanvale watershed, focusing on the effects on water quality of landscape alterations and BMPs.

- Andrew Giguere completed a thesis examining community response to construction of the "highway to nowhere" in Baltimore. Andrew graduated in June and will soon start a Ph.D. in Geography at the University of Toronto.

- For the second year in a row, Co-PI Geoff Buckley delivered the lecture, "Environmental History and Historical Geography: Data and Methods" in support of the on-line course From Yardstick to Gyroscope.

- BES research continues to provide critical examples for lectures by Co-PI Mary Cadenasso in her core upper division undergraduate course "Urban Ecology" at the University of California, Davis. Publications produced as a result of the BES are also frequently included as required course reading. During the past year eleven undergraduates enrolled in the course and represented four majors.

- BES research also provided illustrations of ecological concepts for the lectures in Co-PI Mary Cadenasso's core graduate course "Ecosystems and Landscapes" offered for the first time this year and taken by approximately thirty graduate students from the graduate groups of Ecology, Geography, and International Agriculture. Next year the course will be open to undergraduates; four undergraduates enrolled in it this past year.

- BES research was critical to guest lectures Mary Cadenasso provided during the past year in 1) Introduction to Environmental Horticulture and Urban Forestry, 2) Sustainable Landscape Design, and 3) graduate seminar for the REACH IGERT, System response to rapid environmental change.

- BES-related research findings on the urban water cycle are incorporated in both undergraduate and graduate courses at the University of Maryland, Baltimore County.

- Co-PI Andy Miller hosted high-school teacher Richard Foot this summer who was part of the NSF summer RET program. His experience will be incorporated in his teaching and is expected to lead to further collaboration and outreach involving his students collecting and analyzing data from BES study sites.

- Bird monitoring studies are used in Green Career Ladder and other educational programs in Baltimore.

- The Spatial Analysis Laboratory at the University of Vermont continued to support the community of BES researchers, collaborators, and educators by providing access to socio-demographic, geospatial data sets and cartographic products.

- The USGS MD-DE-DC Water Science Center now resides on the campus of the University of Maryland Baltimore County and its resources are available to students, staff, and other researchers.

- Through the NSF-supported IGERT program, UMBC has made significant contributions to resources for research and education. Thirteen of the nineteen funded IGERT trainees are working with BES Co-PIs as mentors.

- Genuine Progress Indicator theory, methodology, and application to the Baltimore area was discussed in a Fall 2008 University of Vermont undergraduate course titled The Economics of Sustainability.

- The suite of models developed through the Multi-scale Integrated Models of Ecosystem Services (MIMES) project enable research into quantifiable ecosystem services under varying environmental conditions derived from land use change. Research institutes and individual scientists in the field of ecosystem services can utilize the MIMES approach to understand all of the relevant factors that contribute to human well-being through natural, human, social, and built capital. With regards to the Genuine Progress Indicator, research projects that are underway in several other US states applying similar measures of sustainable development can draw upon the Baltimore GPI study for guidance on methods, reliable data sources and management techniques, and comparisons of results. The indicators and ecosystem services research conducted through the Gund Institute directly informs undergraduate and graduate courses at the University of Vermont as well as other institutions of higher education in the United States and other countries (for example, Iowa State University, Oberlin College, New Zealand Center for Ecological Economics, and the Unicamp in Brazil).

Training/Development

- The research has helped to train a post-doctoral fellow (Chona Sister) in project and database management, as well as in the production of published manuscripts. It also helped to train a graduate student (Pei Zhai) in the use of historical documents, geocoding, and GIS database development.

- Students working on vegetation projects have been trained to objectively sample vegetation in the field as well as collect field data.

- Three new graduate students – Michelle Corrigan, Michael Battaglia, and Erin Pierce – initiated their research in support of the BES. Michelle is studying urban gardens, Mike is investigating potential locations for urban tree canopy

expansion, and Erin is exploring the "planning landscape" in eastern Baltimore County.

- HERCULES land cover model is providing training and development for two post-doctoral researchers and one graduate student researchers. One post-doc specializes in remote sensing, GIS, and spatial analysis and he is using this expertise to develop further expertise in landscape ecology theory. The second post-doc is a social scientist and she is working with social and ecological data to investigate the links and feedbacks between the two in an urban setting. Working with ecological concepts and data is new for her. The graduate student has been able to learn basic GIS and spatial analysis skills to add to his hydrologic understanding. Working with HERCULES and the BES data as a springboard, he has developed his dissertation research for the Sacramento metropolitan area.

- HERCULES occupies a central role in the doctoral research of K. Schwarz, Rutgers University.

- Co-PI Mary Cadenasso is working with graduate students and faculty in the community development program at the University of California-Davis to encourage collaborative cross disciplinary research activities on regional change, urbanization of the California landscape, and environmental justice issues.

- We have developed extensive social and ecological data for education, training, and applications. In particular, we have developed hi-resolution landcover data at a parcel level for Baltimore City and County. These data also include attributes such as height and productivity (in the case of vegetation).

- The research in characterizing urban-rural N disposition and CO_2 gradients forms the body of research for MS Candidate, Katherine Middlecamp. Additionally, an undergraduate, Andrew McCarty, was funded by the University of Pittsburgh to assist Katherine with her research.

- Graduate students Hang Ryeol Na and Alexis Ellis learned techniques of computer programming, data management, and geographic information systems.

- Graduate training for Masters and Ph.D. students has been held in ecohydrologic sampling, analysis and simulation; as well as classroom instruction for undergraduate students in courses on hydrology, watershed GIS.

- Co-PI Chris Swan has provided mentoring and training of Ph.D. students Robin Van Meter and Tara Willey. Van Meter is focusing on the consequence of road deicer runoff on urban stormwater pond food-webs. The students are also IGERT trainees at UMBC.

- USGS provides regular development opportunities to its scientists and technicians through its National Training Center, other regional training, and

conference attendance. Cooperators, including BES investigators, are eligible to participate in USGS training programs on a space-available basis.

- Co-PI Sujay Kaushal provided training for four graduate students, two undergraduates, and one postdoctoral research scientist. Also, a new course "Principles and Practices of Ecosystem Restoration" was taught at University of Maryland College Park, which had a module on urban ecosystems. The course was well enrolled by both graduate students and local and state water quality managers.

- The University of Vermont Spatial Analysis Laboratory (SAL) was recognized by the Definiens corporation as their seventh worldwide center of excellence in recognition of the SAL's work in object-based image analysis (OBIA). During this reporting period the SAL provided training on OBIA to other BES researchers and organizations within the LTER network.

- Undergrad student Fawn-Marie Golden, who is a student intern at USGS, is involved with Project BLUE and is learning to develop urban education curriculum.

- Co-PI Ken Belt continued helping with aspects of the new environmental science program at the Baltimore City Community College (BCCC) (field trips, hiring students, providing contacts, advice & information, etc.) working through Hydrology instructor R. Danforth. Conducted Danforth's February 17, 2009 BCCC Environmental Management class (ES 170) designed to facilitate the continuation of their Gwynns Run urban wetland project and preparation for a meeting with Baltimore City DPW (hydraulics, planning, contacts, options, etc.).

- Parks and People Foundation, Inc. implemented the first year of 3-year Schoolyard Habitat & Education Program (SHEP) which combines student-initiated schoolyard habitat installations and professional development workshops at Harlem Park Elementary/Middle, Barclay Elementary/Middle, and Curtis Bay Elementary/Middle Schools. These activities assist teachers in using schoolyard habitats as outdoor classrooms and research sites.

- Provided environmental education and community service learning enrichment for 200 Baltimore youth ages 14-17 participating in the Maryland Civic Justice Corps 6-week reading summer program through Project BLUE.

- Parks and People Foundation, Inc. employed seventeen summer interns to conduct project related to watershed education, restoration and natural resource career development.

- Parks and People Foundation, Inc. provided onsite and staffing support for graduate students conducting vacant lot field studies in Baltimore City.

- Planned, coordinated and hosted the BES Annual Staff Field Safety and Community Awareness Training Workshop, held on May 18th & June 9th, 2009 at UMBC-TRC. Approximately fifteen researchers and interns were trained.

- CUERE continues to host UMBC's IGERT program "Water in the Urban Environment." As of August 2009, thirteen of the nineteen Ph.D. IGERT trainees will be working with BES investigators as their mentors (Groffman, Swan (3), Welty, Pouyat (2), Kaushal, Ghosh, Miller (2), Ellis (2)). The IGERT trainees have interacted with many BES investigators and other graduate students in a number of ways; the IGERT has therefore significantly contributed to building the graduate student population affiliated with BES.

- Parks and People Foundation, Inc. supervised and trained undergraduate and graduate student interns in the following projects:
  - Developing and leading Project BLUE Watershed Ecology Education enrichment program with Parks & People's SuperKids Camp; Bluford Drew Jamison, Franklin Square and William C. March Middle Schools.
  - Developing and organizing capacity-building strategies and educational materials for Watershed 263 Stakeholders Council and Baltimore Harbor Watershed Association's Harris Creek Watershed (246) project.
  - Administering a community asset survey for Baltimore Harbor Watershed Association's Harris Creek Watershed (246) Watershed 263 Stakeholders Council.
  - Implementing a Community Green Space Survey and database construction in collaboration with Baltimore Green Space.
  - Developing Green Career Ladder enrichment activities for BRANCHES summer youth forestry training and employment program.
  - Developing, implementing and analyzing Green Career Ladder program administration and evaluation tools for Project BLUE, BRANCHES and MD Civic Justice Corps.
  - Leading environmental and ecological sciences field studies for BRANCHES and Maryland Civic Justice Corps summer youth forestry program.
  - Continued development of longitudinal database of KidsGrow participants 1998-2007. Will provide baseline for retrospective analysis of environmental education program and curriculum development.

- An undergraduate senior from York University will be visiting the Gund Institute for Ecological Economics in August 2009 to gain practical experience applying the Genuine Progress Indicator. Her research while at the Gund Institute will influence the development of her senior thesis applying the Genuine Progress Indicator to another region.

- Graduate students at the Gund Institute have been in communication with researchers at the University of Maryland Center for Integrative Environmental Research, where a Genuine Progress Indicator project is in development for the State of Maryland with support from government agencies.

- The Baltimore Genuine Progress Indicator research has provided a foundation for further graduate studies in ecological economics, natural resource accounting, and urban development policy.

5. *Contributions Beyond Science and Engineering.*

- Small urban streams are often proximal to urban residents. Therefore the concepts of "buried streams," "gutter subsidies," and "urban karst" serve as useful vehicles for both facilitating understanding of the water systems of residents and resource managers, and as attractive and useful concepts for use in ecological education of students from middle school to university.

- Encouraging students to connect with the environment (their habitat) by keeping journals of everyday observations, which will eventually lead to long term data sets of various environmental variables including precipitation, time of snowfall, time of bird appearances (migratory patterns) and plant phenology (time of flowering and leafing), etc.

- Results of the work in characterizing urban-rural N disposition and CO_2 gradients have important implications for mitigation of emissions from anthropogenic sources on air and water quality.

- USGS continues to add real-time capabilities to stream-gaging stations to provide flood warning and a regular data stream for recreation, education, and water-resources management applications.

- BES contributed significantly to the public conference on entitled "Humane Metropolis Baltimore," held at the Maryland Historical Society in June, 2009.

- BES researchers interacted with and supported the Mayor's Sustainability Commission in the development of the Baltimore City Sustainability Plan. They have made themselves available to support the work of the Maryland State Office for Sustainable Futures, and the Baltimore County Office of Sustainability.

- Paleoecological studies show that forest cover throughout the Chesapeake watershed has been important in maintaining the health of the estuary.

- The CarbonPlus calculator is a web-based application for informing the public about their carbon emissions and promoting action to reduce those emissions. This calculator is based on the structure of the US EPA Personal Emissions Calculator and has been customized to use localized parameters in energy calculations. Specific calculations of the energy benefits of trees, local utilities, plus other information about the roles trees play in urban settings are being modified for Baltimore, Philadelphia, New York, and other localities. One option that cities have in promoting its use is to channel potential donations to carbon offset programs to local projects supporting energy conservation or increasing urban tree canopy, such as TreeBaltimore. The development team is now adapting the calculator to address a wide variety of circumstances applicable in Baltimore, including energy use and emissions generated by businesses and city agencies. Linking the calculator with BES through Question 3 opens opportunities to link the public's knowledge of their carbon footprints with local data from the flux tower, the hydrological network around Baltimore, or other related topics. http://www.itreetools.org/carboncalculator/entry.cfm

- A new hybrid academic/popular journal called Solutions is ready to launch by early 2010. This publication will present scholarly research in a way that is accessible to the general public, and involves new approaches to journalism, academic publication, and collaborative review of transdisciplinary work. The work outlined in this report has also made contributions to the social sciences, by helping to establish new ways of going about the study, application, and management of economics (in particular, incorporating the perspective of a full vs. empty world; including the roles of human, social, natural, and built capital; and including the relationship of human economies to the larger ecological systems in which they are embedded).

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Ntelekos, A.A., M. Oppenheimer, J.A. Smith, A.J. Miller. *In revision* 2009. Urbanization, climate change and flood policy in the United States. Climate Change.

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Carreiro, M.M., R.V. Pouyat, C.E. Tripler, W. Zhu. 2009. Carbon and nitrogen cycling in soils of remnant forests along urban-rural gradients: case studies in the New York metropolitan area and Louisville, Kentucky. Pages 308-328. *In:* McDonnell, M.J., A. Hahs, J. Breuste, eds. Ecology of cities and towns: a comparative approach. Cambridge University Press. New York.

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Chen, Y. 2009. Three essays on the interactions between regional development and natural amenities. Ohio State University, Columbus, OH.

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Other Publications Related to BES Work

Audiovisual Material

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BRANCHES (Building Resources and Nurturing Community Health & Environmental Stewardship) 2008 program video.

http://www.australiandesignreview.com/adrtv/11041-Brian-McGrath – On line Interview for Australia Design Review, speaking about Baltimore Ecosystem Study.

Magazine Articles

The following are magazine articles that mention the Baltimore Ecosystem Study.

Goldman, E. 2008. Greening gray streets: can it clean the waters below? Chesapeake Quarterly. 7(2):4-14.

http://www.australiandesignreview.com/feature/12659-On-the-Origin-of-Cities-Adaptive-Urbanism-Brian-McGrath – On line review in Australia Design Review, about design work with urban ecology, On the Origin of Cities: Adaptive Urbanism, by Adam Russell.

Newspaper Articles

Costanza, R. 2008. Our three-decade recession: the American quality of life has been going downhill since 1975. Los Angeles Times. 3/10/2008.

Stankus, J. 2008. Cary Institute part of $12.5 million grant to promote environmental education. Millbrook Round Table. 12/26/08.

Databases

HERCULES: Additional data layers were added to the Baltimore Ecosystem Study geodatabase housed on the University of Vermont's (UVM) Spatial Analysis Lab. Data layers were also quality checked and documented with metadata. One of the most important data layers created by the UVM lab was high resolution land cover for the Gwynns Falls watershed for 2004. Data are currently available to all BES researchers by request.

High resolution land cover datasets (currently in beta release) based on year 2007 data for Anne Arundel County, Baltimore City, Baltimore County, and Howard County. The high resolution land cover datasets represent seven land cover classes and are derived using object-based image analysis (OBIA) techniques from high resolution remotely sensed datasets. They are available via download from the BES website.

Vegetation data bases—available on the BES website.

Demographic and socioeconomic characteristics of households in floodplains, and adjacent to historic and current shorelines, and historic and current streams from 1950–2000.

Created a database of **zoning variances** in Baltimore from 1930 to the present. These have been integrated with demographic and other data in a GIS format for presentation.

Post doc Chona Sister created the following databases: "Parks GIS layer for Baltimore City, 2008," "Parks GIS layer for Baltimore City, 1965," and "Parks GIS layer for Baltimore City, 1928."

Grad student Pei Zhai created the following databases: "Geocoded Dun & Bradstreet Directory of Heavy Industry (Pseudo-TRI) for Baltimore City, 1980," "Geocoded Dun & Bradstreet Directory of Heavy Industry (Pseudo-TRI) for Baltimore City, 1970," and "Geocoded Dun & Bradstreet Directory of Heavy Industry (Pseudo-TRI) for Baltimore City, 1960."

More data layers and metadata were added to the Baltimore Ecosystem Study geodatabase housed on the University of Vermont's (UVM) Spatial Analysis Lab. Most notably, we have produced a new landcover database for Baltimore City and County and LiDAR data. Data are currently available to all BES researchers by request. UVM is currently in the process of developing a multi-user geodatabase that will allow users outside the UVM campus to access, and "check out" data through a database connection. We also have a number of external hard drives. Because of the size of the databases, we use these external hard drives to disseminate BES data.

CUAHSI Observations Data Model - The BES stream chemistry data and long term study plot soil data was loaded into the CUAHSI Observations Data Model (http://his.cuahsi.org/odmdatabases.html). This database serves as the back end data store for the DASH system (http://his09.umbc.edu/dash) as well as the data source for the CUAHSI WaterML web services.
(http://his09.umbc.edu/BESoil/cuahsi_1_0.asmx?WSDL)
and (http://his09.umbc.edu/BESOD/cuahsi_1_0.asmx?WSDL).
The data contained in this database are available through the DASH system and CUAHSI WaterML web services.

Community Greening and Open Space Census Database.

METADATA: The BES metadata relational database has been mapped to extensible markup language to facilitate inclusion in the Long Term Ecological Research networks Metacat system. The Metacat system allows data from all LTER sites to be searched and combined.

Educational Products

1. ***Biocomplexity and the Habitable Planet: Curriculum for Teaching High School Environmental Science .***

Co-PI Alan Berkowitz and BES Project Director Steward Pickett are part of the Principal Investigator Team developing this innovative capstone course for high school classes with collaborators from TERC in Cambridge, MA. Upon completion, Biocomplexity and the Habitable Planet will be a set of instructional materials that engages students, teachers, and their parents in the science of coupled natural human (CNH) systems. It will include two semester-long modules, each with two units, comprising student guides, teacher's guides, an ecology primer, research protocols, and data and other materials from the LTER and/or BioComplexity research communities.

During the 2008-9 period covered by this report, second drafts of each of the four units were completed based on feedback from initial pilot test teachers. A second round of pilot testing has been initiated which may include BES teachers.

2. ***My City's An Ecosystem: A Handbook for After-School Program Leaders.***

"My City's An Ecosystem" is an engaging set of modules that integrate good, hands-on science, an emersion in nature, and development of citizenship and thinking skills for elementary-aged youth participating in after school enrichment programs. The modules have been used by several KidsGrow after school programs at five different schools in inner-city Baltimore. While designed for school-based sites which serve their own students, the curriculum also is suited for other types of after school programs. This year the curriculum has been modified and leveled into two age groups. Modules are now available specifically for 2nd and 3rd graders and again for 4th and 5th graders. Additionally, a Water in the City module was developed and will be implemented in the 2009-2010 school year. Modules include:

- Creating an Urban Ecology Center in Our Neighborhood
- Habitats
- Microclimates and Mesoclimates
- Hurricanes
- What Happens to Stuff?
- Ecology of Food, Agriculture & Nutrition
- Phenology
- Water in the City
- Black History

The modules are available from Education Leader, Bess Caplan at the BES Baltimore Education office. bess.caplan@parksandpeople.org

Other Products

A dynamic watershed model was developed in the modeling software Simile.