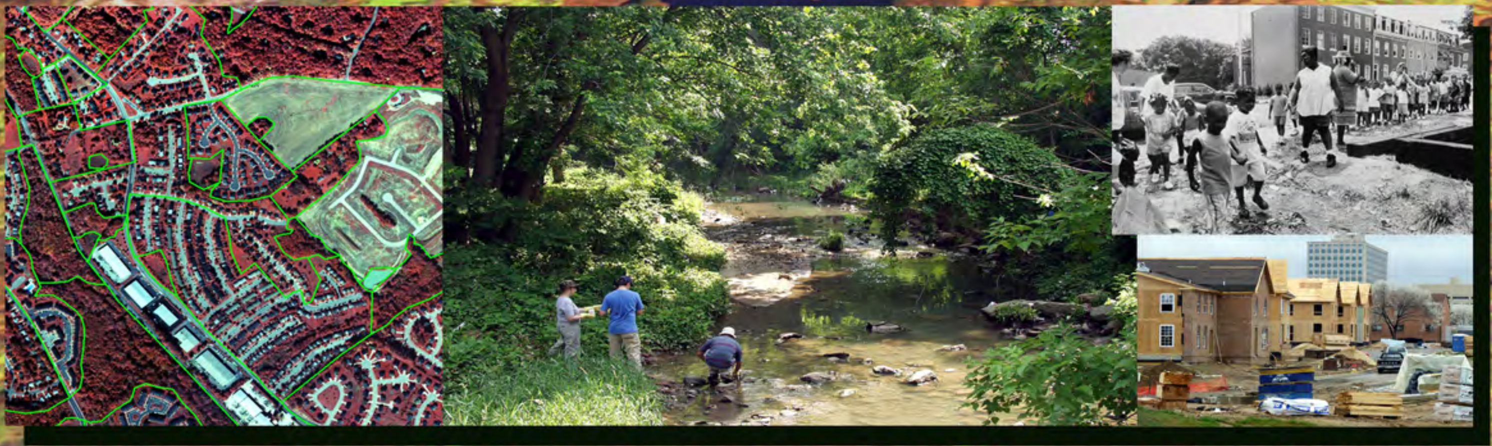

Baltimore Ecosystem Study

Long-Term Ecological Research Renewal Proposal, 2004

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Notes:
Pagination matches NSF requirements
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Cover Photo Credits

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3. Top right, upper: Children touring a new community garden site, ©Steffi Graham. Used by permission.

4. Top right, lower. New housing construction in Baltimore City.

5. Bottom left, upper: Baltimore Skyline from the Piedmont, north Baltimore. BES Photo.

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7. Bottom middle, upper: South Fulton Street, Baltimore City, September 2002.

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Numbers 2, 4, and 6-9 by S.T.A. Pickett.

PROJECT DIRECTOR'S PREFACE:

An Unprecedented Platform for Urban Ecological Research

This proposal to the National Science Foundation represents the efforts of more than 30 researchers, educators, and decision leaders to secure funding for the second phase of the Baltimore Ecosystem Study (BES), Long-Term Ecological Research (LTER) project. It details the accomplishments in research, education, and community engagement that have been achieved during the first six and a half years of this novel, integrative project. More importantly, it portrays the plans and collective vision of our growing collaborative group. Of course, we will not learn the decision of the National Science Foundation for some months, but I wanted to share this proposal with you as a way of deepening the dialog with those who might use the knowledge we generate, or who might help shape new research and educational approaches in the future.

A grant from the National Science Foundation's LTER program obliges us, primarily and fundamentally, to produce, document, and publish high quality data and syntheses on the Baltimore ecosystem. That is our *sine qua non*. If we fail in that, BES will not continue to be funded by NSF. Indeed the LTER Network (www.lternet.edu), a consortium of 24 research sites around the United States, and including two in Antarctica, mandates what kind of basic ecological data we must collect. It requires us to document 1) biological primary productivity, 2) mineral nutrient dynamics, 3) carbon dynamics, 4) important biological populations, and 5) natural disturbances in our ecosystem. These data must be comparable to those from other sites in the LTER Network, which range from tropical forest in Puerto Rico, to temperate forests in New England, to grasslands in the Great Plains, to deserts in the Southwest, and to tundra sites in the Rockies and in Alaska, in addition to the Antarctic sites already mentioned. This is a major job in itself. But BES has additional requirements set by the National Science Foundation. This includes our second mandate: We must study the human population, social institutions, and social dynamics of our metropolitan ecosystem. Third, we are mandated to conduct educational activities that reach from the general public to elementary school pupils. Finally there is the unspoken, but no less important, mandate to engage the communities in which we work. In a sense, we must have the permission and support of a vast number of individuals and organizations as we

> ***BES studies the* human *ecosystem.***

conduct social, biological, and physical research around the five county Baltimore metropolitan area. These mandates amount to a huge task, and the breadth of this undertaking explains how BES has evolved till now.

What has BES accomplished? I believe it is fair to say that together we have built *an unprecedented platform for urban ecological research*. Before BES was conceived, there existed an impressive body of environmental measurements, social science,

BES provides a novel, integrative research infrastructure.

community forestry, and institutional networking in Baltimore. Early partners in what would become BES – the Parks & People Foundation, the USDA Forest Service, and Yale University's Urban Resources Initiative – saw the promise of increasing and deepening the ecological and interdisciplinary knowledge base of the Baltimore metropolitan region. BES was informed by this vision, and has added an integrative research infrastructure to Baltimore's strong environmental knowledge base. This research infrastructure is unusually broad and serves as a platform for increasing the understanding of metropolitan ecosystems. Our research encompasses soil science, atmospheric science, microbial ecology, history, plant ecology, wildlife ecology, social sciences, hydrology, ecological economics, remote sensing, paleoecology, spatial analysis, and urban design. Its goal is to develop a thoroughgoing *understanding of metropolitan Baltimore as an ecological system*, and to share this understanding with educators and decision makers. The BES research infrastructure employs both intensive and extensive sampling plots for biological, physical, and social data. Furthermore, historical data are crucial for extending our view into the past as we build long-term data bases to project into the future. These diverse kinds and sources of data are geographically aligned, and are linked to one another in our models. The research infrastructure is supported by conceptual, theoretical, and quantitative syntheses between the specialties our team represents. The disciplinary breadth and *inter*disciplinary integration of this research enterprise is one of our most important products.

This research platform was also integrated from the start with educational activities and with community engagement. The focus on partnerships between BES and the residents, students and teachers, and leaders in the Baltimore region's communities and governmental agencies has been a crucial component to the success of BES. I am pleased to read in the letters of support, which appear at the end of this document, that our research platform and results have already proven useful to decision makers in the Baltimore metropolitan area and the Chesapeake Bay region. We hope for such applications to continue and to grow.

An important part of our research platform is the culture BES has tried to create. Every institution has a culture, which includes its way of doing things, its accumulated wisdom, and its norms. Such cultures are critical, but rarely recognized, aspects of research institutions. Because the scientists and educators who make up BES are so widely scattered

BES has developed an open, interdisciplinary culture

geographically and disciplinarily, this culture has been all the more important for us. For example, we have established an effective strategy for meetings and for ensuring open communication that attempts to honor all voices in our meetings. Exhaustively documenting and sharing data is another important component of our culture, which originated from the LTER Network. It is one of our major requirements.

A third part of our culture is the strategy to leverage our efforts by seeking additional funding. This cultural precept is expected by the National Science Foundation. Leveraging is an approach that will necessarily have to grow if the request of BES for Phase II support is approved. Although the total grant from the National Science Foundation may seem large, it is important to remember that it is simply not large enough to pay for all the important activities we must accomplish. Because the required costs of core data collection, information management, and coordinating educational activities and community engagement will become an increasingly larger fraction of the core LTER budget, our culture must evolve to encourage the habit of including some support for these project costs in the research and educational proposals that all members of BES write. Without this cultural commitment becoming the norm, our project will become crippled in the later years of Phase II. All of us in BES are learning the need and strategy of leveraging our limited LTER resources, so that this impressive research and education platform can continue to support interesting and important work.

I hope you enjoy exploring this proposal, and the vision that the members of BES have laid out for the future. This document presents our accomplishments to date, and our hopes for the future.

Steward T.A. Pickett, PhD.

BES Project Director
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Institute of Ecosystem Studies
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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 04-2

NSF 04-2

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)

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Institute of Ecosystem Studies

AWARDEE ORGANIZATION CODE (IF KNOWN)

4001926000

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE

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NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE

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ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
☐ SMALL BUSINESS ☐ MINORITY BUSINESS
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TITLE OF PROPOSED PROJECT **HUMAN SETTLEMENTS AS ECOSYSTEMS: METROPOLITAN BALTIMORE FROM 1797 - 2100: PHASE II**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 4,920,000	60 months	11/01/04	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG I.A)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
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PI/PD DEPARTMENT

PI/PD FAX NUMBER

845-677-5976

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PROJECT SUMMARY

The Baltimore Ecosystem Study, begun in 1997, is a Long-Term Ecological Research project designed to understand the controls on urban system structure and function, and how structure and function of the urban ecosystem affect one another. The proposed research will expand work that addresses three fundamental questions: 1) How do the spatial structure of socio-economic, ecological, and physical features of 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 an urban system? How do they relate to one another, 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 to downstream air and watersheds? Conceptual frameworks motivating these questions include ecological, hydrologic and social patch dynamics, the human ecosystem framework, the role of exotics in community organization, socio-spatial theory, resilience, biocomplexity, and urban design theory.

Intellectual Merit. The proposed research builds on data sets ranging from paleoecological, through historic time frames, to simulation of future scenarios. Highlights of our new research efforts include 1) using a $1 billion Baltimore City program to improve sanitary sewer infrastructure as an experimental manipulation, 2) an integrated physical, biological, and social analysis of an urban watershed restoration (Watershed 263) project funded by over $1 million in US Forest Service and other funds, 3) continued development of the first urban micrometeorological flux tower for analysis of carbon and water fluxes; and 4) continued development of our ideas about the "ecology of prestige," where lifestyle groups, rather than more traditional metrics such as race, income and education are used to explain variation in urban ecosystem structure and function. Integration of these efforts will be facilitated by continued development and use of our new, high resolution urban land cover classification system (HERCULES), and by a series of models that operate at different scales for different questions. New education and outreach initiatives include analysis of how formal and informal approaches to education facilitate the ability of people to think about the city as an ecosystem, and development of new modules for the Urban Forest Effects (UFORE) model to evaluate the health of urban forests and their effects on energy use and water and air pollution.

Broader Impacts. The research will exploit new, management-relevant environmental interventions. Watershed 263 is the site of an initiative to explore the role of urban reforestation on stormwater management. Evaluation of improvements to Baltimore City's sewer infrastructure will yield results broadly useful to managers and policy makers, and to educators and community groups in the affected water- and sewer-sheds. Modeling of ecosystem services will be a hallmark of the new research, and will provide information useful and interesting to citizens and decision leaders. Education activities will build on successful curriculum development, teacher workshops, and interaction with K-12 students, with special attention to reaching under-represented groups. Training outside the classroom will include summer internships and after school programs at community centers and city environmental centers, again including under-represented groups. Novel graduate training will focus on a new collaboration in urban design. Multi-city information transfer will be achieved through cross-site LTER projects, and through an Urban Ecology Collaborative.

SECTION 1 - RESULTS FROM PRIOR NSF SUPPORT

The Baltimore Ecosystem Study (BES) asks three overarching questions that address 1) structure, integration, and change of ecological, physical, and social components of the urban ecosystem, 2) fluxes of materials, energy, human-, social-, and built-capital, and 3) development and use of ecological understanding of the metropolitan system. We present major accomplishments of BES during the first 7 years of funding from the National Science Foundation (NSF) long term ecological research (LTER) program.

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

A major objective was to establish a platform for long-term, urban ecosystem research. We created two geo-referenced networks of permanent plots: 1) an intensive network of 12, 40 x 40 m plots for vegetation and biogeochemistry; and 2) an extensive network of 202, 405 m^2 plots across the metropolis to parameterize the Urban Forest Effects (UFORE) model. UFORE couples vegetation, air pollution, and meteorological data to quantify urban forest effects. Soils have been mapped in all permanent plots. In 1999, a 5 yr vegetation sampling rotation began on the intensive plots, and a 3 yr cycle begin on the extensive plots. Long-term, georeferenced social data linked to the plot networks were collected using household telephone and field observation surveys. The telephone survey (1999, 2000 & 2003) assessed household environmental recreation, watershed knowledge, neighborhood social capital, willingness to participate in environmental activities, and perceptions of environmental quality of life. The field observation survey sampled plots on a grid covering metropolitan Baltimore to quantify social patches. The long-term research platform also includes a historical hydrologic database for our focal watershed (Doheny 1999), an LTER Level 3 meteorological (met) station (Heisler et al. 2000), a rain gage network, several ancillary met stations and acquisition of existing, long-term, spatially-explicit demographic, socioeconomic and biophysical data.

Biotic structure. Our extensive survey shows ca. 2,835,500 trees, with 25.2% canopy coverage in Baltimore City. The compensatory value of these trees is $3.4 B. Baltimore trees have a mortality rate of 6.6%/yr (Nowak et al. in press). The standing stock of trees stores ca. 527,300 t C, with a value of $10.7 M. These trees remove ca.10,800 t C/yr ($219,000/yr), and ca. 522 t of air pollutants/yr ($2.9 million/yr; Nowak et al. submitted). Exotic plants (Brush et al. in prep.) were much patchier than expected. Exotic vines are important in urban forest gaps, and compete with native tree saplings (Dijkstra 2002). Bird species richness increased with socioeconomic status in Baltimore and Phoenix (Warren et al. in prep.). The abundance of some exotic bird species correlated with urban development, while abundance of many native species correlated with vegetation cover (Nilon et al. in prep.). The percentage of exotic soil fauna in Baltimore varied between 0 % (Coleoptera: Silphidae) to 100 % (Isopoda: Oniscidea; Szlavecz et al 2003, submitted, Wolf 2003). Introduced species often inhabit new habitats. A diverse soil invertebrate community exists in urban and suburban habitats, e.g. 66% of the earthworm fauna of Maryland (Csuzdi and Szlavecz 2002, 2003, Hornung and Szlavecz 2003, Korsos et al 2002).

Physical structure. Our studies show that soils differ significantly from “typic” urban soil (Pouyat et al. 2002, 2003, Pouyat et al. submitted a, b) and that the standard Soil Taxonomy must be modified to include human effects as a soil formation factor (Effland & Pouyat 1997, Pouyat & Effland 1999). Heavy metal contamination is significant and is related to roads, vehicular traffic, and site history (Yesilonis et al. submitted). Although the urban heat island is well known, we have shown that these effects are more complex than usually thought. In Baltimore, the city is hotter during the day, while in Phoenix, the city is cooler than rural land during the day (Brazel et al. 2000, Brazel & Heisler 2000). Ultraviolet radiation (UVB) is reduced by less than 5% in Baltimore compared to rural areas (Heisler & Grant 2000, Heisler et al. submitted, Grant et al. 200, 2002).

Social structure. Characterization of social patch structure of the Baltimore metropolitan region enabled us to 1) assess changes in social structure over time, 2) analyze cause and effect relationships between social processes and biophysical structures and processes, 3) evaluate temporal complexity such as lags, legacies, and slow processes, and 4) elucidate system resiliency (Boone 2002, 2003, Michaud 2003). We enhanced Claritas' PRIZM (Potential Rating Index for Zipcode Markets) lifestyle market classification to include social and biophysical characteristics of neighborhoods (Grove & Burch 2002, Wilson and Howarth 2002, Grove et al. in press-b) and household land-management (Grove & Burch 2002, Grove et. al. in press -a).

Integrative characterization of structure and links to function. Our new classification for urban land (HERCULES) reconceptualizes land cover for metropolitan areas (Cadenasso & Pickett 2002). HERCULES characterizes the great spatial heterogeneity of urban ecosystems to foster interdisciplinary integration (Cadenasso et al. submitted, Grove et al. in press-b). For example, HERCULES facilitated application of the hydrologically based RHESSys model (Band et al. 2000, submitted) to urban landscapes.

Riparian zones are physical, biological, and social "hot spots" in urban ecosystems. Changes in hydrology associated with urbanization lead to incision of stream channels and a reduction in groundwater levels that alters riparian soil (Groffman et al. 2002, Groffman & Crawford 2003), vegetation (Brush et al. in prep.), and social (Groffman et al. 2003) properties. Data on soil moisture and shallow riparian groundwater (Band et al. 2001, Tenenbaum et al. submitted) have suggested the scale and controls of drainage infrastructure on catchment hydrology in forest and suburban catchments.

Our data suggest that urbanization drives ecosystem structure and function (e.g., soil organic C pools) toward similar endpoints, regardless of the life zone that originally characterized a region (Pouyat et al. 2003). Urban ecosystems are novel habitats that tend to support similar species assemblages, which should homogenize above and below ground pools and fluxes of C.

Question 2: What are the fluxes of energy, matter, human-, built-, and social-capital in an urban system; how do they relate to one another, and how do they change over the long term?

BES research centers on the 17,150 ha Gwynns Falls watershed, which traverses an urban-rural land use gradient. Our long-term, weekly sampling network includes four main channel sites along the Gwynns Falls, and smaller watersheds located within or near it. The main channel sites provide data on water and nutrient fluxes in the different land use mosaics (rapidly suburbanizing, suburban, old residential, urban core), while the smaller watersheds provide data on specific land use types (forest, agriculture, suburban, urban). Five years of weekly stream data are posted on the WWW (http://beslter.org) and have been used by city, county and state personnel interested in urban watersheds and their impact on the Chesapeake Bay. The urban and suburban watersheds have N loads intermediate between forest and agriculture, but with much higher variation (Groffman et al. in press, Law et al. submitted). Retention of N in the suburban watershed was surprisingly high (75% of inputs). Inputs were dominated by lawn fertilizer and atmospheric deposition (14 and 11.2 kg N ha^{-1} y^{-1}, Groffman et al. in press).

The weekly BES stream samples are analyzed for *E. coli* using innovative technology that is potentially available to watershed groups and citizens. Only the 100% and 60% forested streams did not exhibit extremely high levels of *E. coli*, which probably reflects sanitary sewer leakage elsewhere. DNA molecular (PCR and RAPD) approaches, and immuniomagnetic electrochemiluminescence (IM-ECL) techniques were used to assess the pathogens, *E. coli* 0157, *Cryptosporidium*, and *Giardia* (Shelton et al. 2003, submitted).

We established the first permanent urban eddy covariance micrometeorological tower to quantify carbon fluxes and carbon dioxide concentrations in a residential area of mixed cover types. The residential area had high seasonal C uptake, similar to that of a natural deciduous forest, but shows anthropogenic weekday/weekend cycles (Hom et al. 2001, Grimmond et al. 2002).

Social ecological dynamics are more complex than previous research suggests. For example, historical patterns of infant mortality failed to show the hypothesized link with land use, but were correlated with low, poorly drained areas (Hinman 2002). Similarly, the expectation of environmental equity theory that minority groups are more likely to live near environmental hazards fails in Baltimore, although the pattern still reflects a history of segregation (Boone 2002). A final example of complexity in social-ecological relationships is that household lifestyles better predicted watershed knowledge, neighborhood social capital, and willingness to support environmental activities than traditional demographic measures, such as population density, income/education, or race (Grove et al. 2002, in press- B, Wilson and Howarth 2002).

Integrated analysis of structure/function relationships. At the scale of the full Gwynns Falls, we have used a lumped basin model (HSPF) to generate emergent behavior of runoff production and baseflow, and to project land use evolution (Brun & Band 2000). At the small catchment scale we have modeled spatial distributions of hydroecological processes within human dominated ecosystems (Band et al 2001, Law et al, 2004, submitted). We adapted RHESSys (Band et al 1993, 2000, 2001) by adding roads, houses, septic systems and lawns. The additional features exposed spatially explicit human augmentation of water and nutrients at the patch level, rearrangement of hydrologic flowpaths and nutrient feedbacks (Law 2004).

We have also used the Spatial Modeling Environment (SME) and the Library of Hydro-Ecological Modules (LHEM) to model hydrology, water quality, ecosystem dynamics, and ecosystem services for the Patuxent and Gwynns Falls watersheds (Voinov et al. 1999, Voinov and Costanza 1999, Boumans et al. 2001, Costanza et al. 2002, Binder et al. 2003, Costanza & Voinov 2003). We have developed models of social economic dynamics at different scales (Low et al. 1999, Wilson et al. 1999, Costanza et al. 2000, Pickett et al. 2001, Costanza et al. 2001, Band et al 2000, 2001, Law 2004). The General Human Model (GHM) was calibrated for the global scale GUMBO model (Boumans et al. 2002). This model is being adapted to simulate land use, ecosystem services, and economic changes at the regional scale. We have conceptualized, identified, mapped, modeled, and valued ecosystem services at a variety of scales (Costanza 2000, Costanza 2001, Costanza & Farber 2002, Farber et al. 2002, Limburg et al. 2002, Sutton & Costanza 2002, Villa & Costanza 2001, Villa et al. 2002, Wilson et al. in press).

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 to downstream air and watersheds?

Our research shows that information is necessary but not sufficient for effecting environmental change. Our comparative studies of the development of sewer infrastructure in Baltimore and Paris, demonstrated significant struggles between national/state and city powers. Although Paris and Baltimore had equal scientific knowledge about cholera and typhoid, because Maryland constrained Baltimore's autonomy, it was one of the last cities to build a public sewer system, while Paris, a seat of national power, was one of the first.

Educators in BES have built a diverse and effective team to carry out and guide our work. Participants include educators, administrators and scientists in Baltimore city and county public and private schools, the Maryland Departments of Education and Natural Resources, the NSF-supported Baltimore Systemic Initiative housed at Morgan State University (now defunct), virtually all of the region's universities and colleges, and non-profit organizations. The Parks & People Foundation (PPF) plays a key role in BES education and outreach.

BES played a leadership role in the 1999 Cary Conference held at the Institute of Ecosystem Studies, entitled Understanding Urban Ecosystems: A New Frontier for Science and Education. The conference book (Berkowitz et al 2003a) articulated a vision for "understanding urban ecosystems."

The BES has begun to describe the nature of ecology teaching in schools in targeted city and county neighborhoods to provide a baseline against which to measure long-term trends in teaching practices. BES provides seed funds for K-12 school-based ecological investigations. BES scientists and educators have led 11 workshops with master teachers. Five Ecology Education Fellows prepared instructional materials and new workshops. Teacher participants have engaged their students in effective projects. For example, Karen Hinson Steele's AP American History students investigated the environmental history of Baltimore's reservoirs. The book they produced has been used by forest managers (see Grove et al. 2003). Martin Schmidt uses the information from permanent BES stream and weather stations located on his school's property. Roland Park Country School teacher David Brock has worked with BES in the Environmental Science Summer Research Experience for Young Women project, a 9th and 10th grade summer internship program in soil ecology (http://faculty.rpcs.org/brockda/essre.htm).

BES has worked with three minority communities in after-school and summer enrichment programs for youth, combining job training, exposure to a diversity of role models, environmental awareness, and academic enrichment. BES has begun developing a multi-year curriculum for KidsGrow, which can ultimately be disseminated to other organizations. BES is working to build a diverse workforce of urban ecosystem educators, scientists and managers, through programs for youth (e.g., PPF's KidsGrow and Green Career Ladder programs). PPF's Urban Resources Initiative internships provide young professionals with the opportunity to carry out research and community development projects. Finally BES has mentored or supported 14 REU students (including 12 female and minority students), and 24 students (21 African American, 18 women) in the Baltimore Collaborative for Environmental Biology, making significant contribution to recruitment and retention of undergraduates in the field.

We conduct public events to communicate BES work to broader audiences, including two Annual Baltimore Ecosystem Open Houses (2002, 2003), 6 BES Annual Meetings, 3 Quarterly Science Meetings per year, environmental education coordination and presentation sessions, and site tours. We participate in the Revitalizing Baltimore Technical Committee to connect scientists with technical managers in the Baltimore region.

Productivity

We have published 94 papers in refereed scientific journals, 8 books, 44 book chapters and 6 dissertations and theses (Table 1-1 Supplementary Documents (800-BES-LTER)). We are also proud of our "other publications" that represent the significant education and outreach focus that is a necessary component of urban research. These publications are one indicator of our success in reaching out to decision makers, managers, educators, students and the general population of our region. Numerous BES datasets are available on our WWW site (Supplementary Documents Table 1-2) and have been widely used by scientists, the public and decision makers.

As is expected for LTER projects, we have used NSF LTER funding to attract other grants. Each of our major partners has successfully leveraged NSF LTER funds to expand the scope of BES research, education and outreach. The USFS is a major contributor to BES, providing over $6 million over the past seven years in personnel and research support in Baltimore (please see attached letter of support in Supplementary Documents). The University of Maryland Baltimore County (UMBC) used BES research as a platform to establish its Center for Urban Research and Education (CUERE), funded by almost $3 million from EPA. The USGS has leveraged over $500,000 in ancillary stream gaging and personnel support for BES. The Parks & People Foundation has generated over $3 million in grants for their community outreach programs. Individual principal investigators have been successful in obtaining competitive grants. Highlights include over $1.5 million in two NSF/EPA Water and Watersheds Grants (Pickett et al.; Costanza et al.), a $250,000 grant from NSF Geography and Regional Science (Band) to build on our watershed work, over $1 million in EPA grants (Groffman, Fisher) for stream restoration studies, and $300,000 (Smith, Miller) from NSF Hydrologic Sciences for urban water budgets. Brush is a co-PI on a $1.8 million NSF Biocomplexity grant that builds on BES research. Berkowitz has generated funds for education, with grants for Undergraduate Mentoring in Environmental Biology, an NSF GK-12 grant for research and education interns, and an Informal Science Education project on community gardens. We also raised over $100,000 from NSF, NASA, EPA, USDA Forest Service, the Surdna Foundation, and the Nathan Cummings Foundation for the 1999 Cary Conference that focused on urban ecosystem education.

SECTION 2 - PROPOSED RESEARCH

Urban areas, including cities, their suburbs, exurbs, and hinterlands, are complex ecosystems. This renewal proposal requests funds to extend and refine the efforts of the Baltimore Ecosystem Study LTER (BES) to understand how a complex, natural-human system functions and changes. The research will ultimately answer the fundamental question, "What are the controls on spatial structure and urban system function, and how are urban structure and function related?"

The question is important first, because urban areas are expanding in the United States and around the world (UN Population Division 1995, Southall 1998, Zipperer et al. 2000). Understanding the ecological consequences of urban growth can improve the quality of urban life, and mitigate the impact of urban sprawl on agricultural and wild lands (Daniels 1999, Heimlich & Anderson 2001, Luck et al. 2001). Yet the ecological data base on urban areas remains small compared to that on natural systems (Grimm et al. 2000, Heinz Center 2002). Second, the structure and dynamics of urban systems provide an opportunity to better understand stressed ecosystems. For example, urban systems already exhibit many of the changes proposed to accompany global change, such as altered precipitation, reduced soil moisture, increased storm impacts, increased temperature ranges, and elevated trace gas concentrations (Vitousek 1994, Breuste et al. 1998, Brazel et al. 2000). Third, urban systems allow researchers to understand complex, integrated systems (Wu & David 2002). Researchers recognize the importance of feedbacks between social and ecological processes, yet understanding their mechanisms and their system-wide implications is rudimentary in urban systems (Machlis et al. 1999, Pickett et al. 2001). Urban systems also provide an opportunity to operationalize abstract concepts of complexity in addressing these feedbacks (Pickett et al. in press).

The fundamental question of the relationship of urban ecosystem structure and function has been resolved into **three guiding questions** in BES:

1. **Structure**: How do the spatial structure of socio-economic, ecological, and physical features of an urban area relate to one another, and how do they change through time? This question focuses on both historical and on-going changes in system structure, ranging from paleoecological data to model scenarios for the future.

2. **Fluxes**: What are the fluxes of energy, matter, and human-, built- and social- capital in an urban system; how do they relate to one another, and how do they change over the long term? This question probes the magnitudes, pathways, interrelationships, and changes of a multidisciplinary set of fluxes.

3. **Understanding and Application**: 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 to downstream air and watersheds? Conducting research and communicating the results in an urban area may alter the behavior of the system. Rather than try to avoid such effects, we wish to document how ecological knowledge affects decisions made by households and institutions. In addition, to earn the cooperation of the neighborhoods and jurisdictions in which we work, BES must be sensitive to their interests and knowledge.

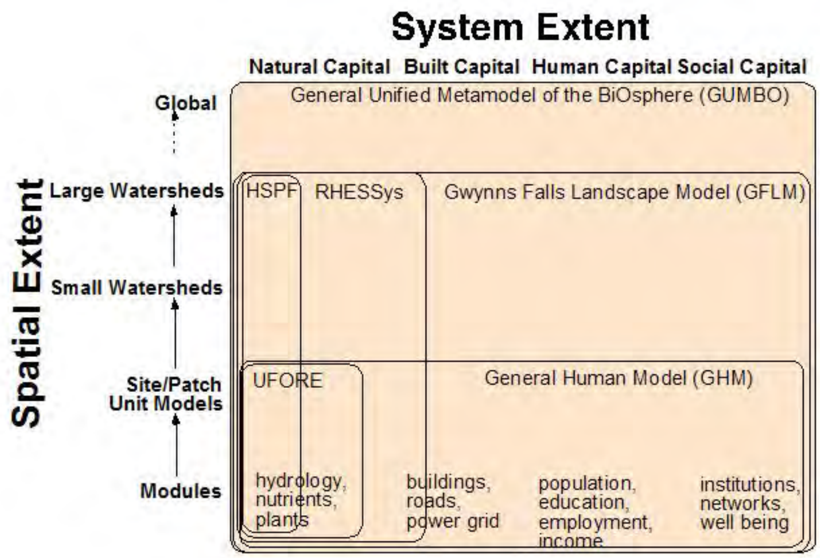


Figure 1. Models are important tools for synthesis, extrapolation and outreach in BES. HSPF is a non-spatially explicit model that simulates watershed hydrologic inputs and outputs, while RHESSys is a distributed hydroecological model that makes use of a hierarchically structured representation of the landscape. Hierarchical elements include progressively nested basins, hillslopes, patches, and strata. Strata can include different types of natural or built land cover forming complex patches. The spatial structure of RHESSys at the patch level is fully compatible with our new urban land classification system (HERCULES, Figs 3, 4).

The Urban Forest Effects (UFORE) model is designed to quantify urban vegetation structure, biogenic volatile organic compound emissions, vegetation carbon storage and sequestration, dry deposition to vegetation and other urban surfaces of gaseous and particulate pollutants, the effects of vegetation on local building energy and use, and consequent power plant emissions. UFORE is driven by data collected at 200 extensive plots throughout the city. It is our major tool for outreach to urban forest managers and policy makers and for cross-site comparisons (applied to more than 10 cities in the U.S.).

The Gwynns Falls Landscape model (GFLM) simulates the watershed within its ecological context of hydrology and biomass production, while the General Human Model (GHM) accounts for socio-economic dynamics. Within the GHM, built capital is the accumulation and value of manufactured goods, human capital is the distribution of information and health, social capital are shared norms, rules and connections within human networks, while natural capital is ecosystems and the goods and services they provide. The GUMBO model simulates land use, ecosystem services, and economic changes at the global scale.

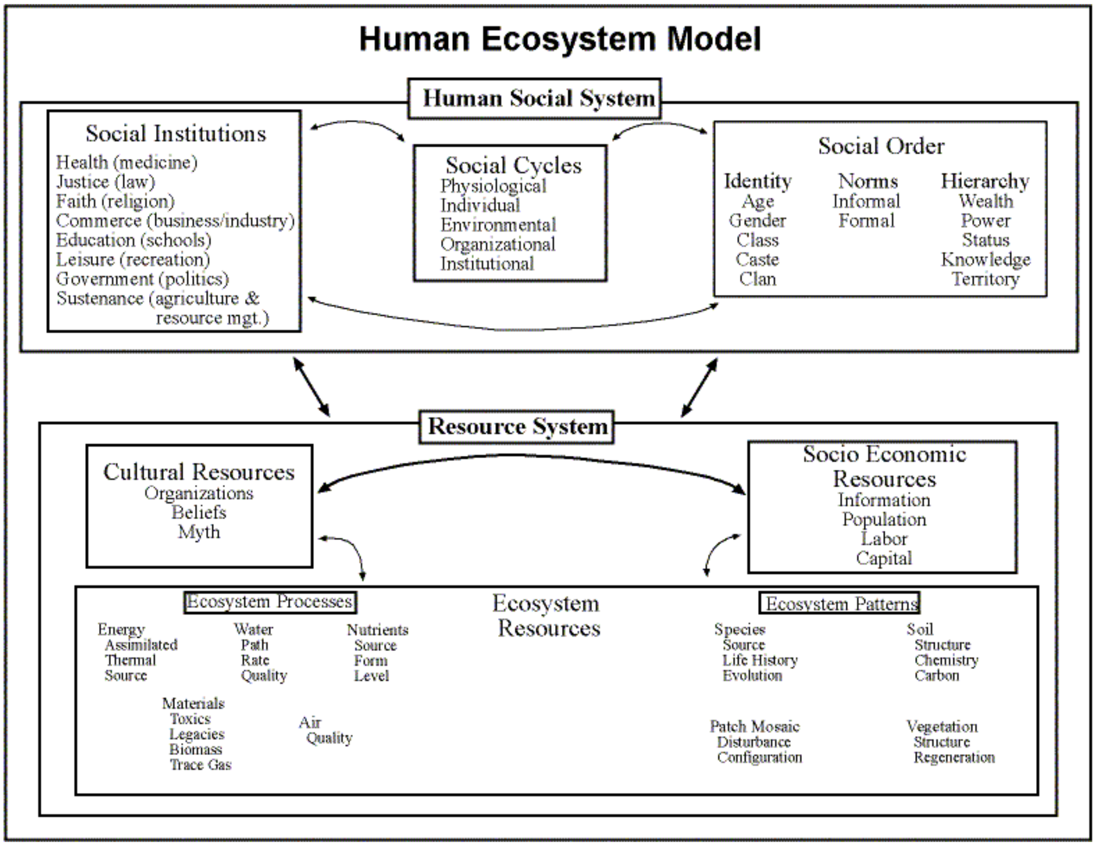
Highlights of Proposed New Research. Our proposed new research will build on these questions with new or refined theoretical and research approaches (Human Ecosystem Framework, Patch Dynamics, Community Organization, Socio-spatial Theory, Resilience, Biocomplexity, Urban Design Theory, and Education), and with several new research, education, and outreach efforts. Highlights of our new research efforts include: 1) using a $1 billion Baltimore City program to improve sanitary sewer infrastructure as an experimental manipulation, 2) an integrated physical, biological, and social analysis of an urban watershed restoration (Watershed 263) project funded by over $1 million in US Forest Service and other funds, 3) continued development of the first urban micrometeorological flux tower for analysis of carbon and water fluxes; and 4) continued development of our ideas about the "ecology of prestige," where lifestyle groups, rather than more traditional metrics such as race, income and education are used to explain variation in urban ecosystem structure and function. Integration of these efforts will be facilitated by continued development and use of our new, high resolution urban land cover classification system (HERCULES), and by a series of models that operate at different scales for different questions (Fig 1). New education research includes analysis of how formal and informal approaches to education facilitate the ability of people to think about the city as an ecosystem. A new outreach effort is the development of new modules for the Urban Forest Effects (UFORE) model to evaluate the health of urban forests and their effects on energy use and water and air pollution.

In the sections below, we first explain how the guiding research questions will be refined in Phase II. Next, we outline new theoretical developments and new research directions to be pursued in Phase II. We then describe new hypotheses and research activities for Phase II, grouped by our three guiding questions.

Refinements to the Guiding Questions. The three questions will continue to be used in BES Phase II. Questions 1 and 2 reflect fundamental ecological concerns with structure, function, and change in systems (Golley 1993). Question 3 reflects the concern of ecology with understanding ecosystem services and supporting adaptive ecosystem management. Although the questions explicitly deal with structure and flux, the causal and mechanistic relationships between structural variables and fluxes were only implied in the guiding questions. Phase II makes function explicit as an issue that cuts across socio-economic, ecological, and physical variables.

Refinement of Theories Supporting BES. Refinements of the Human Ecosystem Framework, patch dynamics, and the dynamics of community organization can be applied to BES. New conceptual frameworks must be added, including socio-spatial theory, resilience theory, biocomplexity, urban design theory, and theories of learning.

Human Ecosystem Framework. The Human Ecosystem Framework (HEF) identifies the roster of social, economic, and biogeophysical factors that may interact in urban ecosystems (Machlis et al. 1997, Pickett et al. 1997, Fig 2). Phase I of BES evaluated the adequacy of the HEF, and developed the biogeophysical resource component, adding spatial heterogeneity of ecological patterns and processes. In Phase II, we will focus on interactions among multiple components of the human ecosystem, rather than the first order, or pairwise, interactions that were the focus of Phase I. In addition, by examining feedbacks that are societally valued, we will use the HEF to operationalize the concept of ecosystem services (Daily 1997, Costanza & Folke 1997, Kinzig et



Machlis, et al. 1997

Figure 2. The Human Ecosystem Framework (HEF) identifies the roster of social, economic, and biogeophysical factors that interact in urban ecosystems (Pickett et al. 1997, Machlis et al. 1997). Phase I of BES evaluated the adequacy of the HEF, and developed the biogeophysical resource component, adding spatial heterogeneity of ecological patterns and processes. In Phase II, we will focus on interactions among multiple components of the human ecosystem, rather than the first order, or pairwise, interactions that were the focus of Phase I. In addition, by examining feedbacks that are societally valued, we will use the HEF to operationalize the concept of ecosystem services (Daily 1997, Costanza & Folke 1997, Kinzig et al. 1999, Farber et al. 2002).

al. 1999, Farber et al. 2002). The HEF underlies new hypotheses 1-2, 1-3, 1-4, 2-3, 2-4, 2-5, 2-6 and 3-5 listed in Tables 1, 2 and 4.

Patch dynamics treats any scale of spatial heterogeneity as a mosaic, whose elements and configuration can change through time. This concept is an important principle in ecology, and has contributed to the elucidation of the role of spatial control in biological populations, communities, ecosystems, and landscapes (Wu & Loucks 1995, Cadenasso et al. 2003). In Phase I, we applied patch dynamics to social and behavioral variables, generating social patch mosaics that integrate with ecological and hydrological patch mosaics (Grove & Burch 1997, 2003). This has opened the way for analyses of the reciprocal relationships between pattern and process in coupled natural-social systems (Grove et al. in press - b). We can also use patch dynamics as a tool to translate land use/land cover approaches from geography and GIS into ecology (Agarwal et al. 2002). Many researchers and decision leaders focus on land use/land cover, providing an interdisciplinary and practical link. However, studies of land use/land cover change must be enriched with ecological and social mechanisms (Pickett 1993, Agarwal et al. 2002). This motivated us to create a new classification system for metropolitan land cover (Cadenasso & Pickett 2002). The system challenges the assumptions of standard land use/land cover classifications, and hence represents a theoretical advance. The new system has high *categorical* resolution, and discriminates patch types based on a combination of vegetation and built structures and surfaces. We will use this scheme as a key for our new analysis of patch dynamics and linking ecological, hydrological, and social processes over time, testing new hypotheses 1-1, 2-1, 2-2 and 2-3 listed in Tables 1 and 2.

Community Organization. While the theory of community organization and succession is one of the oldest in ecology, in application to urban systems, there are opportunities for refinements. We highlight two: the causal role of exotic species, and the nature of disturbance. Exotic species are common in urban systems (Drayton & Primack 1996, Lonsdale 1999). However, there are many common and even rare native species in and around cities (Davis 1999). This provides the opportunity to explore the relative contributions of native and exotic species to ecosystem function. While this information will be important to managers and decision makers, our focus on exotic species goes beyond the strictly practical concerns of much research on exotic species (Stein & Moxley 1992). It is important to understand the mechanisms of exotic species invasion and impact *in parallel with* information on native species (Meiners et al. 2001, in press). In urban systems, it is important to understand the role of all species, and to generate information that permits effective management of both native and exotic species. The second need in community theory is to apply the concept of disturbance to urban systems. The concept of disturbance as a disruption of system structure that alters resources and environmental regulators, can be readily applied to different kinds of ecological systems (Pickett et al. 1989). However, the way to apply this concept in coupled natural-social systems is unclear, due to the different kinds of components that might be affected by disturbance (Klinenberg 2002). Therefore, a new research theme will be to assess how to use the concept in human ecosystems, and to design integrated studies to test the role of disturbance involving reciprocal interactions among people, institutions, and environments (see new hypotheses 1-4, 1-5, 1-6, 2-1 and 2-2 in Tables 1 and 2).

Socio-spatial Theory. The socio-spatial approach is a new synthesis in social science (Gottdiener & Hutchison 2000) that sees social interactions as being fundamentally spatial (Harvey 2000).

This theory recognizes many kinds of spatial differentiation, ranging from economic, to political, to cultural factors. An important new development in this realm is the recognition of lifestyle as a key social variable (Gottdiener & Hutchison 2000). Phase I of BES began exploring socio-spatial theory, and we will expand this to a major theme in Phase II. Changes in the spatial distribution of social processes (e.g., investment, disinvestments, government intervention) lead to alteration of urban form, due to uneven development (Krugman 1996). Throughout the United States, such dynamics have led to multicentered metropolitan mosaics (Thompson & Steiner 1997). Social scientists have recognized the need to incorporate ecological factors in the understanding of spatial differentiation (Gottdiener & Hutchison 2000), but they have too often relied on faulty ecological principles (Vasishth & Sloane 2002). The socio-spatial approach underlies new hypotheses 1-2, 1-3, 2-3, 2-4 and 2-5 (Tables 1 and 2).

Resilience. Classically, resilience has referred to the ability of a system to return to an equilibrium state after disturbance. However, ecologists have come to recognize that in non-equilibrium or evolving systems, this classical concept of resilience may fall short. Therefore, a new concept of resilience has been proposed, i.e. the ability of a system to adapt to changing internal or external processes (Holling 1994, Peterson et al. 1998, Holling & Gunderson 2002, Pickett et al. in press - b). The concept of resilience underlies new hypotheses 1-4, 1-5, 2-4 and 2-6 listed in Tables 1 and 2.

Biocomplexity. Concern with resilience is closely related to the concept of biocomplexity, introduced as a programmatic stimulus in the late 1990s (Colwell 1999, Michener et al. 2001). Resilience is associated with self-organization, which is an important characteristic of complexity. Additional features of complexity include emergence and non-linearity (Krugman 1996, Auyang 1998). These characteristics of complexity arise from its fundamental definition: “a multiplicity of interconnected relationships and levels” (Ascher 2001). In order to operationalize these abstract concepts in a coupled natural-social system, we have developed a framework that articulates complexity along three dimensions: spatial heterogeneity, historical contingency, and organizational connectance (Pickett et al. in press – a, Cadenasso et al. submitted). We will explore how these dimensions of complexity apply to disciplines in BES, and analyze how models of different degrees of complexity represented by each dimension, succeed in depicting integrated system function by testing hypotheses 1-1, 1-2, 1-6, 2-1, 2-3, and 2-6 listed in Tables 1 and 2.

Urban Design Theory. Articulating a theoretical aspect to the practical profession of urban design and planning is important for developing an interface between design and ecology (Spirn 1984, Ndubisi 1997, Lyle 1999). We have begun to explore integrated ecological design theory and practice through symposia, panels, and hands-on work in urban design studios. Applying the integration to creative urban designs for Baltimore’s vacant and underutilized lands will be an important broader impact of Phase II (see hypotheses 2-1, 2-4 and 3-4 listed in Tables 2 and 4).

Education Theory. Educators have long held experience to be a powerful motivator for learning (Dewey 1938, Darling-Hammond et al. 1995, NRC 2000). Underlying BES instructional modules is the assumption that science is best learned through engaging in scientific inquiry, and that a deeper understanding of ecological systems and appreciation for the natural world will arise as students connect with issues relevant to their surroundings, and make use of scientific

Table 1. New Hypotheses for Proposed Research under Question 1: How do the spatial structure of socio-economic, ecological, and physical features of an urban area relate to one another, and how do they change through time?

Hypothesis 1-1. A model of land cover designed to account for the complexity of urban areas as systems that intrinsically link human and natural components will better predict ecosystem functions such as N retention than a model that addresses urban areas as merely complicated systems in which natural and human components are unintegrated.

Hypothesis 1-2. Novel approaches to the classification of neighborhoods, based upon social group identity and status, are better predictors of variations in a) social and biophysical structure and b) community stability than traditional approaches using demography, social stratification, or environmental equity.

Hypothesis 1-3. The Genuine Progress Indicator is a better measure of quality of life or well-being. It should therefore correlate more closely with survey responses to quality of life questions than conventional measures of economic performance (i.e. GDP).

Hypothesis 1-4. System memory of past land use practices is a function of both slowly varying ecosystem state variables (e.g. groundwater chemistry, forest structure) and persistent social and economic patterns (e.g. residential patterns, infrastructure).

Hypothesis 1-5. Exotic plants and soil fauna are a significant component of disturbed landscapes, both agricultural and urban. Their patchy occurrences suggest that some are occupying new niches created by disturbance and therefore may be performing a fundamental role in biogeochemical cycling that may no longer be accomplished by native species.

Hypothesis 1-6. Distribution and abundance of bird species can be predicted from socioeconomic status, heterogeneity in land use, vegetation cover, and management decisions made by property owners and managers.

data and data collection protocols to do so (see hypothesis 3-2 in Table 4). Education in BES reaches beyond the classroom, to the broader community and public understanding. Here we see promise in the dynamic interplay between formal and non-formal institutions in helping all learners develop more sophisticated understandings of their local surroundings (see hypotheses 3-1, 3-3 and 3-4 in Table 4).

New Hypotheses and Research Activities

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

Hypothesis 1-1. A model of land cover designed to account for the complexity of urban areas as systems that intrinsically link human and natural components will better predict ecosystem functions such as N retention than a model that addresses urban areas as merely complicated systems in which natural and human components are unintegrated.

During Phase I, a new land cover classification, HERCULES, was developed (Cadenasso & Pickett 2002, Band et al. submitted, Cadenasso et al. submitted, Grove et al. in press, b, Fig 3). This new classification captures the heterogeneity of urban systems using characteristics hypothesized to influence ecosystem function. In phase II, we will pursue three goals. First, the elements within the HERCULES classes must be quantified, and the classification must be automated so that it can be applied more extensively. Second, the link between HERCULES and ecosystem function needs to be tested to determine whether HERCULES is a better predictor than standard classifications (e.g. Anderson et al. 1976). Finally, changes in land cover must be described and quantified.

The type and density of structures, and the proportion of different vegetation textures define HERCULES patches. The elements within each patch type must be quantified to increase the rigor of the class definitions. Transects distributed randomly over the imagery will be sampled for the elements intersected, such as roof, lawn, tree, street. The transect approach retains adjacencies. The data will define the HERCULES classes based on percent cover of each element. We also intend to automate HERCULES by using "eCognition" software, which will be trained to recognize objects and to classify the imagery based on the pattern of the objects. The automation of HERCULES will be used to determine spatially explicit changes in land cover in the Baltimore metropolitan region based on historical and contemporary imagery.

HERCULES will be integrated with ecological, social, and physical data from BES to determine whether structure is linked to system function. We will determine how land cover is related to N retention, C storage, consumer behavior, biodiversity and hydrology. Contemporary ecosystem functions in the social, physical and biological realms quantified in BES may reflect past land cover. Comparison of variables with past patterns of land cover will detect historical lags in the system, which are a component of biocomplexity. To accomplish these analyses, the HERCULES landscape representation will be incorporated as the patch level in the RHESSys model (Fig 1, Band et al. 2000, 2001). This model embeds patches within a hierarchy structured as catchment -> hillslope -> patch -> strata. Strata represent different land covers and canopy elements within a patch, allowing for process representation of their interactions and providing a

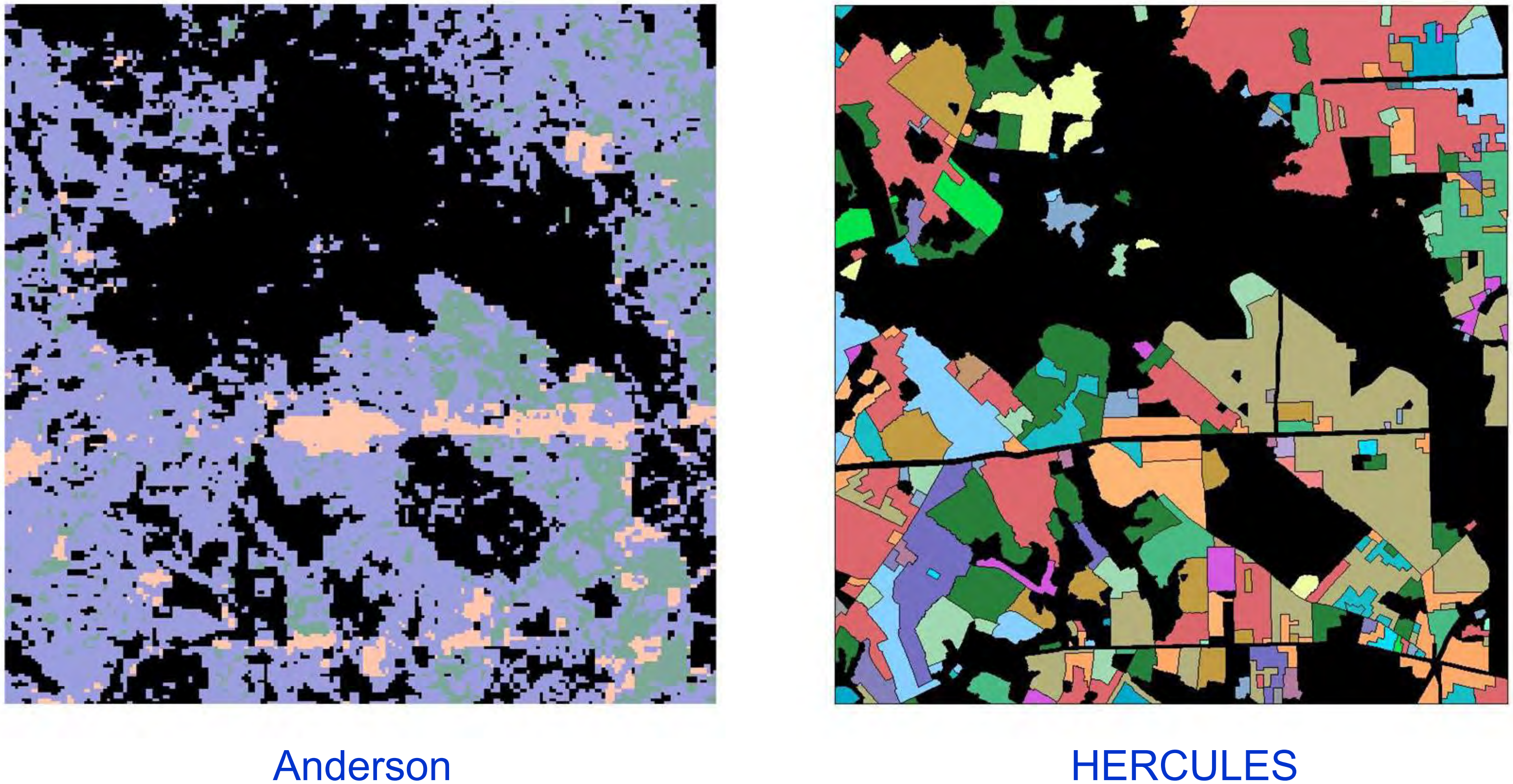


Figure 3. Comparison of the new BES urban land classification system (HERCULES) with the "industry standard" classification developed by Anderson et al. Anderson classifies the region into three classes, high and low intensity residential (green and blue, respectively) and commercial/industrial complexes (pink) while HERCULES defines classes along three axes: 1) building type and density, 2) vegetation type and proportion cover, and 3) the presence of impervious surfaces. We hypothesize that HERCULES will be a more effective predictor of ecosystem functions (e.g., nitrogen retention) in urban and suburban areas than Anderson, because it does a better job of indexing the complex factors underlying ecological functions. For nitrogen, its explicit inclusion of the mix of impervious and pervious surfaces should be a strong indicator of hydrologic alteration and loss of sinks (areas that prevent the movement of nitrogen to surface waters), and its treatment of vegetation structure should be a strong indicator of soil and vegetation storage of nitrogen, which we hypothesize is notably high in the young, actively growing vegetation in urban and suburban ecosystems.

mechanism to describe and vary the complexity of the HERCULES classification. Processes include between and within patch fluxes of water, carbon and nutrients, as well as direct and indirect human individual and institutional augmentation and alteration of these fluxes (Fig 4). To date, we have been refining patch descriptions in RHESSys to incorporate the range of significant elements within suburban landscapes (Law 2004). In the next phase of the BES, we will explore the integration of the HERCULES patch dynamics classification with the RHESSys spatial process model to study the existence and significance of key hydrological, ecological, and socioeconomic feedbacks within the urban ecosystem. In Phase I of BES, we initially worked at the "edge of development," focusing on the BES forested reference watershed (Band et al 2001), low density suburban catchments (Law 2004), and then medium density suburban catchments. In Phase II, small catchment sampling and model development will be applied to more urbanized watersheds (Table 3, page 2-20) and Watershed 263 (described below), within the framework of the HERCULES classification. Following the framework of progressively increasing complexity of patch description, we will intensify the collection and linkage of household and neighborhood socioeconomic information to include irrigation and fertilization patterns, improving the ability of the model to represent urban ecosystem features. We will improve model representation of septic sources, and build stochastic representations for sanitary wastewater sources from the urban sewer system (e.g. surcharge, leakage) as well as input/infiltration (I/I) losses from stream and groundwater into the sewer system (described below).

To "leverage" LTER funds to use HERCULES to explore relationships between ecosystem structure and function, proposals have been submitted to the NSF Biocomplexity competition on Coupled Human and Natural Systems (December 2003) for evaluation of the ability of HERCULES to improve our prediction of nitrogen retention (Pickett, Cadenasso, Band & Groffman, PIs) and to the NSF Ecosystem Studies program (July 2003, to be resubmitted in July 2004) to use HERCULES to analyze carbon dynamics (Jenkins, Cadenasso, Groffman, PIs).

Hypothesis 1-2. The classification of neighborhoods, based upon social group identity and status are better predictors of variations in a) social and biophysical structure and b) community stability than traditional approaches using demography, social stratification, or environmental equity.

This hypothesis is that "ecological prestige" drives household land management. We will develop and test this hypothesis by comparing 1) demographics (population density), 2) social stratification and environmental equity (income, education, and race), and 3) social identity and status using the Potential Rating Index for Zipcode Markets (PRIZM®, Claritas; Fig 5). However, because PRIZM does not capture all of a neighborhood's important social and ecological characteristics, we must extend these marketing data to include air and water quality, safety, presence of lawns, trees, and gardens (e.g., Weiss 2000). Determining whether these factors are associated with different PRIZM classes is crucial for understanding how social groups differentially affect ecological structure. Thus, we propose the following hypotheses. First, PRIZM classes modified by *social ecology* data (PRIZM-SE) will better predict vegetation structure (HERCULES) than demographics (population density), social stratification or environmental equity (income, education, and race). The distribution of vegetation structure is temporally complex, with legacies and time lags. Thus, historic social neighborhood characteristics (*sensu* PRIZM-SE), will better predict the present distribution of vegetation

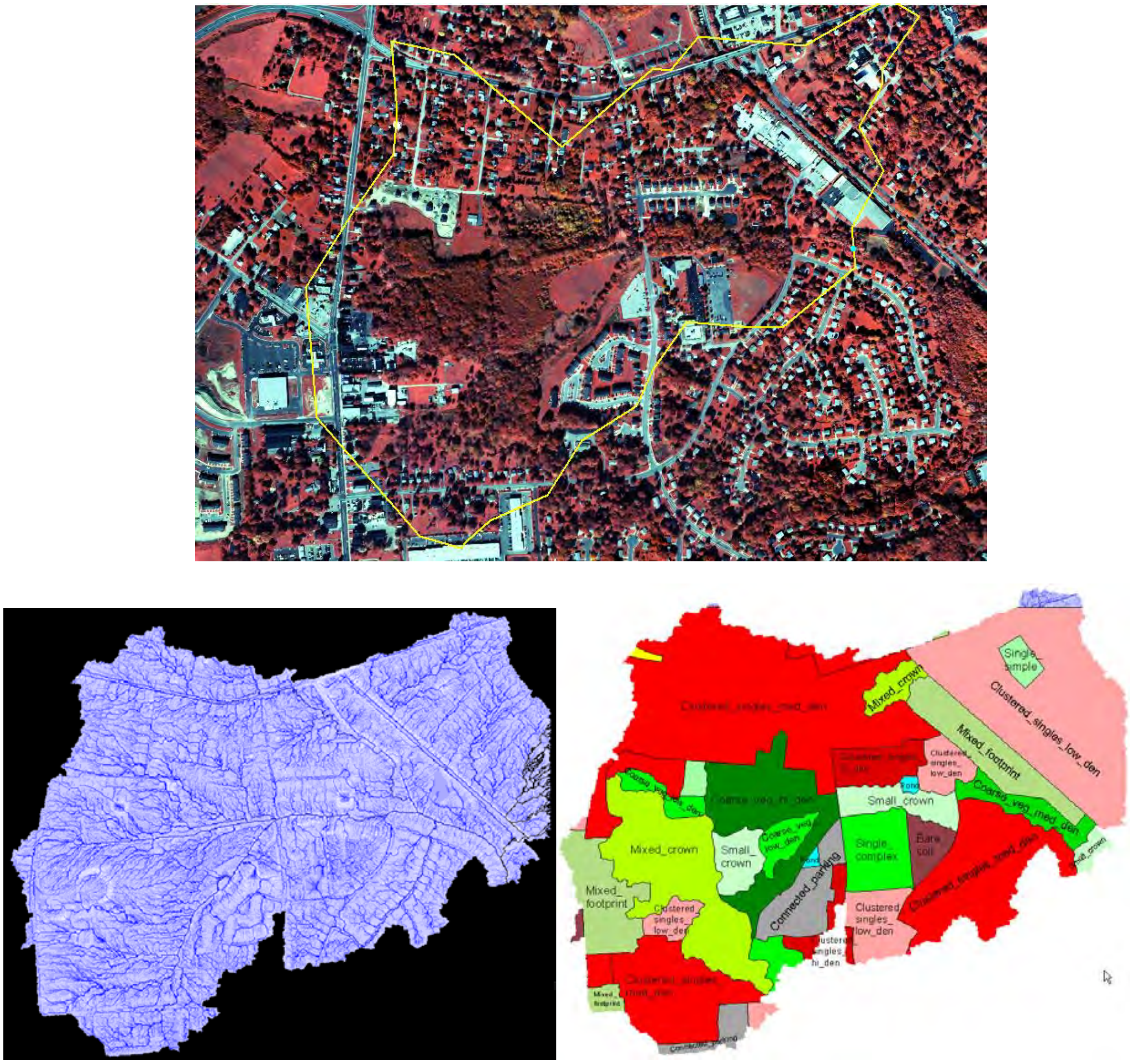


Figure 4. Three representations of the Glyndon suburban catchment; high resolution color infrared imagery (top), the HERCULES patch classification (bottom right) and flow paths derived from a 1m LIDAR- derived DEM (bottom left). Note that the LIDAR resolves street drainage, with flowpaths down both curbs of the streets, detention ponds, and other infrastructure drainage features. A major effort of the proposed research is to incorporate the HERCULES landscape representation as the patch level in the RHESSys model. This model embeds patches within a hierarchy structured as catchment -> hillslope -> patch -> strata. Strata represent different land covers and canopy elements within a patch, allowing for process representation of their interactions and providing a mechanism to describe and vary the complexity of the HERCULES classification.

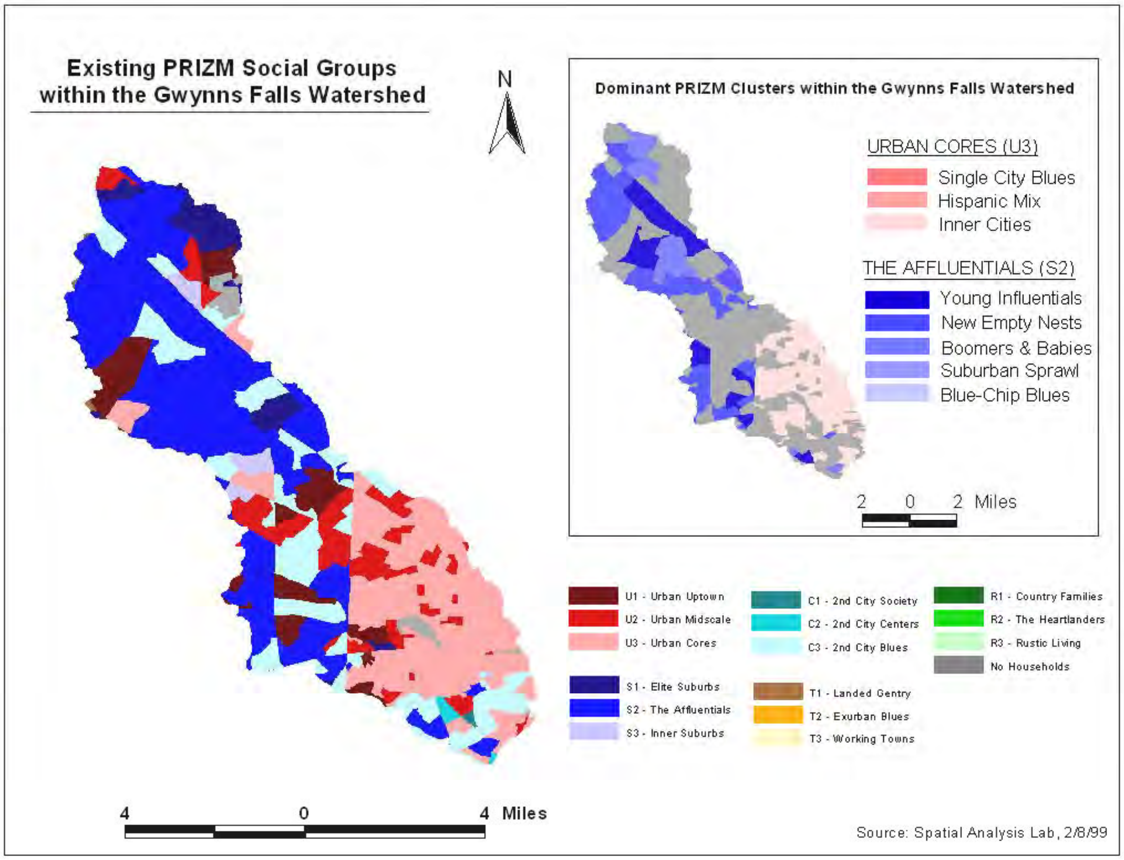


Figure 5 Claritas' PRIZM (Potential Rating Index for Zipcode Markets) classification system to characterize neighborhoods at the US Census Block Group level for the Gwynns Falls watershed. The PRIZM classification system categorizes people and their urban, suburban, and rural neighborhoods into lifestyle clusters using Census data about household education, income, occupation, race/ancestry, family composition, and housing and associates these clusters with characteristic household tastes and attitudes using market research surveys, public opinion polls, and point-of-purchase receipts. PRIZM essentially represents a spatially-explicit classification of group identity and social status based upon reference group behavior theory and consumer behavior data in terms of household preferences for a wide spectrum of market and non-market goods and services (Grove & Burch 2002). Because PRIZM is designed to predict household preferences for market goods and services, it is well-suited for understanding variations in household land-management preferences and behavior. In BES, we adapt and apply what we call PRIZM-SE (social ecology) to extend beyond interpretations of existing, marketing data through the collection and incorporation of supplemental, social and ecological primary data. These supplemental data are necessary because PRIZM does not capture all of a neighborhood's social and ecological qualities.

structure than contemporary PRIZM-SE classifications. The distribution of vegetation structure is also organizationally complex, and measures of social stratification, which reflect access to public and private investments at the municipal level, will be better predictors of variations in woody vegetation structure on public lands and rights-of-way than PRIZM-SE at the neighborhood level. Also, historic measures of social stratification will be better predictors of variations in vegetation structure than present measures of social stratification. These questions also address organizational and temporal complexity (Pickett et al. in press - a). Finally, PRIZM-SE will be a better predictor of neighborhood stability, social identity, and social order than demographics, social stratification or environmental equity.

We will use our long term demographic and socioeconomic data from the US Census to measure changes in population density, income, education, and race at the neighborhood level (1900-2000). We will use variables from these datasets to create historic "pseudo-PRIZM" classifications comparable to current PRIZM classifications obtained from the Claritas Corporation. We will continue our field observation survey, stratified by PRIZM class, median housing age, and municipality. BES will purchase annual, parcel-level, property GIS data for the Baltimore Metropolitan Region from the Maryland Department of Planning. Finally, we will use "bottom-up" patch delineations using Geographic-Weighted Regressions (GWR) and hedonic analyses to cross-validate PRIZM-SE at the Census Block Group level.

We will address one of the most challenging problems in housing economics -- the delineation of housing submarket boundaries (Dale-Johnson 1982, Bourassa, et al. 2003, Goodman & Thibodeau 2003, Thibodeau 2003), which are complex entities defined by geographic and socio-economic relationships. This is an important component of socio-spatial differentiation. Higher order statistical measures of GWR hedonic regressions, parameter estimates, and test statistics will be spatially plotted to delineate housing submarkets. Hypotheses concerning locational features, e.g., nearby tree cover, can test willingness to pay for tree cover.

While LTER funds will support this research, additional funds come from Morgan Grove's 5 yr Presidential Early Career Award for Scientists and Engineers (PECASE) award, the Maryland DNR Forest Service, the US Forest Service, and the Advanced Spatial Analysis course at the University of Vermont, taught by Austin Troy and Grove.

Hypothesis 1-3. The Genuine Progress Indicator is a better measure of quality of life or well-being than conventional measures of economic performance (i.e. GDP). It should therefore correlate more closely with survey responses to quality of life questions.

We will construct a Genuine Progress Indicator (GPI - a version of the Index of Sustainable Economic Welfare) for Baltimore. The GPI is a more comprehensive assessment of economic progress than conventional measures like Gross Domestic Product. GPI adjusts for income distribution effects, the value of household and volunteer work, costs of mobility and pollution, and the depletion of social and natural capital. Coupled with the Social Capital trend analysis (hypotheses 2-3 and 2-4), this information is of particular interest to the Baltimore-based Parks & People Foundation as they seek to better understand the relationship between neighborhood activism and environmental revitalization throughout the Baltimore region. To test our hypothesis, we will calculate the GPI for Baltimore city, the Baltimore metro area, and the state of Maryland and compare the results to both the conventional economic measures and to the survey data on quality of life also being collected as part of BES. This work will be leveraged with ongoing work in Burlington, VT and work at the national and global scales.

Hypothesis 1-4. System memory of past land use practices is a function of both slowly varying ecosystem state variables (e.g., groundwater chemistry, forest structure), and persistent social and economic patterns (e.g., residential settlement, infrastructure).

Past land use influences contemporary flows of nutrients, sediment and water through the landscape and into aquatic/estuarine systems. These fluxes, which are also affected by geology and physiography, influence available resources for humans and hence affect social and economic structure. As people shift their resource exploitation strategies, social and economic changes result. To understand how humans manage resources, and to predict social and economic ramifications of future change, we will document how major resources have changed over periods of both anthropogenic and climatic change, addressing questions such as; what are the social, economic and political consequences of the loss of a major resource such as the oyster today, the end of chrome mining in the 1800s, and the shrinking tobacco market in the 1700s?

We will use both historical and paleoecological records to test this hypothesis. Most patch dynamic studies are limited to time periods covered by remote sensing and aerial photography. Yet the major human transformations of the landscape occurred over centuries. We will use the original property boundaries in the Gwynns Falls watershed to interpret the effect of colonial and early Federal period property allocation (Fig 6) on modern property boundaries and land use (Bain & Brush submitted), and to examine whether these act as a complex legacy for vegetation or social patch structure. Sediment cores taken throughout the Gwynns Falls riparian area will be used to predict the length of time that agriculture practiced 200 years ago is likely to affect the ecology of these waterways. Changes in geomorphology are being reconstructed from historical maps and records of bridge building, land filling, dredging, etc., and will be compared to contemporary LIDAR data to document landform evolution. Historical records will be used to study the effect of shifting resources (farming, lumbering, iron mining, etc) on the social and political structure, as different ethnic groups and migrants participated in different industries. Sediment cores from the mouth of the Gwynns Falls, Baltimore Harbor and the Chesapeake Bay will be used to reconstruct changes in watershed activities and regional resources.

This research will be leveraged by a NSF Biocomplexity grant "Comparative Stability and Resiliency of Ecosystems: Five Centuries of Human Interactions with the Environment on the Eastern Shore of Virginia" (Brush, co-PI), and by funds from grants from NOAA and EPA.

Hypothesis 1-5. Exotic plant and soil fauna species are significant components of species diversity in urban ecosystems. Their patchy occurrences suggest that some are occupying new niches created by disturbance, and may therefore be performing a fundamental role in biogeochemical cycling no longer accomplished by native species.

Exotic plant species are an important part of the urban landscape (Hope et al. 2003). While urban tree and shrub species are predominantly native, about 50% of the Gwynns Falls riparian

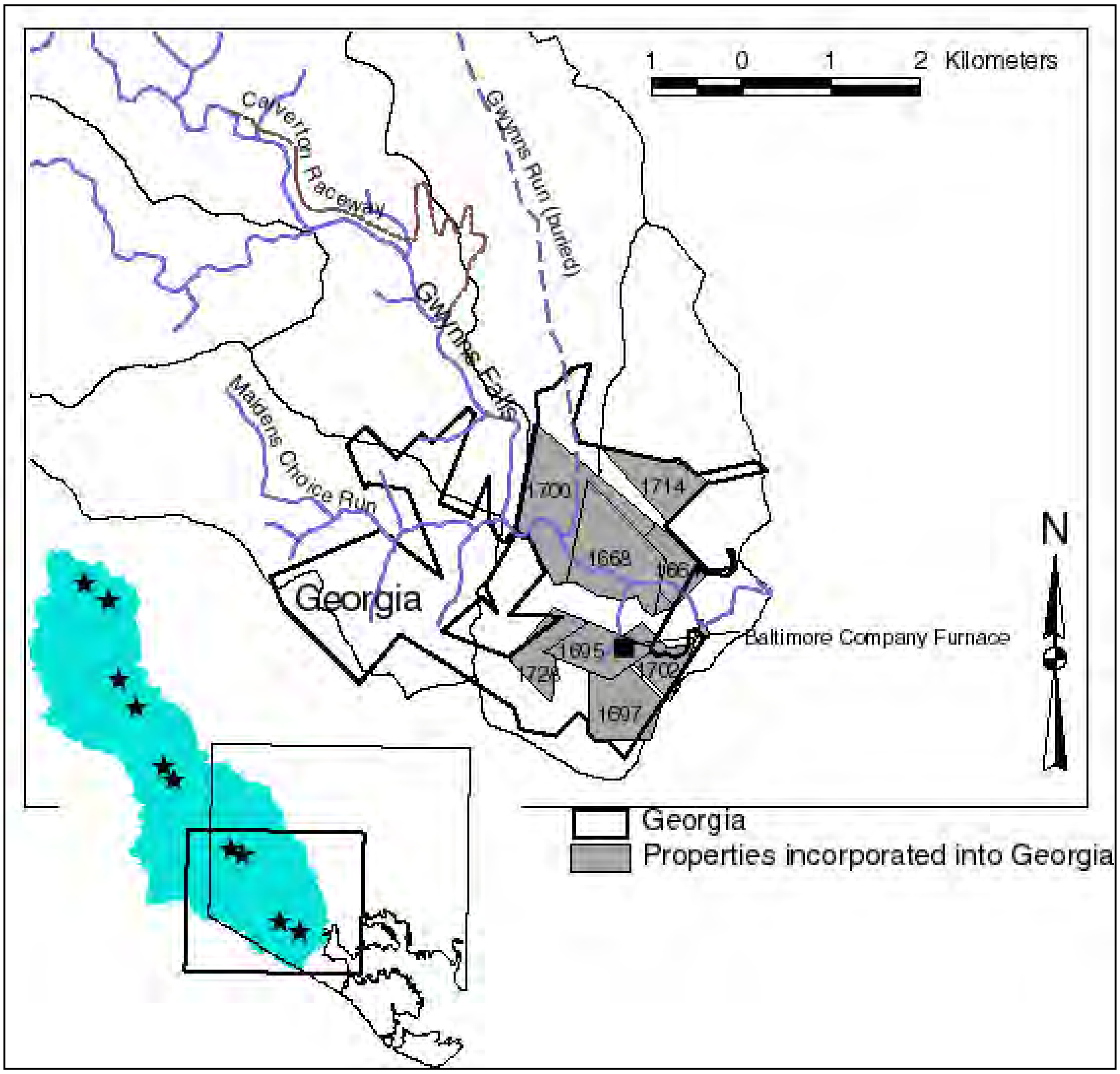


Figure 6. Early colonial land use in the lower portion of the Gwynns Falls Watershed. Inset: Gwynns Falls watershed is in blue and the 10 stars indicate mills established by 1776. The City of Baltimore is outlined in black. The thick black box outlines the area contained in the detailed map. The areas in gray are properties incorporated into Georgia, an early land grant (shown with thick line) in 1732 (years of the earlier grants are indicated on the properties). Notice the emphasis of the Georgia claim on riparian zones (cf. to the earlier grants adjacent to water). Dotted lines show the approximate paths of the buried Gwynns Run and the Calverton Raceway, both engineered disruptions of riparian hydrology. Gwynns Run is a target of the sanitary sewer infrastructure improvement program recently started by the City of Baltimore.

herbs are exotic. Our vegetation and soil surveys have shown that the majority of exotic herbs occupy discrete areas suggesting that the disturbed landscape, both agricultural and urban, provides habitats for new species. However, we do not know whether the increased species diversity due to exotics has altered *functional* diversity.

We have quantified the distribution of exotic species in riparian and upland plots throughout the Gwynns Falls Watershed (Brush et al. in preparation). In Phase II, we will analyze the relationships between the distributions of exotic plant and soil invertebrate species, and past and present patterns of land cover, biogeophysical factors, and socio-economic factors.

The performance of exotic species relative to native species must be examined in order to test the widespread assumption that exotic species are always a negative factor in ecosystems. Such a conclusion may be premature in urban systems. Ecologists and managers need to know whether exotic species in urban systems are performing functions no longer accomplished by native species. In order to quantify the role of exotic plant species, their growth, nutrient dynamics, and associations with microbial communities and functions must be known. We propose to examine how native and exotic species differ in performance characters listed above. We further propose to examine the relationship of performance to different habitats and patch types along the urban to rural gradient. For soil invertebrates, we will compare physiological and life history traits of populations in their native and new habitats. We will also compare characteristics of invasive species and closely related species with a restricted area of distribution. Three taxonomical groups will be examined: Collembola, Oligochaeta and Oniscidea.

A second important question arises from the common strategy to remove exotic species in restoration efforts. Before expending the resources to remove exotics, it is important to know what difference their removal makes in the system, and how persistent any effects of exotics are. This suggests a long-term experimental approach. We propose to remove exotic species from sites that park managers wish to restore, and subsequently measure soil fertility and microbial activity, and changes in the native plant community in response to the removal. Such removals are planned by the Baltimore City Department of Recreation and Parks, with the support of high school interns to be supervised by staff of the Parks & People Foundation. This is a new application that opens an opportunity for before and after, and reference site comparison of exotic plant removals. BES PI Cadenasso and URI Coordinator Cox are part of the working group to define the management treatments to be done on exotic species in city parks. The response of soil invertebrates can also be included in these measurements.

To accomplish this work, BES funds will be leveraged through proposals to study the relationships between microbial communities and exotic plant species, being developed by Brush, Cadenasso, and a microbiologist at JHU, to be submitted to NSF in July 2004. Szlavecz, Groffman and Pouyat have submitted a proposal to NSF Ecosystems in January 2004 for analysis of exotic earthworm distributions and effects on N cycling processes in riparian areas. Other proposals on the role of exotics will be submitted to NSF and possibly USDA.

Hypothesis 1-6. Patterns of bird abundance can be predicted from socioeconomic status, heterogeneity in land use, vegetation cover, and management decisions made by property owners and managers.

Table 2. New Hypotheses for Proposed Research under Question 2: What are the fluxes of energy, matter, capital, and population in an urban system; how do they relate to one another, and how do they change over the long term?

Hypothesis 2-1. Urban ecosystems have altered nutrient cycling and export patterns which are functions of augmented sources, and changes in sink patterns and strengths related to altered land cover and hydrologic flows:

- Leaks from sanitary sewers represent the major source of nitrogen (N) in urban streams as leaks and surcharging provide input of nutrients proximal or directly into the channel.

- Reforestation of urban watersheds can alter hydrologic dynamics and N retention.

- Interactions between shallow groundwater, sanitary sewers and stream channels influence delivery of N to streams, instream N dynamics, and watershed N retention.

- Lawns and other natural and semi-natural pervious surfaces have high potential for N retention, higher than "natural" forest ecosystems, because they are dominated by actively growing, soil organic matter-accumulating plant communities.

- Riparian zones do not function as hotspots of N removal in urban ecosystems as they do in many less human dominated ecosystems.

- Instream retention of N will not be a major process in urban streams as it is in many less human dominated ecosystems.

- Dissolved organic N is a dynamic and significant component of N export from urban streams.

Hypothesis 2-2. Carbon fluxes in urban and suburban ecosystems are dominated by natural processes (photosynthesis, respiration).

Hypothesis 2-3. Novel approaches to the classification of neighborhoods, based on social group identity and status, yield better predictors of social and biophysical functions than traditional approaches using demography, social stratification or environmental equity.

Hypothesis 2-4. Neighborhood-level environmental quality, well-being, public health, and conservation of public lands will co-vary with social capital.

Hypothesis 2-5. Neighborhood stability, well-being, and environmental quality will co-vary with the delivery of ecosystem goods and services and the delivery of ecosystem goods and services will co-vary with Baltimore neighborhood PRIZM clusters.

Hypothesis 2-6. Integrated dynamic spatial monitoring can be used to forecast land use changes, economic activity, migration patterns and quality of life effects within the region.

We will apply socio-spatial and lifestyle theories described above to test our hypotheses regarding avian community structure. We will test the above predictions using bird monitoring data from five different kinds of sites. The linchpin of these sites will be a randomly drawn subset of the 202 spatially extensive UFORE plots (N=50). Data collection by other BES researchers at these sites will allow us to estimate the relative importance of factors such as vegetation, socioeconomic status, and land use type for determining avian distributions. The design also allows us to compare the efficacy of HERCULES and other patch classification procedures for predicting bird community structure. Three additional monitoring efforts will separately measure the impact of the following factors on distributions and abundance of bird species: neighborhood socioeconomic status (selected using PRIZM, N=50), smaller scale management decisions by property owners (Cub Hill, N=10), and restoration of vegetation cover (Watershed 263, N=27). Finally, we will place the urban environment in context by monitoring birds along the urban-rural gradient in similar sized forest patches selected to correspond to other BES forest monitoring. Cross-site comparisons have been conducted with bird monitoring projects at Central Arizona-Phoenix LTER (Warren et al. in prep.), and future monitoring efforts will facilitate these comparisons by using parallel survey protocols and site selection processes (UFORE, neighborhood socioeconomic status). We plan to leverage LTER funds by seeking funding for studies of the permeability of urban patches to bird movement and contrasting approaches for managing urban pest species such as crows and blackbirds. We will also incorporate volunteer projects with Baltimore Bird Club and the National Wildlife Federation's Backyard Wildlife Program.

Question 2: What are the fluxes of energy, matter, and human, built and social capital in an urban system; how do they relate to one another, and how do they change over the long term?

Hypothesis 2-1. Urban ecosystems have altered nutrient cycling and export patterns which are functions of augmented sources, and changes in sink patterns and strengths related to altered land cover and hydrologic flows.

Our long-term watershed research centers on the 17,150 ha Gwynns Falls watershed, extending from the urban core of Baltimore, through older urban residential (1900–1950) and suburban (1950–1980) zones, rapidly suburbanizing areas and a rural/suburban fringe (Fig 7; Table 3). Our long-term sampling network includes four main channel sites along the Gwynns Falls as well as several smaller (5-1000 ha) watersheds within or near the Gwynns Falls. The longitudinal, main channel sites provide data on water and nutrient fluxes in the different land use zones of the watershed (suburban, rapidly suburbanizing, old residential, urban core), while the smaller, more homogeneous, watersheds provide data on specific land use types (forest, agriculture, suburban, urban).

BES stream gauging stations are maintained by the US Geological Survey. Weekly water chemistry samples are collected (subsamples filtered) and stored in 150 mL Nalgene bottles. Blanks and spikes are processed along with samples in our laboratory at the University of Maryland Baltimore County (UMBC) each week and are shipped to IES for chemical analysis. A Dionex LC20 series ion chromatograph is used to quantify nitrate, sulfate and chloride, and an Alpkem RFA 300 continuous flow analyzer is used for phosphate. Total nitrogen and

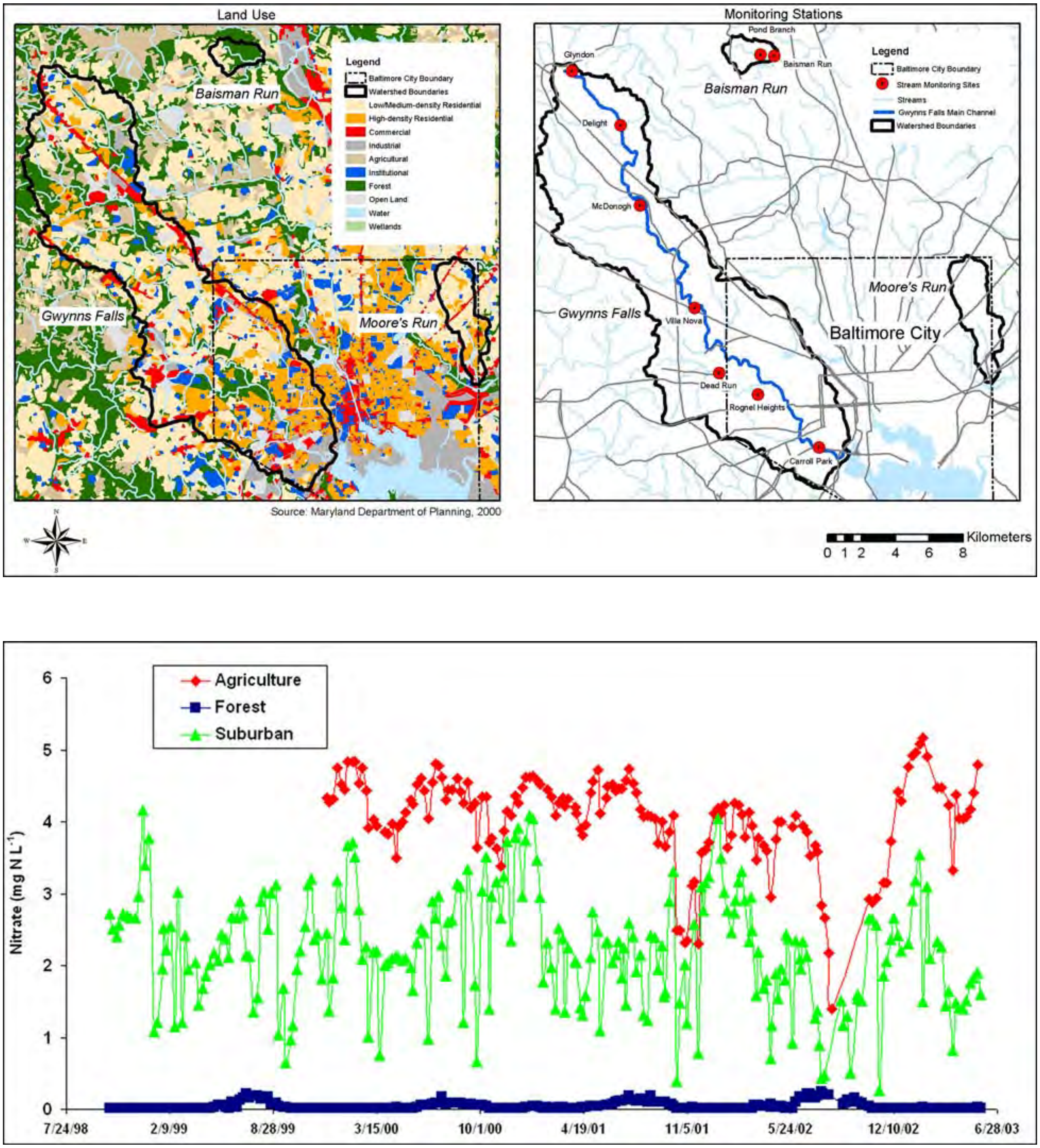


Figure 7. Top – maps of the Gwynns Falls watershed showing dominant land use patterns and the location of BES long-term monitoring sites (described in detail in Table 3). Bottom - weekly nitrate concentrations in forested reference, suburban and agricultural streams sampled by BES from Fall 1998 – Summer 2003. From Groffman et al. (2004).

Table 3. Characteristics of Gwynns Falls main channel watershed reaches and completely forested, agricultural, suburban and urban small and medium size watersheds. From Law et al. (submitted).

Station	Land use/context	Total drainage area	Reach drainage Area	Population density	Land Use: Forested	Residential	Agriculture	Impervious
		ha	ha	per ha	%	%	%	%
Main channel reaches								
Glyndon	Suburban	81	81	9.4	4	47	0	0
Gwynnbrook	Suburban	1,066	985	16.4	11	68	6	6
Villa Nova	Suburban/urban	8,348	7,282	12.2	22	50	8	8
Carroll Park	Urban	16,278	7,930	19.7	17	52	5	5
Small and medium watersheds								
Pond Branch	Forested	NA	32.3	0	100	0	0	0
McDonogh	Agriculture	NA	7.8	0	0	0	100	100
Baisman Run	Suburban/forest	NA	381	1	66	34	1	0
Dead Run	Suburban/urban	NA	1414	12.6	7	43	41	3

NA – Not applicable.

phosphorus are analyzed by persulfate digestion followed by analysis of nitrate and phosphate. Nitrate in these digests is analyzed on a Lachat Quikchem 8000 flow FIA. The weekly BES samples are analyzed for *E. coli* using standard techniques as well as by DNA molecular (standard PCR and RAPD approaches) and immuniomagnetic electrochemiluminescence (IM-ECL) techniques for the pathogens *E. Coli* 0157, *Cryptosporidium*, and *Giardia* (Shelton et al. 2003, submitted). Caffeine (a tracer of wastewater) is analyzed periodically using a deactivated silica gel column and a gas chromatograph with mass spectrometry (Buerge et al. 2003). Our previous research, as well as work in the CAP LTER (Baker et al. 2001), showing surprisingly high nitrogen retention (~75%) in urban watersheds, suggests the questions we will address in new research. We propose these key activities:

1. **Evaluating response in watershed nitrogen exports to improvements in sanitary sewer infrastructure.** In April 2002, the city of Baltimore reached a consent decree agreement with the Department of Justice, the Environmental Protection Agency and the state of Maryland to upgrade its sanitary sewer infrastructure to bring the city into compliance with the Clean Water Act. The improvements will cost approximately $940 million over 14 years to end chronic discharges of raw sewage into local waterways. Details of the consent decree, including the construction schedule are posted at http://www.ci.baltimore.md.us/government/dpw/images/Consent%20Decree_final.pdf and http://www.usdoj.gov/opa/pr/2002/April/02_enrd_252.htm.

The consent decree represents a nearly $1 billion experimental manipulation of the BES main study watersheds, and is a centerpiece of our proposed new LTER research. Our six years of weekly stream sampling provide a strong pre-treatment dataset for this "natural" experiment. The consent decree specifies which streams will be most affected by infrastructure improvements allowing us to make predictions about which of our long-term monitoring sites will be "treated" and which will serve as "reference" sites. While the Dead Run and Carroll Park sites will be significantly affected by infrastructure improvements, our other long-term sites will function as forested (Pond Branch), agricultural (McDonogh), unsewered residential (Baisman Run) and sewered residential (Glyndon, Gwynnbrook, Villa Nova) reference sites. To further our evaluation, we will add two sites to our weekly sampling network, Maidens Choice and Gwynns Run, which are heavily contaminated with sewage and are the target of major infrastructure improvements under the consent decree. We already have a full year of weekly data from Gwynns Run, which enters the mainstem of the Gwynns Falls just above our Carroll Park station. We estimate that this small, but heavily contaminated, stream contributes from 30 – 50% of the N load at Carroll Park.

We hypothesize that sewage leaks constitute > 50% of the N load in BES streams and that infrastructure improvements will markedly reduce N export from BES watersheds. Further, we hypothesize that a trend of downstream decreasing NO_3^- concentrations, measured in Phase I, will be enhanced as this intervention targets urban areas with a high density of sanitary sewers. We further suggest that because even new sanitary sewer systems are not water tight, there will still be significant contamination after infrastructure improvements. We will test these hypotheses by quantifying changes in total N loads as well as indicators of sewage contamination (e.g., fecal coliforms, caffeine).

2. Evaluate the hydrologic and biogeochemical response to aggressive reforestation of an urban watershed. Funding from USFS and the City of Baltimore is being used to assess neighborhood greening and revegetation as a strategy to improve storm water quality and reduce urban runoff to the Chesapeake Bay. The project is being conducted in a 364 ha watershed defined by the storm drain network containing 21 km of pipes of $\geq$ 1m diameter, and emptying into Baltimore Harbor through a 10 m diameter outfall. This entirely urbanized drainage, labeled Watershed (WS) 263, is home to 30,000 residents, and contains 30% public and private open space, some of which is accounted for by 976 vacant residential lots (30 ha). The WS 263 project is intended to be a prototype for non-point management of storm water in urban systems based on sound science and community participation. In fiscal 2003, $700,000 was devoted to 1) vegetation, soil, and infrastructure mapping; 2) establishing gauging stations for 2 small sewersheds and the outfall; 3) acquiring social-demographic data; 4) community interaction and revitalization; 5) application of HERCULES; and 6) calibrating a model to run scenarios of various Best Management Practices. The WS 263 project will serve as a centerpiece for integrated soil-hydrologic-vegetation-social research in Phase II.

The project will test the hypothesis that reductions in impervious surface and increases in vegetation will result in significant changes in urban hydrology and N retention. We will compare small storm sewer watersheds in WS 263 to those that are part of the BES long-term monitoring network. We will use a "before and after control impact design" (BACI) to: 1) characterize soil, vegetation, and water resources of WS 263; 2) develop baseline measurements of water quantity and quality (heavy metal and organic contaminants, nutrients, pathogens, and coarse debris) for the entire WS 263 and two nested sub-watersheds; 3) identify potential sources of contaminants in each of these watersheds; 4) further develop and apply the RHESSys hydroecological model to represent urban vegetation, soil and impervious surface mosaics to simulate and study water, carbon and nutrient cycling and interactions in this setting and 5) develop and test a UFORE hydrology module to foster interface between science and policy and management. Rain and continuous flow gauges, and storm water sampling stations will be constructed at the paired sub-storm sewersheds in WS263. Samples will be analyzed for contaminants and coarse debris at UMBC, pathogens at the Agricultural Research Service in Beltsville, MD, and nutrients at IES. We will then coordinate with the Parks & People Foundation to implement discrete restoration practices, focused on reforestation, for each of the paired watersheds and continue monitoring storm events. Social science responses will be monitored as described under hypothesis 2-4.

3. Groundwater research. To date BES hydrologic data have focused on the surface component of the hydrologic cycle. The location of the aquifer potentiometric surface and the magnitude and direction of groundwater flow are unknown. These hydrologic data are essential to couple with long-term observations of ecological and biogeochemical processes in watersheds, and for testing our hypothesis that there are dynamic interactions between shallow groundwater, sanitary sewer infrastructure and natural stream channels that influence instream N dynamics and watershed N retention. During Phase II, potentiometric surfaces at low flow and high flow will be mapped by sampling water levels in all accessible existing wells, which are presumed to number in the hundreds. This survey will be conducted by USGS in cooperation with BES. The net flux of groundwater into or out of a stream reach using seepage transects provides only an

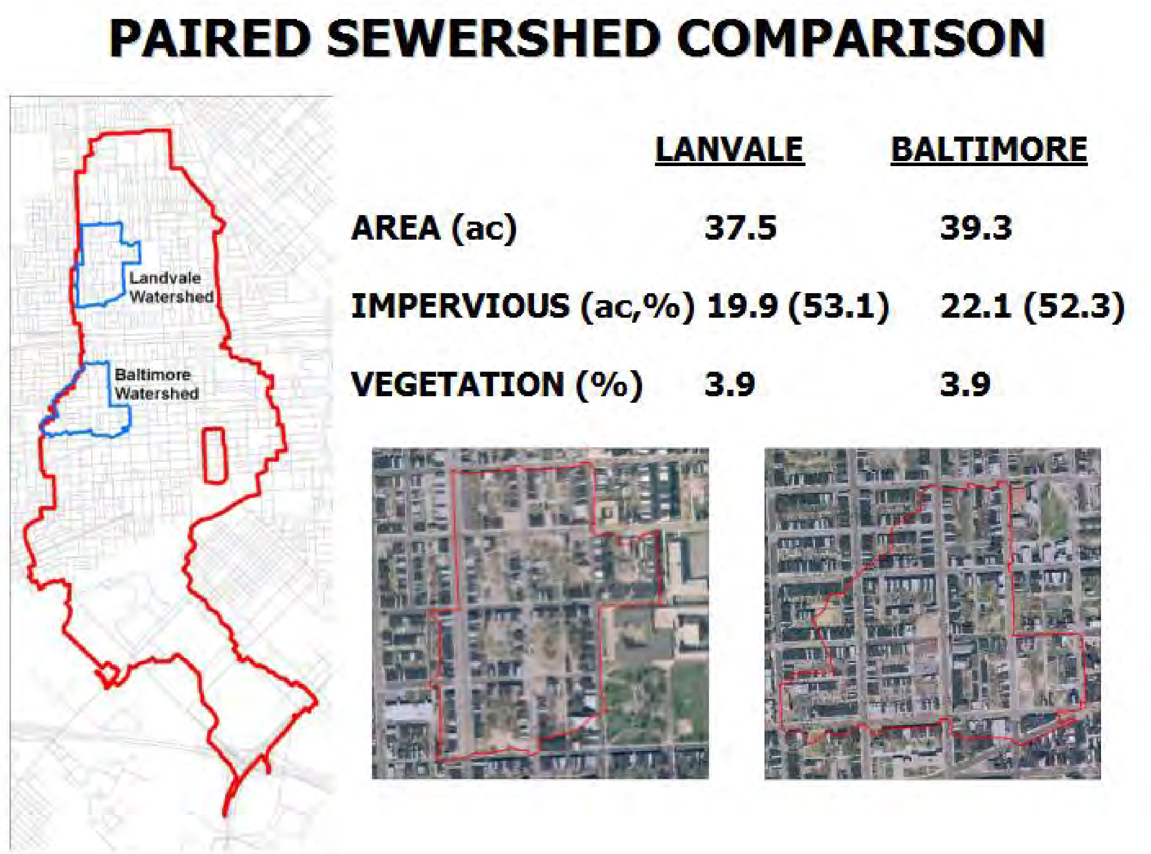


Figure 8. Study design for the Watershed 263 project. This 364 ha storm drain watershed (or sewershed) is home to 30,000 residents and is entirely urbanized with mixed industrial, institutional, and residential land uses. The overall goal of the W263 project is to develop a model of urban watershed hydrology and management that is based on sound scientific investigations and community participation. Research will occur at multiple scales, with observations made at the scale of an individual plot (e.g., a plot in a vacant lot), city block (e.g., street gutter), or stream reach to watersheds the size of 10-100 ha and to the entire 364 ha watershed. We will 1) characterize soil, vegetation and water resources of WS 263; 2) develop baseline measurements of water quantity and quality (heavy metal and organic contaminants, nutrients, pathogens, and coarse debris) for the entire WS 263 and two nested sub-watersheds (Lanvale, Baltimore); 3) identify potential sources of contaminants in each of these watersheds; and 4) help develop and test a UFORE hydrology module. We will then coordinate with the Parks & People Foundation to implement discrete restoration practices for each of the paired watersheds and continue monitoring storm events (i.e., a BACI, or before-after-control-impact design). In addition, direct comparisons will also be made between the paired sewersheds in WS 263 and other similar sized watersheds that are part of the BES stream sampling network.

average for the study length and does not quantify the spatial variability of the flux along the geologic heterogeneity of a reach. We will explore airborne thermal-infrared imaging as a reconnaissance method to determine the spatial variability of groundwater influx. We hope to use LTER supplement funds to allow Claire Welty at UMBC/CUERE to develop this approach.

4. Biogeochemistry of home lawns. Residential watersheds contain significant amounts of pervious surface in lawns. Our eight forest and four grass long-term biogeochemical plots provide data on hydrologic and gaseous N outputs and suggest that there is significant N retention in grass-dominated ecosystems. These plots are instrumented with tension and zero tension lysimeters to sample soil solutions, and *in situ* flux chambers to sample soil:atmosphere gas fluxes. They have been sampled monthly since fall 1999. Our data show that grass plots have surprisingly low NO_3 leaching and surprisingly high levels of soil respiration and organic matter, suggesting an active C cycle that facilitates N retention in lawn systems (Fig 9). We will continue monitoring these variables on our long-term study plots, but we are also pursuing other funds to more rigorously evaluate C and N dynamics in grass plots to assess their contribution to regional C pools and fluxes. A proposal submitted to NSF Ecosystem Studies (Jenkins, Cadenasso, Groffman, PIs) in July 2003 got two “excellents” and will be resubmitted in 2004.

5. Riparian zones. Our work suggests that riparian zones do not function as hotspots of N removal in urban ecosystems as they do in many less human dominated ecosystems (Fig 10) because alteration of the drainage network by urbanization has hydrologically isolated the riparian zone. Hydrologic isolation is also created by incision of stream channels, which leads to lowering of water tables beneath the riparian zone. Hydrologic isolation thus dries riparian soils, which reduces the potential for denitrification, an anaerobic process. In Phase II, we propose to continue monitoring riparian water table levels and N cycle processes in four long-term riparian plots set up in 1999. Other work, funded by EPA (Groffman, Fisher PIs), will investigate the effects of geomorphic stream restoration on riparian denitrification. This work will evaluate whether restoration to stabilize channel incision will restore riparian denitrification functions. We are also pursuing funding to expand our riparian research, with two proposals; one to the NSF Ecosystem Studies panel submitted in January 2004 to investigate the importance of hydrologic changes and earthworm community changes on N cycling (Szlavecz, Groffman, Pouyat, PIs) and one to the NSF Biocomplexity Coupled Biogeochemical Cycles competition (Miller, Groffman PIs) to investigate drying and rewetting dynamics.

6. Instream retention of N is a major flux in small streams in forested watersheds. We suggest that this will not be a major process in urban streams because the ability of urban stream channels to store the organic matter that drives N retention is greatly reduced by the high storm flows and incised channels common in urban streams. At the same time, urban hydrologic changes enhance fluxes of leaf litter and particulate organic matter (POM) into streams which result in POM loads that are greater than in similarly sized forested catchments. In the EPA funded project described above, we are testing whether restoration designed to stabilize stream channels improves C and N retention. We have also submitted a proposal (Groffman co-PI with Emily Bernhardt (Duke), Mike Paul (Howard University) and Margaret Palmer (University of Maryland) to the NSF Ecosystem Studies program in January 2004 to investigate organic matter and N dynamics in urban streams, and to assess the potential for restoration of this N removal function by manipulating stream channel structural complexity and C dynamics.

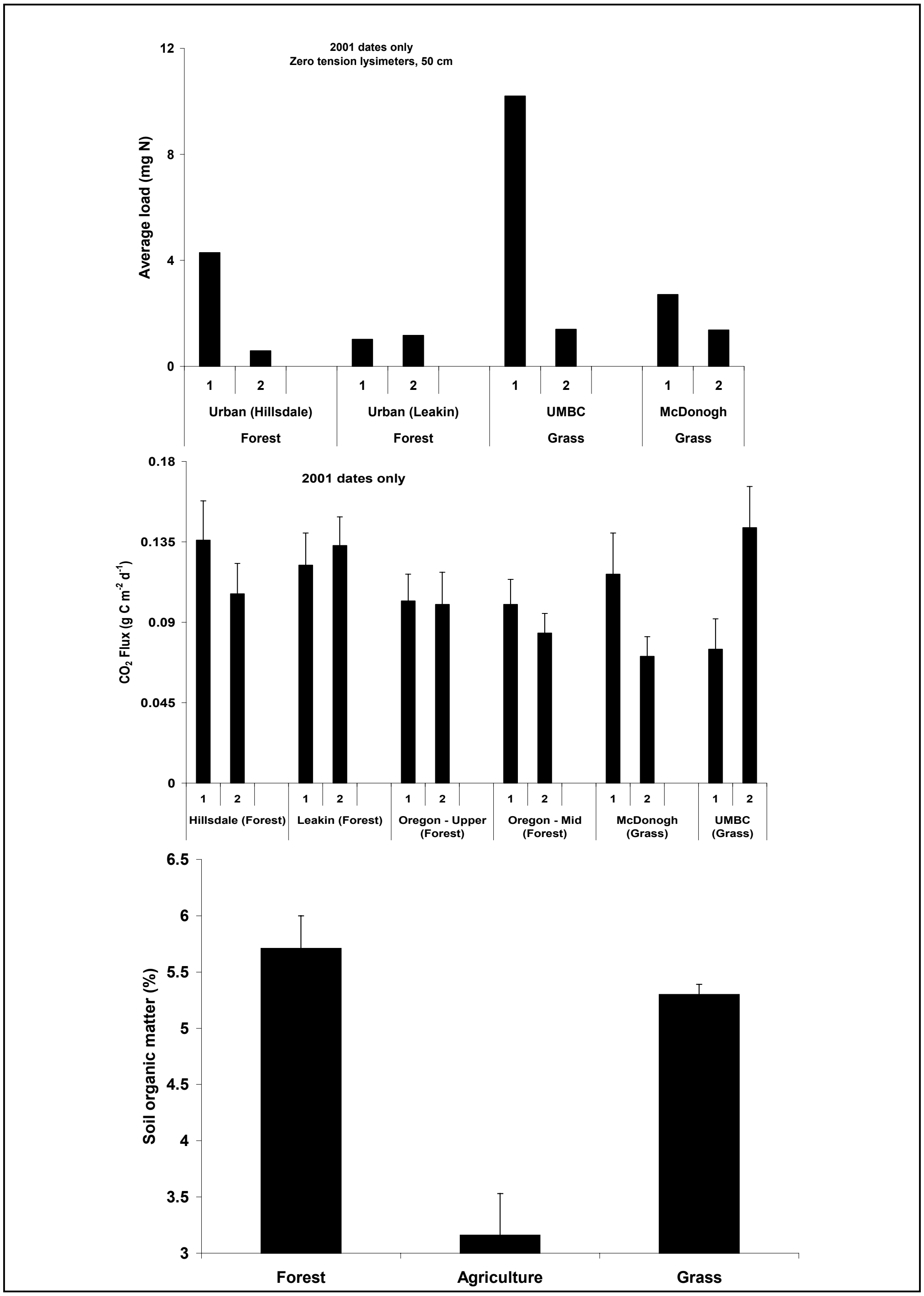


Figure 9. Nitrate leaching (top), *in situ* total soil respiration (middle) and soil organic matter content (bottom) in BES long-term intensive biogeochemical study plots dominated by grass, forest or row crop agriculture. Grass areas have surprisingly low nitrate loss, likely because the vigorously growing grass community supports an active carbon cycle (shown by high respiration and organic matter) that facilitates plant and microbial uptake and storage of N.

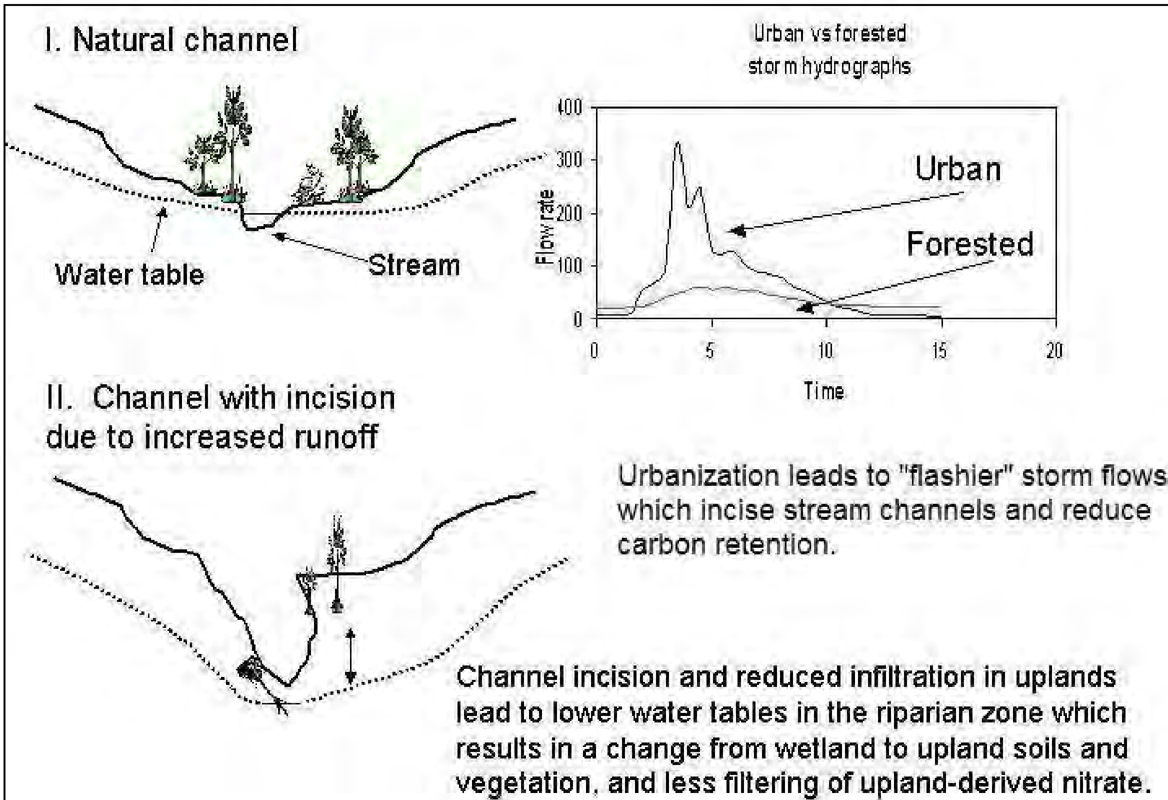


Figure 10. Riparian zones and headwater stream channels do not function as hotspots of nitrogen removal in urban ecosystems as they do in many less human dominated ecosystems. Alteration of the water drainage network by urbanization has led to hydrologic isolation of the riparian zone through burial of headwater tributaries and direct routing of stormwater into the channel through a pipe network. Hydrologic isolation is also created by incision of stream channels, which leads to lowering of water tables beneath the riparian zone, and separation of the biologically active zone of riparian soils from subsurface flow paths. Hydrologic isolation leads to drier riparian soils, which reduces the potential for denitrification (the anaerobic conversion of inorganic nitrogen into nitrogen gas). Geomorphic stream restoration may be able to restore the nitrogen removal function of urban riparian zones.

6. Dissolved organic nitrogen. In 2003, we began studies of dissolved organic N (DON) pools and lability that will continue over the next funding cycle (Kaushal & Lewis. 2003). We propose to combine field measurements of N species and generation of DON with laboratory measurements of N transformations to test the hypothesis that DON generation and remineralization occur at faster rates in urban than in forested watershed streams and that DON is a significant, but cryptic component of N export from urban watersheds.

Hypothesis 2-2. Carbon fluxes in urban and suburban ecosystems are dominated by natural processes (respiration, photosynthesis).

The USFS, CUERE and BES will continue to support the Cub Hill flux tower that provides data on carbon dynamics with land use change, human patterns and energy cycles (Fig 11). We initiated a profile system for CO_2 and H_2O concentrations in February 2001, and an eddy correlation system for C, H_2O, and energy fluxes in May 2001. We are pursuing other funds for monitoring ecosystem parameters around the tower, and enhancing existing work on measuring and modeling local scale energy and mass exchanges in urban environments (Grimmond, Indiana University, 2001-2004, NSF BCS-0095284*)*. Specific objectives for Phase II are: 1) Determine the seasonal and annual rates of C sequestration based on eddy covariance techniques comparable to other AmeriFlux sites to compare this site with other eastern deciduous forests; 2) Monitor and analyze the effects of human temporal patterns and energy cycles on CO_2 concentrations in urban areas; 3) Analyze the effects of land use change and housing development on exchanges of CO_2 through historic air photographic and topographic change analysis using source area footprint/flux analysis and modeling; 4) Compare urban forest inventory plot estimates of annual uptake with micrometeorological estimates of C sequestration rates; and 5) Compare adjacent native forest ecosystem C pools and fluxes with residential managed systems.

Hypothesis 2-3. Classification of neighborhoods, based upon social group identity and status, yields better predictors of variations in social and biophysical functions than traditional approaches using demography, social stratification, or environmental equity.

We will test the functional aspects of our ecology of prestige hypothesis by comparing neighborhood-level demographics (population density), social stratification and environmental equity (income and education, race), and social identity and status, with a suite of social and biophysical functions. Specific social functions that we will examine are recreation behavior (types and frequency), watershed knowledge, neighborhood social capital, willingness to participate in or support environmental activities, environmental perceptions, perceptions of neighborhood environmental quality of life, and environmental neighborhood satisfaction. Particular biophysical functions are associated with land management practices: hydrologic function, water quantity, quality, and fertilizer inputs, and bird diversity.

We will use several sources of existing data to test our hypotheses, including the BES telephone survey, field observation survey, and photonarrative survey. In 2002, we completed the initial analysis of telephone surveys (Wilson et al. in press), and in October 2003 we completed data collection for a second telephone survey of household environmental behaviors. The next

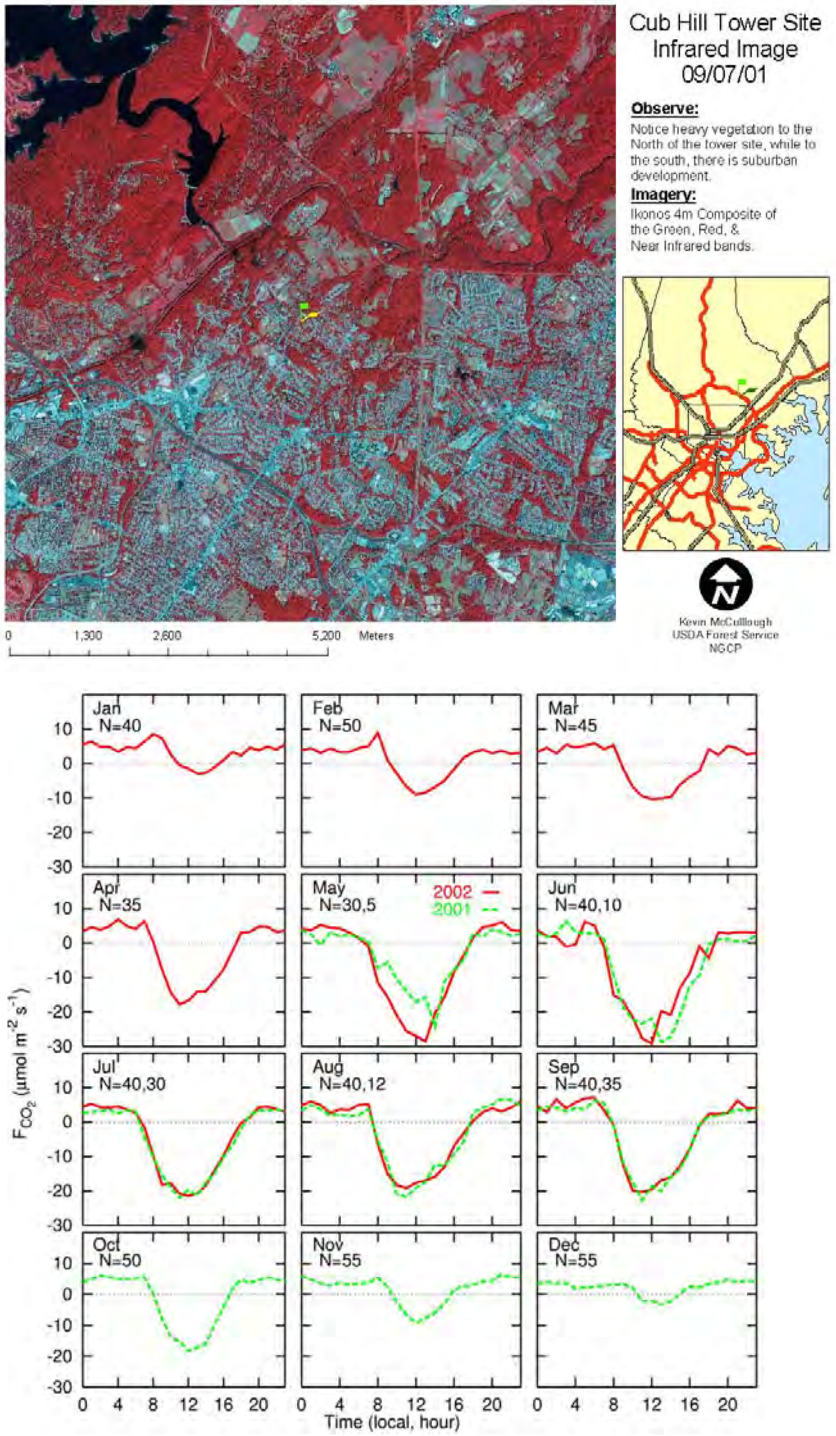


Figure 11. Location of the Cub Hill micrometeorological flux tower (top, yellow star in center of image) and monthly net CO_2 flux in 2001 and 2002. Net uptake of carbon was similar to that of a natural temperate deciduous forest ecosystem and showed the influence of two dominant vegetation patterns: seasonal deciduous canopy and grass/maintained cover, which has a longer growing season (i.e. creates uptake during the winter months).

telephone survey is scheduled for 2006. The spatially explicit sampling framework throughout the Baltimore study area (i.e., social patch analysis) will be used to analyze the relationship between biophysical and social trends.

In WS 263, we have established baseline measures of social and biophysical structure and function using our existing data infrastructure. We will collect follow-up data to examine how the process and results of environmental restoration affect the social and biophysical functions listed above. We hypothesize that social functions will respond more quickly to the process of restoration than the results of restoration. Further, we suspect there might be an ecological restoration "placebo" feedback effect: even if biophysical functions do not improve, social functions will change positively. Because social andbiophysical functions do not change at the same rates, i.e. they are temporally complex, we will use our long term data to identify and measure social legacies for biophysical functions.

BES support will be leveraged with support for work at the global scale concerning well-being using data from the World Values Survey, and work supported by the UN and World Bank on proxies of social, human, built and natural capital. Additional funds for this research come from Grove's five-year PECASE award, the Maryland DNR Forest Service, the US Forest Service, and the University of Vermont, Advanced Spatial Analysis course, taught by Troy and Grove.

Hypothesis 2-4. Neighborhood-level environmental quality, well-being, public health, and conservation of public lands will co-vary with social capital.

Environmental Quality: We adopt an empirical definition of social capital and link it to the environment through neighborhood collective action. Social capital refers to *the shared knowledge, norms, rules and networks that facilitate collective action* (Coleman 1988, Putnam 1995, Ostrom 1999, Woolcock 2001). We ask two key questions: 1) How do observed variations in social capital affect the likelihood of people engaging in collective action to improve the environmental quality of their neighborhoods? 2) Do neighborhoods with low levels of social capital exhibit higher levels of environmental degradation?

Environmental Well-Being: The literature on well-being is extensive and many synonyms are used, i.e., life satisfaction, subjective well-being, and quality of life (Schuessler & Fisher 1985, Hass 1999). Our goal is to understand the subjective sense of satisfaction felt by a community of individuals. We will answer the question: "Is neighborhood well-being higher in neighborhoods with higher levels of environmental quality?" We will use GIS databases to test our hypotheses about social capital, environmental well-being, and environmental quality. From the BES telephone survey, data include measures of social capital, willingness to participate in or support environmental activities, perceptions of environmental quality of life and well-being, and neighborhood satisfaction. The Parks & People Foundation maintains a GIS database of all community stewardship projects in the City. Finally, BES maintains GIS data on air and water quality and vegetation cover.

Public Health: Klinenberg (2002) examined social and ecological factors associated with > 700 deaths during a one-week heat wave in Chicago in 1995. One major finding was that variation in neighborhood-level social capital was a significant predictor of mortality for "at-risk" populations. Further, he proposed that social capital is probably a significant factor in survival rates in many types of ecological disturbance. We will test Klinenberg's hypothesis that social capital is an important "resilience" factor in survival rates for "at-risk" populations subjected to ecological disturbances such as heat waves, freezing conditions, epidemics, and floods. To create the necessary record of "forensic social ecology," we will collect data from the following sources: Baltimore City Vital Statistics, data and reports from the Department of Health archives, newspaper accounts, and historic Census data.

Conservation of Public Lands: In 1904, the Olmsted Brothers proposed a comprehensive park system for the Baltimore region. The plan was only partly implemented. We hypothesize that conservation of public park and forest lands is significantly affected by the social capital of neighborhoods, enabling them to encourage or block public investments in the conservation of public lands. We will use the 1904 Olmsted plan as a social ecological hypothesis of what should exist now. Where the 1904 plan and the current park distribution do not match, we will classify as residuals (errors) of commission those parks that were proposed but a) not built, or b) if built, not maintained, and classify parks that were built but not planned, as residuals of omission. We will then determine whether residuals of commission are associated with the absence of social capital, and whether the residuals of omission are associated with the presence of social capital.

Additional funds for these efforts will come from Grove's five-year PECASE award, and the US Forest Service. An NSF proposal to study the relationships among social capital, environmental quality, and environmental well-being was submitted to the NSF Regional Sciences Program in January 2003 and will be revised and resubmitted in August 2004.

Hypothesis 2-5. Ecosystem goods and services represent the benefits that humans derive from functioning ecological systems. We hypothesize that neighborhood stability, well-being and environmental quality will co-vary with the delivery of ecosystem goods and services across neighborhood and watershed scales, and that the delivery of ecosystem goods and services will co-vary with Baltimore neighborhood PRIZM clusters.

Landscapes are altered by humans to enhance the delivery of ecosystem goods and services—more fresh water, fewer floods, more trees, more food products, fewer pollutants, etc. In Phase II, we seek to better understand how human stressors and landscape transformations affect the delivery of ecosystem services in an urban system. For example, we ask: how do ecosystem goods and services and their underlying ecological support systems respond over time to anthropogenic stressors? Are some goods and services more resilient to stress than others? Is there an 'optimal' spatial and temporal scale for observing, monitoring and managing the delivery of different ecosystem goods and services within the urban landscape?

We will improve extant theory, test economic valuation methods, and collect empirical data on the delivery of ecosystem goods and services within BES and the LTER network. To improve theory, we will delineate a typology of goods and services, and identify the complex pathways through which they interact with socio economic drivers. Economic valuation methods, including but not limited to meta-analysis and benefit transfer methodology, will be used to estimate the economic value of ecosystem goods and services. Data collection will also be done

Table 4. New Hypotheses for Proposed Research under 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 to downstream air and watersheds?

Hypothesis 3-1. Ecosystem knowledge and environmental perceptions are asymmetrically distributed in the metropolis, with important functional consequences for individual behavior, and for management and decision making. Low knowledge or awareness may be due to a number of interacting factors:

1) Learning about and understanding complex ecological systems (e.g., the roles of exotics in ecosystems, multiple interacting causes, etc.) is intrinsically difficult.
2) Formal and non-formal education systems and the media pay only limited attention to urban ecosystem concepts or awareness.
3) Urban areas are note perceived as suitable for environmental education, depriving children of opportunities to learn about and explore nature in their neighborhoods.
4) There are significant legacies in individuals and communities in terms of their beliefs and values regarding the environment and science.

Hypothesis 3-2. When students engage in activities where they actively explore questions and phenomena relevant to their everyday lives and local surroundings, they develop a deeper understanding of the complexity of the city as an ecosystem. Such inquiry-rich activities can also help students develop critical scientific abilities (scientific questioning, analyzing and synthesizing data, using evidence to make scientific arguments, communicating results).

Hypothesis 3-3. Formal education institutions and programs play an incomplete and variable role in fostering a useful understanding of the urban ecosystem, but they <u>can</u> play a vital role under the right circumstances. These include: a strong basis in the community focusing on issues of genuine interest and importance; working in collaboration with non-formal, out-of-school programs; and taking a partnership approach involving scientists (researchers), community members and educators, managers and decision makers.

Hypothesis 3-4. Scientists play a pivotal but complex role in adoption of innovations within formal and non-formal education initiatives about urban ecosystems.

Hypothesis 3-5. The definition of urban environmental issues, who participates in urban environmental decision making, and who benefits from environmental management have changed significantly over the past 100 years.

Hypothesis 3-6. An understanding of the ecosystem services that tree canopy cover can provide in urban watersheds, including replacing functions lost to hydrologic changes associated with urbanization, will result in improved management and environmental quality of the Baltimore ecosystem.

at multiple scales in order to incorporate land use/land cover information (i.e. USGS National Land Cover Data) and output from BES models (HERCULES, RHESSys, and GFLM-GHM), to assess the complex, dynamic links between socio-economic values, ecosystem goods and services, and land use change over time.

Leveraging and collaborative projects include the Ecovalue Project for the Maryland DNR, (http://ecovalue.uvm.edu/esp), a cross-site (BES, FCE, KBS) project funded by the LTER network, and a funded NCEAS working group to document and analyze the status of ecosystem goods and services across the LTER network.

Hypothesis 2-6. Integrated dynamic spatial monitoring can be used to understand and forecast land use changes, economic activity, migration patterns, quality of life effects and a range of other variables within the Baltimore region.

We will use drivers of land use change that are proxies for built, human, social, and natural capital. Specifically, we hypothesize that neighborhood stability derives from: 1) Sufficient income enjoyed by residents, 2) Low travel costs/short travel times to work; 3) High density of roads 4) High status for the inhabitants; 5) High level of "quality" employment; 6) Multi cultural/race interactions; 7) Strong social interactions and civic involvement; 8) A broad knowledge base within a community; 9) Large/small household sizes; 10) Short distances to green spaces; and 11) Large distances to brown fields.

Models developed in Phase I included the Gwynns Falls Landscape model (GFLM), and the General Human Model (GHM) (Fig 1). The GFLM simulates the watershed within its ecological context of hydrology and biomass production, while the GHM accounts for socio-economic dynamics. GHM was applied within a global context to simulate the development of wealth in different types of capital (built, human, social and natural). Within the GHM, built capital is the accumulation and value of manufactured goods, human capital is the distribution of information and health, social capital comprises shared norms, rules and connections within human networks, while natural capital is ecosystems and the goods and services they provide.

We will integrate the GFLM and the GHM to understand and forecast land use changes, economic activity, migration patterns, and quality of life effects in the Baltimore region. The GFLM-GHM integration will add the ecological dimension to human decision-making within land use change and migration models. Such ecological context is missing in land use change models based on cellular automata (e.g. Clarke et al. 1997) but also in land use change models that rely on census datasets such as UrbanSim (Waddell 2002). Through the GFLM-GHM integration we will explore how the social preference function for household residency evolved in Baltimore. We will explore the interaction between ecosystem services, social preferences, and residential dynamics, and the effect of residential dynamics on ecosystem services.

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 to downstream air and watersheds?

Hypothesis 3-1. Ecosystem knowledge and environmental perceptions are asymmetrically distributed in the metropolis, with important functional consequences for individual behavior, and for management and decision making. Low knowledge or awareness may be due to a number of interacting factors: 1) learning about and understanding complex ecological systems is intrinsically difficult; 2) Formal and non-formal education systems and the media pay only limited attention to urban ecosystem concepts or awareness; 3) Urban areas are note perceived as suitable for environmental education, depriving children of opportunities to learn about and explore nature in their neighborhoods; and 4) there are significant legacies in individuals and communities in terms of their beliefs and values regarding the environment and science.

We propose to describe how people in the Baltimore region learn about the urban environment, how they develop their perceptions of the environment, and how they use their knowledge and perceptions in their everyday lives. We will use multiple approaches to measure trends and correlates of understanding of the urban environment over time across the metropolis. The periodic telephone "social science" surveys of Baltimore residents will continue to include questions that gauge people's understanding of the urban environment. Property values will be analyzed to assess the degree to which environmental quality and amenities are valued in different neighborhoods (see hypotheses 2-3 and 2-4 above). Analyses will quantify the variation in knowledge, and seek to explain this variation both over space (i.e., across neighborhoods or PRIZM cluster patches), and over time. We will develop a more detailed and extensive assessment of understanding to use with students in targeted schools with which BES is working (see below). Finally, we will compile and analyze information from existing sources, such as standardized city, county and state tests, to describe regional and temporal trends in environmental knowledge where that information is available.

Hypothesis 3-2. When students engage in activities where they actively explore questions and phenomena relevant to their everyday lives and local surroundings, they develop a deeper understanding of the complexity of the city as an ecosystem. Such inquiry-rich activities can also help students develop critical scientific abilities

Phase II will explore teaching and learning of key facets of urban ecosystem understanding (e.g., systems thinking, trans-disciplinary thinking, spatial cognition) by crafting a long-term research effort focusing on students and teachers in BES education programs. The breadth of existing BES curriculum modules (Table 5-1) and plans for teacher professional development, provide fertile ground for studying the effectiveness of compelling and content-rich learning experiences organized around local phenomena and real scientific data. Existing partnerships among BES, school sites, and community groups will expose the nature of the interplay between formal and non-formal institutions in helping students and community members better understand urban ecological systems (Burch and Carrera 2003). We will use a range of data collection methods to evaluate the effectiveness of these approaches and programs. We will conduct extensive field observations of participants engaged in BES curriculum activities, examine student work generated from BES activities, and conduct interviews with students and teachers. To help track changes that occur over time and to understand the factors or experiences precipitating such changes, and dimensions of sustained impact, we will administer surveys to participants at various points in their engagement in BES educational activities. We also will examine the links between knowledge, action and environmental quality by carrying out in-depth assessments of youth participating in the community-based enrichment programs (described in Section 5 - Education Plan).

Hypothesis 3-3. Formal education institutions and programs play an incomplete and variable role in fostering a useful understanding of the urban ecosystem, but they can play a vital role under the right circumstances. These include: a strong basis in the community focusing on issues of genuine interest and importance; working in collaboration with non-formal, out-of-school programs; and taking a partnership approach involving scientists (researchers), community members and educators, managers and decision makers.

We will explore the roles of schools and other institutions in fostering understanding and the flow of knowledge and information (Berkowitz 2003b). We will continue, refine and expand the current effort to assess how ecology is being taught in target schools to include all schools in Watershed 263, BES partner schools (Green Schools, etc.), and schools in other areas where BES work is concentrated. We would like to complement this work with an assessment of the general public in these same areas to determine the important sources of environmental knowledge and information for various groups, including the roles of schools, other education programs and other sources (e.g., media). This effort will depend on additional funding for new proposals based on our long-term data. Members of the Demographics/Social Science Team will continue to explore questions about information transfer and the functioning of knowledge networks, and analyses of historical case studies where environmental knowledge was applied to decision making and management.

Hypothesis 3-4. Scientists play a pivotal but complex role in adoption of innovations within formal and non-formal education initiatives about urban ecosystems.

BES scientists participate in educating the public about urban ecosystems on a variety of planes and in multiple venues. Availability of data from BES and accompanying protocols, for example, allows students, teachers, and community members to ask questions of, collect, and analyze data that speaks to pressing and relevant scientific areas of study. Such a model offers the chance to examine how scientific data and tools can engage schools and community members with scientific questions, attend to local problem solving, and bridge seemingly disparate groups around common issues. We will study the ways in which scientists engage in work with community groups and analyze the ways in which their work extends to and gets picked up by schools and classrooms, science-rich institutions, local government, community advocacy groups, and the media to support and facilitate learning about urban ecological systems. In addition to observations, and analysis of relevant documents, we will interview scientists, local policy makers, teachers and other educators, and key players in community organizations, focusing on scientific contributions to program planning and decision making.

Hypothesis 3-5. The definition of urban environmental issues, who participates in urban environmental decision making, and who benefits from environmental management have changed significantly over the past 100 years.

Information and knowledge are necessary but insufficient for affecting urban environmental change. Over the course of the past 100 years, there have been three dominant phases in environmental decision making in the United States: 1) private markets and individual decision-making; 2) public institutions, organizational capacity, and professional “experts;” and 3) collaborative decision making. The development of each phase should not be seen as one type of decision making replacing another, since the elites in the City persist, harnessing public institutions, organizations, and technocracy to support their interests. Each type of decision making influences how information and knowledge are legitimized and used to influence the environmental quality of the region. Our research will examine how decision making changed over time: in terms of what is defined as an urban environmental issue, who participates, and who benefits. We will apply this research to the long term relationships among public health, forests, and parks in urban areas. These relationships have not been examined over the long term and have not been addressed in our understanding of land use change.

We will collect data from the following sources: City administrative records and reports, newspaper accounts, and historic and current Census data. We will conduct higher order analyses using the Human Ecosystem Framework by including multiple variables representing biophysical, social, and cultural resources, social institutions, and social order. We will apply our analyses to long term trends in public health, conservation of public lands, management of urban parks, forests, community gardens, environmental justice, the implementation of the City’s $1 billion consent decree and restoration of Watershed 263. We will also continue cross-site comparison research with the Piren-Seine Zone Atelier in Paris, France.

While LTER base funds will be used to pursue this research, additional funds come from Grove’s five-year PECASE award and the US Forest Service. An NSF proposal to study the relationships among public health, parks, and land use change was submitted to the Regional Sciences Program in January 2003 and will be revised and resubmitted in August 2004.

Hypothesis 3-6. An understanding of the ecosystem services that tree canopy cover can provide in urban watersheds, replacing functions lost to hydrologic changes associated with urbanization, will result in improved management and environmental quality.

In December 2002, the Executive Council of the Chesapeake Bay Program (CBP) issued Expanded Riparian Forest Buffer Goals as part of their effort to reduce nutrient loading to Chesapeake Bay. A major component of these new goals is expansion of urban tree canopy cover, based largely on BES research showing that much of the hydrologic connection and buffering function of riparian areas is lost in urban and suburban watersheds. The CBP has decided to focus on the hydrologic and biogeochemical benefits associated with restoring urban tree canopies. USFS/BES scientists are developing a new hydrologic component for the UFORE model and crafting a version of the model that will be easy to use to help citizens and managers plan and assess tree canopy restoration efforts. The model will be calibrated using stream measurements from existing BES sites. Outputs of the model will include hourly hydrographs of changes in stream flow and various chemicals. During and after the development and dissemination of the model, BES researchers will document both the nature of use of the model, and the long-term changes the resultant tree planting initiatives have on the Baltimore environment.

SECTION 3 - PROJECT MANAGEMENT

Institutional Arrangements. The Baltimore Ecosystem Study LTER is administered by the Institute of Ecosystem Studies, with subcontracts for research, education, and outreach. The University of Maryland, Baltimore County (UMBC), through its Center for Urban Environmental Research and Education (CUERE), provides the intellectual and logistic home for BES in Baltimore. Through a Memorandum of Understanding (MOU) and a subcontract, UMBC/CUERE maintain wet and dry laboratories, geographic information system (GIS) facilities, equipment storage, field staging, and office space for technicians and PI's at the Technology Research Center building. CUERE provides administrative support for BES on site, and a Project Facilitator is in residence at IES. The USDA Forest Service Northeastern Research Station provides in kind support (approximately $1 million per year), including staff time for research in soils, vegetation, social science, atmospheric processes, C dynamics; for administration, and outreach; and for the Cub Hill eddy flux tower. The US Geological Survey maintains the stream gaging stations, and contributes staff time for research effort. Subcontractors include the Parks & People Foundation, for community outreach and non-formal education and training, Johns Hopkins University for paleoecology, vegetation, and biodiversity research, the University of Maryland, College Park for stream and education research, the University of Missouri for biodiversity studies, the University of North Carolina for hydrologic modeling, Ohio University for social science and a GIS for social data bases, the University of Vermont for social science, ecosystem services, and spatial analysis, and Yale University for social ecology research. IES research includes stream chemistry, land use change, soil microbial ecology, vegetation, and education. Training of graduate students associated with BES has been conducted through all the universities listed above, plus Rutgers and Columbia.

Personnel. The project is supported by a Project Facilitator, Ms. Jennifer Sullivan, based atIES. Through e-mail and telephone, she is the point of contact for project participants, the public, and persons wishing to become involved in BES. A toll free number (800-BES-LTER) is maintained for the public. She is responsible for project reporting, arrangements for the BES science meetings, and editing the BES Bulletin, which is intended for members of BES and a wider audience. This 60% time position is funded primarily by IES, with additional funds from the BES core grant. The full time BES Information Manager, Mr. Jonathan Walsh, is headquartered at IES. He coordinates data acquisition from BES researchers and outside sources, enforces metadata standards, and facilitates interactions with other information management systems. He maintains the BES web site, coordinates with the Open Research System as a data portal and back up site for BES data. The Education Coordinator, Ms. Janie Gordon, is funded by the BES core grant and leveraged support. She is stationed at the Parks & People Foundation (PPF) in Baltimore, and is responsible for linking education with the community, summer, and after-school programs of PPF. She also coordinates with the educational activities of CUERE at UMBC. The Urban Resources Initiative Coordinator at PPF, Ms. Mary Cox, is responsible half time to BES, for facilitating interactions with communities, government agencies, and community groups with which we must work to conduct research and outreach. She provides a conduit to the press, to the community-oriented programs, and the local expertise of PPF. CUERE provides GIS services to BES through partial funding of Mr. Michael McGuire's time. CUERE also provides incidental office logistic support. The Project Facilitator and Information

Manager report to the Project Director. The CUERE staff report to CUERE Director and BES Co-PI , Dr. Claire Welty. The Education Coordinator reports to BES Co-PI Dr. Alan Berkowitz, and the Urban Resources Initiative Coordinator reports to Co-PI Ms. Jackie Carerra, Director of PPF.

The project represents racial and gender diversity. Of 32 PI's, two are African American and 10 are women. Of our 27 graduate students, 13 are women, 3 are African American and one is Asian. Of our 63 undergraduate students, 29 are African American, 2 are Asian, and 37 are women. We attempt to increase the diversity of BES at all levels by interacting with faculty from minority-serving institutions, inviting REU participation from these schools, and interacting with the SEEDS program. The USDA Forest Service provides support for students and minority researchers through its Civil Rights grants. We actively reach out to researchers beyond the LTER program through our Annual Meeting and Quarterly Science Meetings, Community Open House, field trips to Baltimore and visits to subcontractor campuses. BES PI's seek interaction with non-LTER scientists at national and regional scholarly meetings.

Administration. BES is administered by a Project Management Committee, which meets approximately monthly (Fig 3-1, Table 3-1). Minutes are posted to the internal BES web site to promote communication throughout the project. A graduate representative sits on the PMC. Once a year, a Steering Committee, including all Co-PIs, the graduate representative, and staff members, is convened. The PMC and Steering Committee make project policy, and charge members and staff with administrative tasks. The presence of all supervisors of project staff on the PMC assures that assignments and schedules are achievable. The PMC represents the subcontracting institutions, and all project activity areas. It includes a rotating position as another mechanism to ensure breadth of viewpoint. Other committees include those for Information Management, Science Meetings, Annual Meetings, Community Open House, Field Station and the BES Bulletin Editorial Board. These committees report to the PMC.

Research decisions are shaped by discussions at the quarterly science meetings, which update researchers on progress and explore changes or new projects. Linkage of projects and sharing of core project resources are considered at these meetings. Potential collaborators, users, and affected communities are invited to these meetings.

Fiscal Procedures. The Project Director with the assistance of the two Co-PIs at IES are responsible for budgetary decisions. Subcontract allocation takes into account the input from science meetings, and the productivity and adherence of subcontractors to the overall project goals. Suggestions for supplement requests are gathered through the PMC.

Logistic Issues. BES is a distributed project, and regular communication among project participants is crucial. All hands are invited to four meetings per year, and the Bulletin and web site are used in the interim. Ad hoc research groups, as well as the education team, meet regularly to plan and coordinate group and individual research. Extraordinary effort is devoted to smooth, reciprocal interactions between BES, local communities, and government agencies with which we must work.

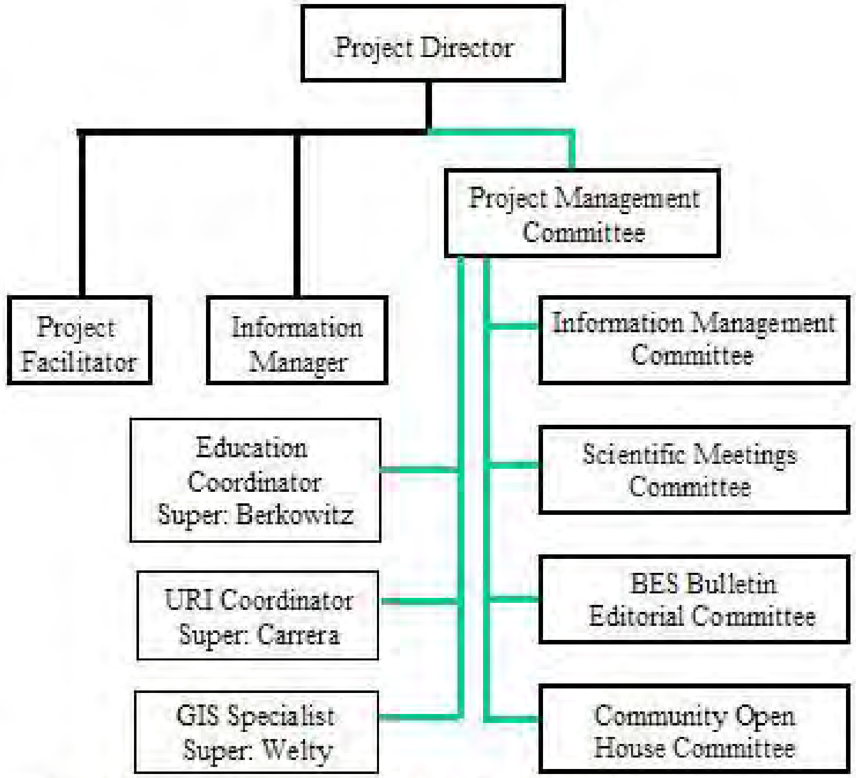


Figure 3.1 Administrative structure of BES. The Project Management Committee (PMC) makes formal recommendations for project policy and administration. The Director supervises the IM and Project Facilitator. PMC members supervise the other adminstrative staff of BES. Black lines = supervision; blue lines = information.

Table 3.1. The Project Management Committee.

Alan Berkowitz, IES
Jacqueline Carrera, Parks & People Foundation
Mary Cox, Urban Resources Coordinator
Janie Gordon, Education Coordinator
Peter Groffman, IES
Morgan Grove, USFS
Andrew Miller, UMBC
Tommy Parker, Graduate Student
Steward Pickett, IES
Richard Pouyat, USFS
Katalin Szlavecz, Johns Hopkins University
Jennifer Sullivan, Project Facilitator
Jonathan Walsh, Information Manager
Claire Welty, Director CUERE, UMBC

SECTION 4 – INFORMATION MANAGEMENT

DESCRIPTION OF THE INFORMATION:

The Baltimore Ecosystem Study provides high quality information to scientists, students, teachers, and the public online. It is presented in forms that facilitate synthesis and collaboration. Since ecological information consists of disparate forms of data, e.g. spatial land cover, infrastructure, climate time series, stream chemistry, and demography, special planning is made in its collection, storage and presentation to provide a unified, cohesive collection. The BES data collection comprises a matrix of space and time. Therefore, a GIS geospatial database that contains references to the data sets has been created. See http://www.beslter.org/geodatabase.html. Long-term preservation of the data is ensured by the use of multiple storage platforms and locations (See http://www.beslter.org/backup_apparatus.html).

DESIGN AND PLANNING OF INFORMATION INFRASTRUCTURE

The BES information management system is carefully structured to serve the needs of a widely distributed research community. The distributed nature of BES, in combination with the wide variety of data types, makes integration extremely complex. Jonathan Walsh, the Information Manager (IM) oversees all BES information to ensure the result is a useful product for the scientific community. Electronic collaboration using the internet is utilized, allowing the information to be dispersed among the investigators and also kept in a central location. Additionally, the information is kept in separate "mirror" locations to provide security.

Guidelines to resolve issues relative to scientists' rights and their responsibility to make the data available are contained in the BES Information Management Policy online at http://www.beslter.org/dm_policy.html.

The IM takes part in the planning of research projects to facilitate proper data management. Collection, storage, and formatting methods are integrated into the project plan. Additionally, consideration is given to how any new data will interface with existing data. An Information Management Committee, chaired by the IM, meets regularly to plan and evaluate the information system. The committee is made up of a selection of BES scientists and technicians who are most concerned with information management. BES scientists work through the IM to store and retrieve data. The scientists submit the data to the IM continuously who checks for quality.

The IM develops software applications necessary to facilitate data collection and dissemination. These include database utilities, such as an online stream chemistry database, online forms for collection of information, communications within the study and with the public, such as online discussions and email groups, and the website. BES has created a Relational Database of Metadata using a combination of Access and the Cold Fusion database language system. The Open Research System (ORS) allows the scientific community to easily obtain BES data and metadata. It features a semantic search function that allows free text searches of the metadata. Additionally, it features a graphical search based on the Human Ecosystem Framework (Figure

2-2) that allows combinations of datasets to be retrieved based on their relationship to the framework. (See http://www.orsprivate.org/search/search.graph.cfm) The results can be downloaded or read online and contain links to the corresponding data which can then be downloaded. This process involves a tracking facility so BES can know which data are being used. The system also registers the party using the data, and displays a policy statement requesting that BES (NSF, #DEB-9714835) be acknowledged for the data and that any improvements to the data are returned to BES. In addition, this system allows investigators an online facility in which to enter their metadata. The system accepts and delivers ArcGIS metadata in its native XML format. The metadata records are immediately available on the web. The information can be accessed publicly two years after the completion of a component of the study, or earlier when deemed fit for the scientific community to use, or held private and shared with collaborators or other members of the study. Protected data are those collected by graduate students and relatively junior members of the research team, such as post-docs.

A File Transfer Protocol (FTP) server was established to allow research groups within BES to share files. As a result, the BES scientists have a central location to share data and findings. Data sets are thus quickly made available to other researchers.

A web server was established to facilitate the BES website at http://www.beslter.org. The website serves as the public interface to the study with content about the specific research projects, theoretical and conceptual underpinnings of the program, photographs, maps, contact information, abstracts from the annual meetings, publications list, and links to the data and metadata. It also has a password protected area to convey schedules, files, and news to the participants of the study.

A Structured Query Language (SQL) server was installed to facilitate gathering data online. It has been programmed for remote entry of stream chemistry data and biodiversity data. These applications will be extended to other major information flows. As a result, the data can be entered from the locations where it is gathered, and subsequent information, such as sample analysis can be entered as it occurs, from a different location. Finally, the results are posted to the online database.

These systems promote integration of the Information Management Program and the Science Program and allow the LTER Network and others to share BES data as it is gathered.

ACCESS TO BES INFORMATION:

All BES information is available via the website. Using the website, one can learn about the study, contact members of the study, and obtain all the public data and metadata. An Open Source agreement is displayed during the process whereby the user agrees to give credit to BES and the NSF and report any improvements to it. Active links are maintained to United States Geological Survey's National Water Information System for BES stream gauges.

DEVELOPMENT OF AUTOMATED DATA HARVESTING AND DISTRIBUTION TECHNOLOGY:

BES participates in larger information sharing schema such as the LTER Network Data Table of Contents (DTOC) system wherein BES maintains an online file of links to its data which is "harvested" by a central server, making the data available through the LTER website. Ecological Metadata Language (EML), whereby BES metadata and pointers to the data are stored in machine-readable code, facilitates seamless combination of BES metadata with that from all the other LTER sites. BES climate and hydrology data are also online in a format which can be harvested by CLIMDB, HYDRODB and PERSDB, which, like the DTOC system, allow climate, hydrology and personnel data from all the LTER sites to be combined.

FACILITIES:

BES Information Management Facilities are distributed. See the document http://www.beslter.org/im_facilities.html for equipment descriptions and locations. All information is archived at the Institute of Ecosystem Studies. BES data and metadata are backed up to tape and to DVD/CD disks weekly on a rotating basis. Tapes and disks are stored in a fire resistant container. Copies of the data are stored offsite on a rotating basis. Each investigator keeps copies of their data.

METADATA:

Metadata are stored in a form suiting the LTER Network EML standard. This format also satisfies the Federal Geographic Data Committee (FGDC) guidelines, the FGDC fields being a subset of the EML fields. Metadata are collected online using a Relational Database Management System (RDBMS). The RDBMS in turn makes the metadata available online. A web interface (http://www.orsprivate.org/group/bes/index.cfm) provides public access to the metadata. This interface allows the data to be searched with keywords or graphically. The RDBMS can export the metadata into any other form to facilitate use by a range of applications programs.

NETWORK PARTICIPATION:

BES actively participates and assists with LTER Network activities such as the ongoing design and implementation of the Ecological Metadata Language, as well as annual meetings, discussion groups and workshops.

ANTICIPATED CHANGES:

A system is being built whereby data will be automatically exported from the metadata database directly into EML format. A server capable of distributing "web services" will be placed online beginning with the BES Climatologic data. The BES stream chemistry and meteorological data will be added next. BES will utilize this server to participate with the LTER Network in the International Information Grid for Ecology and the Environment (I2G).

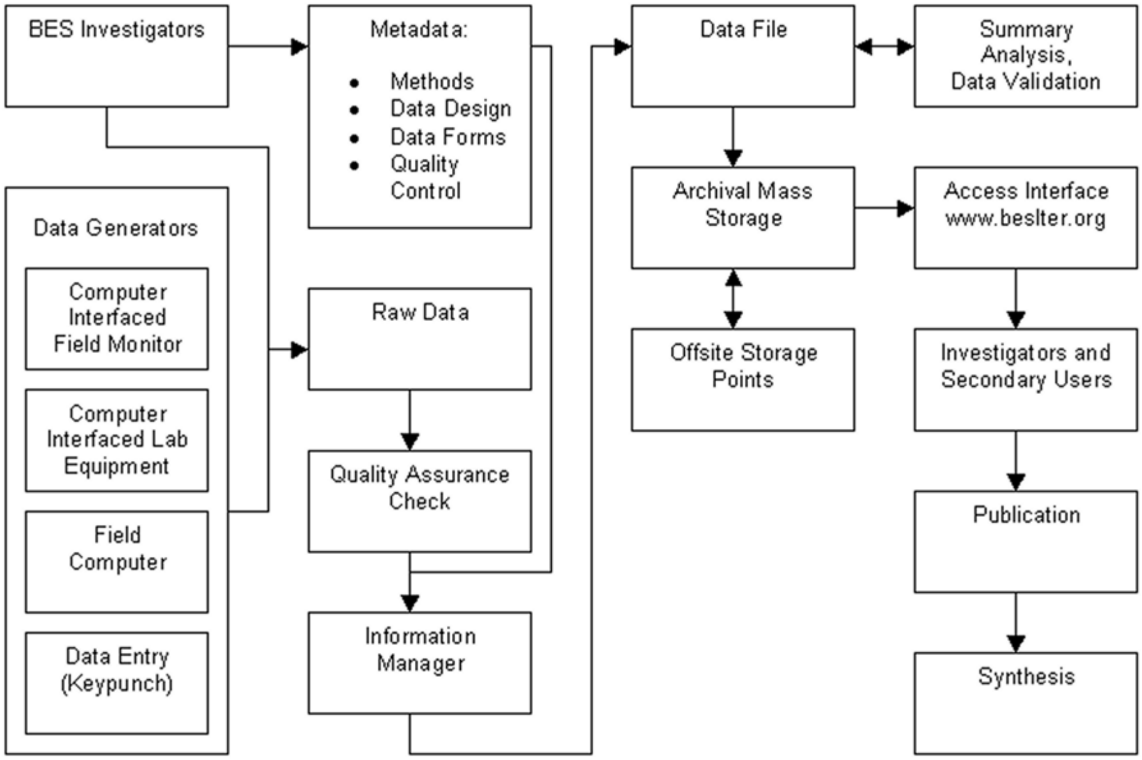


Figure 4-1 – BES Information Flow Diagram – Adapted from Michener & Brunt (2000)

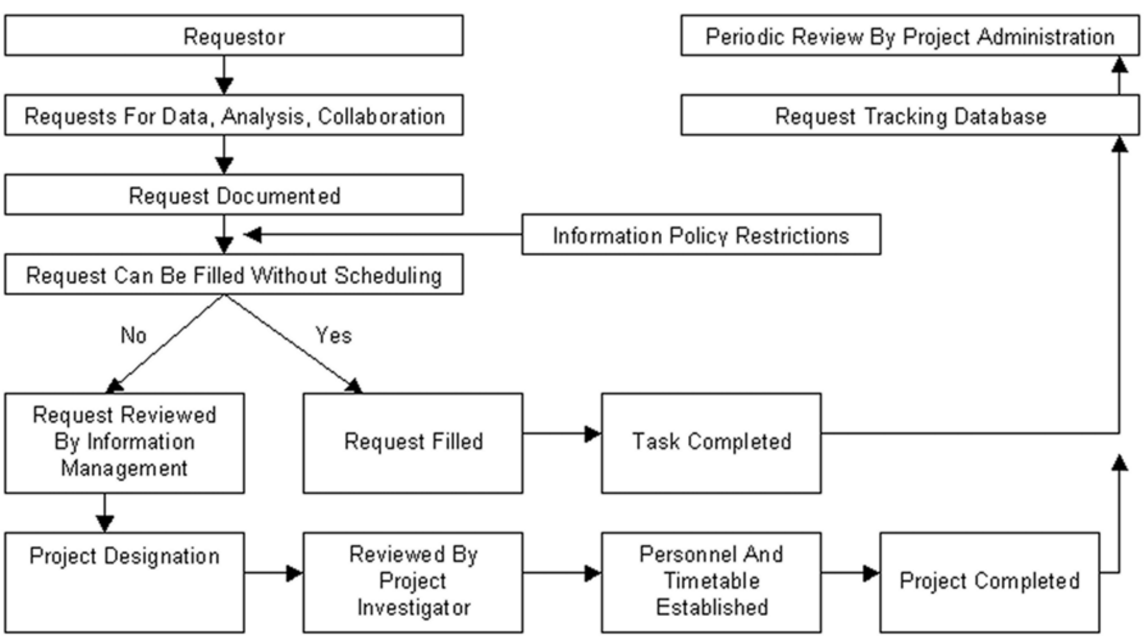


Figure 4-2 – BES Request Tracking Diagram – Adapted from Michener & Brunt (2000)

SECTION 5 – OUTREACH

Goal 1. Foster innovative teaching and learning about urban ecosystems at all levels of the formal and non-formal education system by sharing the best and most exciting of BES data and approaches with students, educators and citizens.

1a. Investigating Urban Ecosystems (IUE). We will develop a full set of IUE teaching modules in the next 6 years (Table 5-1). Each module includes BES datasets unique to Baltimore, and protocols based on BES work that students can use to carry out their own studies, and are produced by teams of teachers, educators and scientists. These instructional support materials can be used flexibly by educators, though each is targeted to one middle- or high-school science or social studies course. Core funding will support 1-2 teacher institutes each year (2-3 days with school year follow-up); leveraged funding from other sources (e.g., NSF LTER schoolyard supplements) would allow us to serve a larger number of teachers and schools.

1b. Schoolyard Greening programs. BES, PPF and partners will develop curricula and provide teacher support as part of the Watershed 263 project, including protocols to monitor environmental changes, and student- and teacher-outcomes from the project. These methods will be folded into the IUE Schoolyard Ecosystem module (Table 5-1) to support other schools who want to establish long-term ecosystem studies in their schoolyards and neighborhoods.

1c. BES/School Partnerships. We will solidify and expand partnerships with schools to help infuse BES-based teaching and learning into the curriculum, avail students of BES data, and provide scientist role models. Partnerships include: Watershed 263 schools; the Env. Science Summer Research Experience for Young Women program (Roland Park Country School and Johns Hopkins Univ. Center for Talented Youth); Woodlawn High School (an urban hydrology project, NSF Biocomplexity proposal pending); a proposed environmental high school (Nat. Ctr. for Science Envt. proposal to the Gates Foundation pending); McDonogh School (a permanent BES sampling site); and schools surrounding the Cub Hill atmospheric monitoring tower.

1d. Community-based youth programs. BES and PPF will continue to collaborate in offering after-school and summer enrichment programs for upper elementary, middle and high school youth, targeting those in minority neighborhoods. The KidsGrow curriculum will be expanded and the model disseminated to other organizations, parks, recreation centers and schools through partnerships in Baltimore, and through the Urban Ecology Collaborative.

1e. Park-based ecology field stations. BES is collaborating with PPF and both the Baltimore City and County Departments of Recreation and Parks, to explore the idea of an urban ecology field station based at a park.

1f. Undergraduate and graduate curriculum and instruction. BES scientists have developed state-of-the-art modules and entire courses in urban ecosystems, applying BES science to their teaching. New efforts will include: 1) posting courses on the BES website; 2) 1-2 quarterly science meetings on teaching; 3) a Baltimore field course for Univ. of Vermont and other students, 4) a Design Studio with BES data sets, GIS and architectural 3-d CAD to support interdisciplinary planning and design instruction at Columbia's Graduate School of Architecture and Planning; and 5) work with the Howard Univ. site of FIRST (Faculty Institutes for Reforming Science Teaching, an NSF-supported project for teams of college faculty).

Goal 2: Help recruit, retain and train a diverse workforce of urban ecosystem researchers, educators and managers.

2a. Green Career Pathway programs. BES, PPF, CUERE and others will build the KidsGrow and Green Career Ladder into a coordinated set of programs to encourage interest in environmental and scientific career paths for late elementary, middle and high school students.

2b. College, graduate student and young professional internship programs. PPF, with BES collaboration and support, will continue to offer 4-8 summer and semester internships through the Urban Resources Initiative (URI) program. A diverse group of interns will engage in community-oriented research, education and neighborhood revitalization. We plan to continue working with 2-3 undergraduates each summer through REU supplements and the IES site grant.

2c. Opportunities for educators. Core LTER funds will provide support for one Ecology Education Fellow annually. We are submitting a Center for Teaching and Learning proposal to NSF, and considering RET supplements to expand our opportunities for educators.

2d. Training programs for managers, decision makers, citizen activists and applied scientists. PPF's Community Forestry Program will deliver a new series of workshops to connect BES research and scientists with Baltimore residents, neighborhood groups and managers involved in neighborhood greening. BES collaborates with Civic Works' B'More Green, training predominantly low-income minority workers for entry-level environmental jobs.

2e. Graduate training programs. UMBC BES collaborators are developing an urban environment-focused graduate program through CUERE. An IGERT proposal will be submitted this March. At Columbia Univ. the Graduate School of Architecture will continue to employ urban ecosystem thinking to link urban studies in architecture, and urban design and planning degree programs and to foster interdisciplinary work with the Earth Institute at Columbia.

Goal 3: Make BES knowledge, data and expertise available directly to managers, decision makers, community activists, and the general public.

3a. Linking science to decision making. PPF facilitates a strong, two-way relationship between BES and the Revitalizing Baltimore (RB) Technical Committee and contributes to the BES "Linking Science and Decision-Making" web pages. The BES modeling group and PPF are creating lay-accessible versions of their simulations of the Baltimore metropolis. We are seeking additional funds to develop expanded watershed research and restoration projects that link science and management in Watershed 263 and the Gwynns Falls watershed, and for new initiatives in the Harbor, Jones Falls and Herring Run watersheds. PPF and BES work at the science/management interface will be disseminated throughout the Northeast by the Urban Ecology Collaborative, and worldwide through LTER and ILTER connections.

3b. Maximize the value of the BES web site. The BES website is a growing resource for disseminating information, data and perspectives about Baltimore and urban ecosystems in general. We will continue to develop the education and information utility of the site.

3c. Media and informal education outreach. PPF will lead BES efforts to publicize our findings via press releases, media contacts, news stories and topical newsletters (including the BES Bulletin, IES Newsletter and PPF quarterly newsletter). We are seeking funds for a planned educational video about Baltimore as an ecosystem and will be contributing to a new traveling exhibit (Nature in the City) under development at the Bell Museum in Minnesota.

3d. Targeted publications. PPF, with BES scientists, educators, interns and graduate students, is producing accessible materials for managers, decision makers and the general public.

3e. Public meetings and participation. The public is invited to the BES quarterly science meetings, an annual Community Open House, and the BES Annual Meeting.

BES Education Table 5-1. Investigating Urban Ecosystem Module topics, components and partners responsible.

Topic	Core BES dataset(s)	Other Components	BES Partners
Visualizing Gwynns Falls Watershed – a resource for data & design retrieval.	• multi-dimensional visualization of processes over time • GIS data layers	• Baltimore time formation (3-d model) • urban design as models of patch dynamics • design proposals and scenarios	McGrath, Troy, Marshall, Towers, Martin
Reading the Waters - urban hydrology, water quality, and watershed.	• Gwynns Falls and trib. flow • water quality and fluxes • watershed descriptions	• storm event sampling • what urban runoff means to streams, wetlands, the Chesapeake Bay.	Schmidt, Band, Fisher, Groffman, Welty, Miller
Tree Treasures – the ecology of Baltimore's 2,600,000 trees.	• city tree census (every 3-5 yrs) • permanent plot vegetation data • neighborhood tree surveys	• permanent plots and street tree census sites • the population biology of Baltimore's trees • modeling environmental benefits of city trees	Wilson, Nowak, Galbraith Brush, Cadenasso
The Ecological History of Baltimore – linking people & environments over time..	• environmental equity analysis • census data on migration • infrastructure/ human health	• interactive timeline of Baltimore's history • thinking about environmental equity/justice • participatory & historical research methods	Koenig, Grove, Boone, Buckeley, Brush
The City Breathes – our air and what it tells us.	• Cub Hill CO2 levels and fluxes • other air quality data	• links to understanding global climate change • student investigations of local CO2 levels	Harrison, Hom, Heisler, Berkowitz
Brown Infrastructure - the soils beneath Baltimore and their role in the city.	• soil processes data • soil mapping • soil invertebrates (e.g., worms)	• earthworms and other invertebrates • essential ecosystem services from soils • impacts on ecosystem and human health.	Harvey, Pouyat, Yesilonis, Szlavecz
Land Use Change – the patterns, causes, & effects of transition from agric.	• land use coverage data • historical data from paleo work • air photos of specific sites	• air photo interpretation of sites near schools • comparison of Baltimore to other regions • interviewing farmers and residents	Reynolds, Grove, Boone, Buckley, Troy, CAP AgTrans
Schoolyard Ecosystems - revealing the human ecosystem framework .	• schoolyard land cover • schoolyard biodiversity • water movement in schoolyards	• describing biotic and physical patterns • ecosystem functions (water, nutrients) • human use, recreation and aesthetics	Berkowitz, Gordon, Bell, Pouyat
Animals in the City – who else lives in the city and how are we connected?	• birds in parks data • long term bird census data • squirrels in Balt. & London	• patch framework for studying animals • Cornell Lab. of Ornithology's protocols • birds/ and small mammals (squirrels)	Nilon, Warren, Middendorf
Neighborhood Ecology - the quality of urban life.	• photographic data sets • neighborhood assessments	• indicators and integrators of QOL in the city • envtl. perception & decision making	Grove, BNIA

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Facilities of the Baltimore Ecosystem Study Long-Term Ecological Research Program

The Baltimore Ecosystem Study LTER is a collaboration among many widely distributed individuals and institutions. Headquartered at the Institute of Ecosystem Studies (IES), BES maintains research and educational resources in Baltimore. On the campus of the University of Maryland, Baltimore County (UMBC), in close association with that university's Center for Urban Environmental Research and Education (CUERE), we maintain a dry lab, a wet lab, GIS facilities, and six offices for resident and visiting researchers. Samples from long-term aquatic and terrestrial monitoring sites are collected and processed at the UMBC laboratories and then sent on to IES for chemical analysis. The newly-built (July 2003) CUERE soils/water wet lab is equipped with a large reverse osmosis water source, 1 drying oven, 2 muffle furnaces, a fume hood with hot plate, 2 scales, shaker table, soil sample grinder, fire proof solvent storage cabinet, safety eye wash and shower, and two scales that measure to 0.1 gram. A centrifuge and spectrophotometer are due to arrive in February 2004. A dry lab is equipped with two sample refrigerators, Wiley mill, freezer, large drying oven, two small drying ovens, and vacuum manifold. An instrument and scale room is equipped with 10 stereo microscopes and a Mettler Scale that measures to 0.0001 gram. A small fleet of four IES and Forest Service vehicles is available for loan when not being used for core LTER data collection. High speed Internet connection is maintained through UMBC, and at neighborhood and environmental centers in Baltimore where BES maintains active research and educational partnerships.

Analytical facilities at IES include a Waters HPLC system with controller, photodiode array detector, autosample and Millennium chromatography analysis software; three Shimadzu model GC-8 and two GC-14 gas chromatographs and a Tracor 540 GC gas chromatograph with thermal conductivity, flame ionization and electron capture detectors; Perkin-Elmer Analyst 300 atomic absorption spectrometer with graphite furnace; Perkin-Elmer P400 inductively coupled plasma emission spectrometer, and autosampler; Carlo-Erba NA 1500 CNS analyzer; three Dionex DX500 ion chromatographs; two high quality Shimadzu UV-visible dual-beam spectrophotometers; Perkin-Elmer spectrofluorometer and plate reader; Alpkem Flow Solution III Analyzer; two Lachat Quikchem 8000 flow injection analyzers; two Turner Designs fluorometers; micro Kjeldahl analyzer, Shimadzu model 5050C gas analyzer for determination of dissolved and particulate carbon; leaf area meter; optical microscopes; inverted microscope; fluorescence microscopes; glove box; two image analyzers; Rockman L5C-1600 scintillation counter; ultra centrifuge; laminar flowhood; freeze dryer; drying ovens; rotary evaporators; incubators; walk-in cold room; Ultra-low freezer; muffle furnace; soil processing equipment; electronic balances (including microbalances); pH meters and electrical conductivity meters.

The CUERE Spatial Analysis Laboratory is a joint venture with BES, IES and the US Forest Service. The mission of the laboratory is to apply an interdisciplinary approach to advance the understanding of human impact on the environment through the provision of spatial analysis and data visualization. The laboratory consists of a Dell PowerEdge 2550 File/ArcSDE Server connected to a Dell PowerVault 220 SCSI Storage Device, Dell Precision 420 Web/ArcIMS server, a Dell PowerVault 120T DLT 7000 Tape Autoloader, 7 GIS workstations, 1 large-format plotter, and 1 large format scanner. The hardware is linked via a high speed network. The CUERE Spatial Analysis Laboratory also has the full suite of ESRI™ GIS products including

ArcGIS™, ArcIMS™ and ArcSDE™. Other spatial analysis products include ERDAS Imagine 8.6 for image analysis, and TerraScan™ for LIDAR point classification and analysis. Other spatial analysis activities for BES are carried out in laboratories located at IES, the USFS (Burlington and Syracuse), the Universities of North Carolina and Vermont and Johns Hopkins University.

Table 1-1: Publications from BES, LTER Research

Journal Articles
Published

Balmford, A., A. Bruner, A. Cooper, R. Costanza, S. Farber, R. E. Green, M. Jenkins, P. Jefferiss, V. Jessamy, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment, S. Rosendo, J. Roughgarden, K. Trumper, and R. K. Turner. 2002. Economic reasons for conserving wild nature. Science 297:950-953.

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Table 1 – 2. List of Available BES Datasets

Dataset Type	***Dataset***	***Dataset Description***
Census	Urban/Rural: 1790 - Present	Classification of land use into Urban or Rural.
	County: 1790 - Present	County level census time series date related to populations & households, housing, education, employment, household income, family composition.
	Tract: 1940 - Present	Tract level census time series date related to populations & households, housing, education, employment, household income, family composition.
	Neighborhood Change Database (NCD) 1970 - Present	Tracts standardized to Census 2000 Tract boundaries. Census time series related to populations & households, housing, education, employment, household income, family composition.
	Block Group: 1980 to Present	Block group level census time series date related to populations & households, housing, education, employment, household income, family composition.
Household Telephone Survey 1999, 2000, 2003	Recreation	Data on whether, how often, with whom, and where a person does a particular recreation activity.
	Days on Water	Data on how many days a person spent on the shore or at a body of water.
	Watershed Knowledge	Data on whether a person could identify the watershed in which they live.

Dataset Type	*Dataset*	*Dataset Description*
Household Telephone Survey 1999, 2000, 2003	Environmental & Neighborhood Awareness	Level of awareness of; cleanliness of streets; quality of parks; safety and security; air quality.
	Environmental & Neighborhood Problems	Data on existence of problems with: cleanliness of streets; quality of parks, safety and security, air quality, water quality. Also index of all problem indicators.
	Environmental & Neighborhood Improvement	Existence of improvement with: cleanliness of streets; quality of parks, safety and security, air quality, water quality. Also index of all improvement indicators.
	Environmental Quality of Life (2003)	Life Satisfaction, neighborhood satisfaction, neighborhood environmental satisfaction, neighborhood rating, leave neighborhood.
	Environmental Behavior	Data on how likely a person is to pay increased usage fees, support a tax increase, support legislation, or volunteer for environmental clean up. Also an index of all four activities.
	Yard/Garden Management	Data on existence of yard, garden at home, garden elsewhere; who in household makes management decisions and info on use of fertilizer.
	Social Capital	Data on whether one agrees or disagrees with: people in neighborhood willing to help; live in close knit neighborhood; one can trust neighbors; can work to solve community problems; active neighborhood association; adequate municipal services.
	Respondent and Spouse Demographic Information	Data on marital status, age, education, employment, income, race, and gender.

Dataset Type	*Dataset*	*Dataset Description*
Household Telephone Survey 1999, 2000, 2003	Housing Information	Data on housing type, ownership, and tenure.
	Household Information	Data on location of household, number of people in household, and number of people under 18 in household.
Neighborhood Field Observation Survey	Intensive plots - 100m	Home type; land use Trash - type, description, and amount; vegetation, animals, water, patch details, presence of alarm systems, vegetation.*
	Intensive plots - 300m	Land use, description, nearest permanent plot, patch descriptions, recreation and leisure items (e.g. basketball hoop, picnic table), bus stops, parked cars, vehicle flux, sounds.*
	Extensive plots - 100m	Home type; land use Trash - type, description, and amount; vegetation, animals, water, patch details, presence of alarm systems, vegetation for 200 plots of forested land for the UFORE model.*
	Extensive plots - 300m	Land use, description, nearest permanent plot, patch descriptions, recreation and leisure items (e.g. basketball hoop, picnic table), bus stops, parked cars, vehicle flux, sounds for 200 plots of forested land for the UFORE model.*
	Watershed 263 - 100m	Home type; land use Trash - type, description, and amount; vegetation, animals, water, patch details, presence of alarm systems, vegetation for Area of Watershed 263.*

Dataset Type	*Dataset*	*Dataset Description*
Neighborhood Field Observation Survey	Watershed 263 - 300m	Land use, description, nearest permanent plot, patch descriptions, recreation and leisure items (e.g. basketball hoop, picnic table), bus stops, parked cars, vehicle flux, sounds for area of Watershed 263.*
Neighborhood Photo-narrative	Intensive plots	Neighborhood recreation, environment, identity and social capital.*
	Extensive plots	Neighborhood recreation, environment, identity and social capital.*
	Watershed 263	Neighborhood recreation, environment, identity and social capital.*
Potential Rating Index by Zip code Markets by Claritas (PRIZM)	1990	Intra-neighborhood classifications based on patterns of consumer behavior toward products, services, media and promotions by Census Block Group.
	2000	Intra-neighborhood classifications based on patterns of consumer behavior toward products, services, media and promotions by Census Block Group.
	2003	Intra-neighborhood classifications based on patterns of consumer behavior toward products, services, media and promotions by Census Block Group.
Consumption	Lawn care supplies: 2003	Purchases of lawn care supplies by household for each census block group.
	Lawn care services: 2003	Purchases of lawn care services by household for each census block group.
Conserved Land	County Parks	Data consisting of land areas that are run and maintained by county and municipal authorities.

Dataset Type	*Dataset*	*Dataset Description*
Conserved Land	DNR Land	Location information that represent those lands that are owned by the Maryland Department of Natural Resources.
	Federal Lands	The Federal Lands data consists of land areas that are run and maintained by U.S. Governmental authorities.
	Forest Legacy Area	Location data layer created for the planning purposes of the Maryland Department of Natural Resources. Designed to identify and protect environmentally important forest lands through the use of easements between willing sellers and buyers.
	Maryland Agricultural Land Preservation Foundation (MALPF)	Location of agricultural lands perpetual easements.
	Maryland Environmental Trust Easements (MET)	Statewide local land trust conservation easements.
	Private Conserved Land	Data representing a collection of properties that are protected from development by ownership of a Private Conservation group or Society.
	Rural Legacy Areas	Digital file of the Rural Legacy designated areas. The purpose of the Rural Legacy Program is to protect Maryland's best remaining rural landscapes and natural areas through the purchase of land or conservation easements.
	Greenways	Location of greenways established by the Maryland Greenways Commission.
	Green Infrastructure	Satellite image mapping of green infrastructure.

Dataset Type	*Dataset*	*Dataset Description*
Administrative	Vital statistics	Vital statistics.*
	Maryland Property View	Parcel-specific data on ownership, residential or commercial structure types, value, location, etc.*
	Property values	Property values.*
	Zoning	Zoning.*
	Covenants	Deed covenants.*
Network Analysis	Natural Resource Management Organizations	Organizational network analysis to describe and characterize the natural resource management regime in the Gwynns Falls Watershed.
Newspaper articles	Public health	Newspaper articles relating to public health in the Baltimore MD area.*
	Water	Newspaper articles relating to water issues in the Baltimore MD area.*
	Parks	Newspaper articles relating to parks in the Baltimore MD area.*
	Forests	Newspaper articles relating to forested areas in the Baltimore MD area.
Historic photographs	Forests	Historic photographs of forested areas in the Baltimore, MD area.*
Remote sensing	Landsat: 1973, 1981, 1990, 2000	Satellite imagery of the Baltimore metropolitan area.*
	Emerge: 1999	Aerial photographic imagery of the Gwynns Falls watershed.*
	IKONOS: 2001	High-resolution satellite imagery of the Baltimore City.*

Dataset Type	*Dataset*	*Dataset Description*
Topography	Light Detection and Ranging (LIDAR)	High resolution grid of XYZ data points 1m spacing 15cm accuracy recorded for the Gwynns Falls *watershed area.*
Landuse	Anderson Level II	Classification of Gwynns Falls watershed 1973, 1981, 1990, 1997.*
	Baltimore City Boundary	GIS Boundary - Baltimore City boundary.
	Minor Civil Division	GIS Boundary - minor divil division boundary.
	City Block Groups	GIS - Baltimore City block groups in the Gwynns Falls watershed.
	County Block Groups	GIS - Baltimore County block groups in the Gwynns Falls watershed.
Landcover	NLCD	National Land Cover Dataset from USGS - 1992, 2001.
	HERCULES	Land classification data.
	Forests: 1914	State foresters classification of Baltimore County and Baltimore City, and Anne Arundel County.*
	Forests: 1938, 1957	Delineated from aerial imagery.*
	Forests: 1873, 1981, 1990, 1997	Classified from satellite imagery.*
Ecosystem Valuations	Baltimore, 2000	GIS-based data to assess ecosystem service values in the Baltimore metropolitan region.*
Streams	Chemistry	Anions/cations, suspended solids, nitrogen, phosphorous, turbidity, fecal coliform, temperature, pH, dissolved oxygen.

Table 1-2:7

Dataset Type	*Dataset*	*Dataset Description*
Streams	Flow	Stage, crest stage, velocity, volumetric flow per unit time, average daily flow, peak flows.
	Biota	Fish, macroinvertebrates, algae and macrophytes.
Atmosphere	Precipitation	Stream locations, photographs, and rainfall amounts.
	Chemical Flux	Passage of selected chemicals and compounds through a designated area gathered using collection apparatus mounted on a tower. *
Biodiversity	Vegetation	Various data for trees, saplings, shrubs, vines and groundlayer species for several permanent plot areas in the Baltimore, MD area.
	GIS	Spatial representation of vegetation data.
Soil	Chemistry	Soil solution chemistry, temperature, flux of carbon dioxide, nitrous oxide and methane from soil to atmosphere, in situ nitrogen mineralization, nitrification and denitrification.
	Moisture	Time domain reflectomitry probe measurements of soil moisture for BES permanent plots.

Items marked "*" are not available online

Letters Of Support

1. U.S. Forest Service – Letter of support and funding commitment (Michael Rains)

2. Mayor of Baltimore (Martin O'Malley)

3. City of Baltimore Department of Recreation and Parks (Kimberley Flowers)

4. Baltimore City Public School System (Bonnie Copeland)

5. City of Baltimore Department of Public Works (William Stack)

6. Baltimore County Department of Environmental Protection and Resource Management (David Carroll)

7. Baltimore County Public Schools (George Newberry)

8. Maryland Department of Natural Resources (Michael Galvin)

9. Maryland State Department of Education (Rebecca Bell)

10. U.S. Department of Agriculture Chesapeake Bay Program (Albert Todd)

11. U.S. Environmental Protection Agency Mid-Atlantic Integrated Assessment (MAIA) Program (Patricia Bradley)

12. Urban Ecology Institute (Charles Lord)