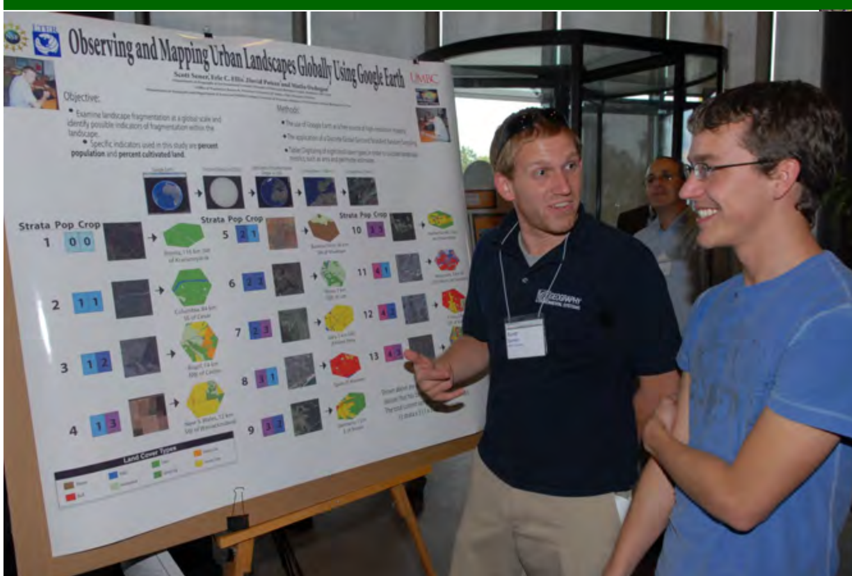
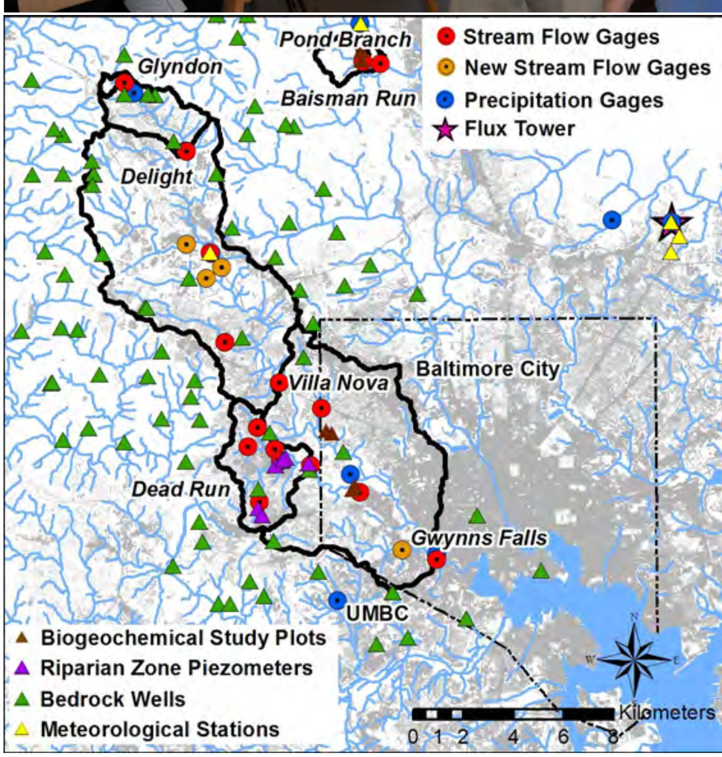
BALTIMORE ECOSYSTEM STUDY

Long-Term Ecological Research Renewal Proposal, 2010

**Baltimore Ecosystem Study, Long-Term Ecological Research:
Phase III – Adaptive Processes in the Baltimore
Socio-Ecological System: From the Sanitary to the Sustainable City**





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Cary Institute of Ecosystem Studies

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1 March 2010

Dear Members and Friends of BES:

You have before you our proposal to the National Science Foundation for renewal of its support of the Baltimore Ecosystem Study, Long-Term Ecological Research project. The proposal is the work of nearly fifty Co-Principal Investigators from twenty-seven organizations, including universities and research institutions, non-governmental organizations, and private professional practices.

If this proposal is successful, it will guide the next six years of research, education, and community engagement for one of the two, founding urban LTER projects in the United States. While we propose to continue collecting key long term data on the structure and function of urban streams and complex landscapes, as well as the social patterns and processes that depend on and influence those environments, we plan to add new theoretical approaches and empirical strategies.

There are three new applications of theory we propose to shape the next six years of our work. One, the metacommunity, is a spatially explicit model of biological diversity as it interacts with the heterogeneous social and built infrastructure of metropolitan Baltimore. A second is a new urban version of the "river continuum concept," a well known framework for understanding how the structure and function of streams change from headwaters to mouth. The third is an application of models to predict the locational choices that households and firms make, and how these influence and are influenced by the biological and physical environment of the city, suburbs, and countryside.

We will turn our long-term data and these new tools to two tasks. First, we hope to better integrate the social and biophysical understanding of metropolitan Baltimore. Second, we hope to help local communities and governmental agencies exercise their growing concern with sustainability throughout the metropolis.

We hope this document stimulates collaboration with BES through a better understanding of where we hope to go in the future. No part of it should be cited, published, or distributed publicly to protect the intellectual investment of our community of scholars and practitioners.

If you have interests in collaborating or learning more about our findings, please contact the Project Facilitator, Ms Holly Beyar, at beyarh@caryinstitute.org or (845) 677-7600, ext 210.

Sincerely yours,

Steward T.A. Pickett
Project Director

Baltimore Ecosystem Study Renewal Proposal 2010

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Corrected : 02/02/2010

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 10-1 **NSF 10-1**	FOR NSF USE ONLY NSF PROPOSAL NUMBER **1027188**
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) **DEB - Long-Term Ecological Research**	

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
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NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE **Institute of Ecosystem Studies**	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE **Institute of Ecosystem Studies** **2801 SHARON TPKE** **MILLBROOK, NY. 125450129**
AWARDEE ORGANIZATION CODE (IF KNOWN) **4001926000**	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions) ☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS ☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **Baltimore Ecosystem Study Phase III: Adaptive Processes in the Baltimore Socio-Ecological System from the Sanitary to the Sustainable City**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 5,640,000	72 months	11/01/10	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
- ☐ BEGINNING INVESTIGATOR (GPG I.G.2)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
- ☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date ________ PHS Animal Welfare Assurance Number ________
- ☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number ________ Exemption Subsection ________ or IRB App. Date ________
- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j) ________
- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS **Box AB** **Millbrook, NY 12545** **United States**
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PROJECT SUMMARY

The third phase of the Baltimore Ecosystem Study (BES III), Long-Term Ecological Research project builds on 13 years of experience in establishing and refining a platform for integrated urban ecological and social research, education, and outreach. BES III takes advantage of the growing shift of urban areas toward sustainability policies, and the need to scientifically understand and evaluate the adaptive processes proposed to promote urban sustainability. BES brings together more than 45 researchers, educators, and community specialists from Baltimore and beyond, and coordinates the activities of members from research institutions, universities, federal agencies, local jurisdictions, and non-governmental organizations to answer the question: What are the effects of adaptive processes aimed at sustainability in the Baltimore socio-ecological system?

Intellectual Merit. BES III will continue to collect long-term data on urban ecosystem structure, function, and change. It will add new research to improve understanding and application of the concept of sustainability, based on hypotheses about the social and biogeophysical processes in Baltimore that can help adapt to local sustainability policy and effects of climate change. The research employs experimentation, comparison, long-term measurement, and modeling. Hypothetical models of feedback between social and biogeophysical processes linked through ecosystem services of water quality and flow, and net carbon storage identify variables and spatial patterns to be measured. The feedback models will also support the development of future scenarios. Three theories new to BES III – socio-economic models of the locational choices made by households and firms, an urban version of the stream continuum concept, and an application of metacommunity theory to the fragmented urban biota – suggest new research questions and stimulate integrated modeling. Modeling will draw on existing ecohydrological, social, vegetation, and ecosystem service modules, but will be refined and operated for enhanced cross-disciplinary integration and prediction. The project will enhance understanding of cities, suburbs, and exurbs as integrated, spatially extensive, complex adaptive systems.

Broader Impact. BES has a firm foundation for engagement between researchers, educators, and the citizens, managers, and policy makers in metropolitan Baltimore. Focusing on urban sustainability will exercise and improve the ability to interact with various constituencies. The project employs education research to improve socio-ecological literacy, and to understand how teaching and learning can advance sustainability. School and informal education programs will produce materials to foster socio-ecological literacy, to train teachers for this instructional task, and to develop school-based assessments of socio-ecological literacy. The program will also support informal and schoolyard-based programs in socio-ecological literacy. Programs for the public and for groups such as managers, decision makers, and community activists will be improved based on study of existing interaction methods, and exploration of new opportunities to co-define questions and share perspectives and knowledge. Finally, BES information and frameworks are employed in training, ranging from web-based graduate education of national scope, to a Green Career Ladder program for youth in Baltimore. Insights from the project will be shared at local, regional, and national scales through the BES Annual Community Open House, BES newsletter, BES website, Revitalizing Baltimore Technical Committee; Urban Ecology Collaborative, and technology transfer programs of the USFS.

SECTION 1: RESULTS FROM PRIOR NSF SUPPORT

The first 12 years of the Baltimore Ecosystem Study (BES) were guided by three overarching questions that addressed 1) structure 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. Our presentation of the major accomplishments of BES to date is organized by these questions and points to the new questions that will guide research during BES III. A full list of project publications is in Supplementary Documents, and ancillary grants are listed in Table 3 of Section 2.

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?

Our platform for long-term, urban ecosystem research in Baltimore includes two geo-referenced networks of permanent plots: 1) an intensive network of 12, 40 x 40 m plots for vegetation and biogeochemistry (Groffman et al. 2006, Groffman & Pouyat 2009, Groffman et al. 2009); and 2) an extensive network of 194 405 m^2 plots across the metropolis to parameterize the Urban Forest Effects (UFORE) model and to characterize soils (Nowak et al. 2004, Pouyat et al. 2007a, Yesilonis et al. 2008). An additional 200 extensive plots were established in 2007 within the Urban-Rural Demarcation Line (URDL; Fig 5, Section 2) in surrounding Baltimore County. UFORE couples vegetation, air pollution, and meteorological data to quantify urban forest effects. In 1999, a 5 yr vegetation sampling rotation began on the intensive plots, and a 3 yr cycle began on the extensive plots. The long-term research platform also includes a historical hydrologic database for our focal watershed, 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.

Long-term, georeferenced social data linked to the plot networks were collected using a nested approach that includes a residential, household telephone survey that has been conducted four times since 1999. In 2006, the household telephone survey had a sample size of approximately 3,300 completed surveys, covering the entire Baltimore metropolitan statistical area (MSA). Associated with each telephone record is the address and location of the household surveyed, allowing each survey to be connected to the parcel property attributes from Maryland PropertyView, other administrative data, census data, commercial data, and biophysical data at the parcel and neighborhood scales (Zhou et al. 2008a). Phenomena examined in the telephone survey include environmental perceptions, preferences, and behaviors; perceptions of environmental, individual and neighborhood quality of life; human and social capital; and recreation and land management practices (Vemuri et al. in press). The telephone survey provides a sampling structure for a field observation survey of residential land management practices and condition (n = ~1,000; Lidman 2008), and face-to-face, open-ended surveys and ethnographies of homeowner land management practices and motivations (n = ~500) and homeowner associations (n = ~25) (Fraser et al. 2007). Ethnographic surveys and research have addressed current and past zoning practices, e.g., Baltimore County's URDL and urban forestry policies and practices at the state and local level (Buckley, in press).

Biotic structure. Our extensive survey shows ca. 2.6 million trees, with 21% canopy coverage in Baltimore City and a mortality rate of 6.6%/yr (Nowak et al. 2004, 2008). The compensatory value of these trees is $3.4 B (Nowak et al., 2002). The standing stock of trees stores ca. 528,700 t C ($10.7 M), removes ca.14,800 t C/yr ($300,000/yr; Nowak & Crane 2002) and an estimated ca. 477 t of air pollutants/yr ($2.6 million/yr; Nowak et al. 2006).

Bird community structure shows signatures of human resource subsidies leading to greater inter-specific competition. Analyses revealed the existence of 4 distinct bird communities in Baltimore, with the abundance of some exotic bird species correlated with urban development, while abundance of many native species correlated with vegetation cover (Pickett et al. 2008, Nilon et al. 2009). Theoretical advances were made in the areas of animal behavior (Warren et al. 2006), human influences on spatial distribution of species (Warren et al. 2008, Swan et al. in press), and the role of competition in structuring urban communities (Shochat et al., in press).

Exotics dominate soil fauna in Baltimore, ranging from 0% (Coleoptera: Silphidae) to 100 % (Isopoda: Oniscidea; Hornung & Szlavecz 2003, Hornung et al 2007, Wolf and Gibbs 2004). A diverse soil invertebrate community exists in urban and suburban habitats, e.g., 66% of the earthworm fauna of Maryland (Csuzdi & Szlavecz 2002, 2003, Korsos et al 2002, Szlavecz et al. 2006, Szlavecz & Csuzdi 2007). Comparative studies showed that soil macrofauna in cities are similar due to the presence of cosmopolitan, synanthropic species, although the overlap varies by geographical region. We introduced the term -urban vicariance" to describe faunal elements in different cities that are taxonomically distinct, but functionally similar (Pouyat et al., in press). Soil surveys along urban-rural gradients showed that urban environments impact forest soil chemical properties (Pb, Cu, Ca) in Baltimore, New York, and Budapest, though characteristics of each city (spatial pattern of development, parent material, and pollution sources) influenced the soil chemical response (Pouyat et al. 2008).

Physical structure. A major focus of BES has been to develop new approaches and methods for characterizing land cover for metropolitan areas. This work involves both re-conceptualizing the factors controlling the functionally of important elements of urban ecosystem structure (Cadenasso et al. 2006, Ellis et al. 2006, Cadenasso et al. 2007, Ellis & Ramankutty 2008) as well as developing new practical tools for high resolution mapping and assessment (Tenenbaum et al. 2006, Zhou et al. 2008b). These tools have facilitated new analyses of the relationships between urban ecosystem structure and function, contributing to new approaches to urban design (McGrath et al. 2007, Pickett et al. 2004, 2005, Pickett & Cadenasso 2008).

Social structure. Characterization of social patch structure enabled us to 1) assess changes in social structure over time (Boone et al. 2009, in press, Lord & Norquist in press), 2) analyze cause and effect relationships between social processes and biophysical structures and processes (Band et al. 2005, Pickett et al. 2008, Troy & Grove 2008, Zhou et al. 2008a, 2009, Boone et al. 2009, Vemuri et al. in press), 3) evaluate temporal complexity such as lags, legacies, and slow processes (Boone et al. 2009, in press, Lord & Norquist in press), and 4) elucidate system resiliency (Boone 2002, 2003, Michaud 2005, Grove 2009). We enhanced Claritas' PRIZM lifestyle market classification to include social and biophysical characteristics of neighborhoods and test the theory of an *Ecology of Prestige* (Grove et al. 2005, 2006a, 2006b, Troy et al. 2007).

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 long term?

The watershed approach has been central in BES, both as a means for comparison with the many other LTER sites that use this approach (HBR, CWT, AND, PIE, FCE, NWT, HFR, GCE, CCE) and as a platform for integration of biophysical and social sciences and education. 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 6 & Table 2, Section 2). 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 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 watersheds provide data on specific land use types (forest, agriculture, suburban, urban).

Highlights from the long-term watershed monitoring over the past six years include derivation of “nutrient duration” curves that show that the vast majority of nitrogen and phosphorus export occur during high flow conditions, a result that is critical for designing strategies to reduce export to receiving waters such as the Chesapeake Bay (Shields et al. 2008). Extreme flood events are generated by short-duration high-intensity warm season thunderstorms and vary with the space-time structure of rainfall and with land-surface properties including impervious cover and structure of the urban drainage network (Javier et al. 2007, Nelson et al. 2006, Ntelekos et al. 2008, Smith et al. 2005, 2006). Significant hydro-climatic variability allowed for analysis of how interactions between climate and land use change amplify nitrogen exports (Kaushal et al. 2008a). Long-term data on chloride levels revealed that contamination of surface and groundwater by road salt is pervasive (Kaushal et al. 2005).

Work with *E. coli* in BES streams has revealed a ubiquitous distribution, with concentrations increasing during and after storm events and a demonstrated consistent presence of pathogenic *E. coli* 0157 H1 (Higgins et al., 2005, Belt et al., 2007.) Subsequent work showed that these pathogens were able to survive in these streams for many weeks. The monitoring of stream temperatures has confirmed that frequent high summer temperatures are likely to exert important thermal impacts on fish in urban streams (Kim 2007). Moreover, work in BES streams has shown that runoff events in small headwater catchments cause thermal spikes and extended periods of elevated temperatures.

In April 2002, the City of Baltimore began a program to upgrade its sanitary sewer infrastructure. The City will spend $940 million over 14 years to end chronic discharges of raw sewage into local waterways. Our long-term weekly stream sampling provided a strong pre-treatment dataset for this “natural” experiment, with several of our long-term monitoring sites “treated” by infrastructure improvements, and others serving as “reference” sites. Data from the small, heavily contaminated tributary Gwynns Run (Fig 11, Section 2) shows the dramatic effects infrastructure improvements can have.

We established the first permanent urban eddy covariance micrometeorological tower to quantify carbon fluxes and carbon dioxide (CO_2) concentrations in a residential area of mixed cover types. Partitioning of the Cub Hill tower’s heterogeneous footprint into 24 sectors with different land use properties allowed us to develop empirical relationships between CO_2 and H_2O fluxes and surface characteristics such as Normalized Vegetation Index (NDVI) and percent vegetation cover (Fig 12, Section 2). Results indicate that the higher urbanization on the south (73 % vegetation cover) than the north (90 % vegetation cover) side of the tower results in a 45% reduction in daytime photosynthetic CO_2 uptake during the growing season.

Integrated analysis of structure/function relationships

One of the great challenges in LTER projects, especially those with a significant social science component, is integration between different disciplines. In BES, “hotspots of integration” (Table 1, Section 2) have emerged over the past six years that have produced some of our most exciting results and lay the groundwork for the questions we hope to address in BES III (Pickett et al 2008, Cadenasso et al. 2008). Construction of nitrogen balances for the BES watersheds (Groffman et al. 2004, Kaushal et al. 2008a) has served as both a hotspot for integration and a platform for multiple lines of research. These balances, which have shown surprisingly high nitrogen retention (> 70%) have raised questions about “where does the nitrogen go?” First we searched for retention in riparian zones, which have long been known as hotspots for retention in agricultural and forest watersheds. Instead, we found significant degradation of riparian zone function in urban watersheds (Groffman et al. 2002, Groffman & Crawford 2003, Kaushal et al. 2008b, Gift et al. 2010) and that we needed to integrate biogeochemical data with historical (Bain & Grush 2004) and social (Grove et al. 2006b) data to understand why this was so (Groffman et al. 2003). This understanding was then fundamental in the development of urban tree canopy goals in the State of Maryland, where recognition of the lack of nitrogen retention in urban riparian forests led to the idea that more a more distributed approach to urban forestry could result in better amelioration of urban hydrology and nitrogen delivery to receiving waters such as the Chesapeake Bay (Cadenasso et al. 2008, Wang et al. 2008).

The riparian work led to the recognition that many streams and riparian zones in urban areas are characterized by a suite of degradation effects collectively referred to as the -urban stream syndrome" (Groffman et al. 2003, Walsh et al. 2005). Efforts to reverse the effects of this syndrome through geomorphic restoration represent major manipulations of stream ecosystems. Comparison of restored streams with degraded and forested reference streams have been a major hotspot of integration in BES with analysis of relationships between structure and function, in a strong social and policy context (Mayer et al. 2004, Groffman et al. 2005, Hale & Groffman 2006, Craig et al. 2008, Kaushal et al. 2008b, Klocker et al. 2009, Gift et al. 2010, Mayer et al. 2010) Doheny et al. 2006, 2007, Doheny & Fisher 2007).

Nitrogen balances showing high retention motivated integrated analyses of lawns on residential parcels. Detailed biogeochemical comparisons of forests and grasslands, centered on our network of long-term study plots, showed that retention was higher and that hydrologic and gaseous losses of nitrogen from lawns were lower than expected given that these ecosystems are fertilized (Raciti et al. 2008, Groffman et al. 2009). These plots have been sampled monthly since 1998 for soil temperature and moisture, fluxes of carbon dioxide, nitrous oxide and methane (*in situ* chambers) and leaching (zero tension and suction lysimeters) of nitrogen and phosphorus (Groffman et al. 2006). Long-term data were used to develop a soil temperature model for the region (Savva et al 2010). The biogeochemical results led to investigations of lawn care practices with surveys of homeowners (Law et al. 2004) and analysis of the social drivers of lawn care practices (Zhou et al. 2008a, 2009). Leveraged funding (Table 3, Section 2) facilitated new research efforts on carbon and nitrogen dynamics in actual home lawns, broader surveys of household level environmental behavior and studies of the importance of lawns in the footprint of the Cub Hill flux tower (Pouyat et al. 2009). The lawn research also has been a platform for cross-site comparative studies with CAP, FCE and PIE.

A physical hotspot for integration in BES has been the experimental evaluation of neighborhood greening and revegetation as a strategy to improve storm water quality and reduce urban runoff to the Chesapeake Bay. Much of this work is centered on a 364 ha watershed defined by a storm drain network of 21 km of pipes of $\geq$ 1m diameter. This entirely urbanized drainage (Watershed (WS) 263), is home to 30,000 residents, and contains 30% public and private open space, and 976 vacant residential lots (30 ha). The WS 263 project is a prototype for non-point management of storm water in urban systems based on sound science and community participation and is testing the hypothesis that reductions in impervious surface, creating bio-retention facilities and rain gardens, and increases in vegetation will result in significant changes in urban hydrology and N retention. Additionally, we expect quality of life (QOL) of watershed residents to be positively affected by these physical changes and are measuring QOL indicators, working closely with community leaders. WS 263 is primarily a project of the Baltimore City Department of Public Works, Parks & People Foundation, and BES/USDA Forest Service, but has attracted additional funding support from many other agencies. This additional funding has facilitated crafting of a restoration plan, a SWMM model, mapping and monitoring of 43 miles of storm drains, over 50 public education and training workshops, removal of 4 acres of schoolyard asphalt, planting more than 800 trees, a resident phone survey, and a street sweeping study (Diblasi, 2008, Law et al., 2008). Concentrations and constituent fluxes in the catchment outflows have revealed a dynamic hydrologic and thermal system with high bacterial concentrations and large nutrient and heavy metal loads and concentrations, suggesting that older, ultra-urban residential catchments are hotspots for pollutant exports.

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 education research has focused on the potential role of formal and after school education programs in fostering an understanding of urban ecosystems among students. We led a 5-city study confirming that non-formal programs can provide a range of environmental education services to a diverse urban audience, while also highlighting important gaps in coverage (such as climate change and environmental justice). An Ecology Teaching Study (2005) described high school biology and environmental science teaching practices and needs. In an NSF supported Teacher Modification of Curriculum project, video-based research revealed some of the obstacles teachers face in attending to student thinking during instruction, especially during field investigations (Tang et al. 2010). BES and 3 other LTERs are collaborating in the NSF/MSP-funded Culturally Relevant Ecology project to define environmental science literacy and citizenship for K-12 students, building on earlier efforts to set goals for urban ecosystem education (Berkowitz et al. 2003) and to define ecological literacy (Berkowitz et al. 2005).

During BES II, we significantly expanded and solidified our partnerships with local schools. We offered 13 workshops with 93 teacher participants, engaged 7 teachers as summer RET Fellows, and 8 teachers in year-long Fellowships. As part of the NSF/MSP project, we currently are engaged with 12 schools in Baltimore, providing training in environmental science research and teaching techniques. We have produced instructional materials: 1) *Investigating Urban Ecosystems* (IUE, see: http://www.beslter.org/frame5-page_5a.html); 2) *My City's an Ecosystem* (see: http://www.beslter.org/frame5-page_5c.html); and 3) *BioComplexity and the Habitable Planet* (an NSF-supported curriculum led by collaborators at TERC to be published in 2011).

There has been a BES Open House each year in conjunction with a well-attended Community Greening Celebration coordinated by the Parks & People Foundation. The audience for the combined events has grown from 40-50 people to 150-175 people.

As discussed above, the U.S. Forest Service's urban tree canopy (UTC) assessment program grew out of BES research (Troy et al., 2007). The Troy et al. data were used by then-mayor Martin O'Malley to establish a UTC goal and program to increase the tree canopy for the City of Baltimore, in part through educational outreach to residents, businesses and institutions. Through networks such Urban Ecology Collaborative (UEC), this program has spread to over 30 communities in the United States. Of note is New York City's 1 million tree initiative, a goal established using scientific protocols developed by BES researchers.

BES scientists have been very active in undergraduate and graduate education. In 2006, UMBC was the recipient of a NSF IGERT award, ―Water in the Urban Environment" (C. Welty, PI), with BES providing: 1) inspiration for the program theme; 2) mentors for IGERT trainees; 3) a rich database and support for place-based research; and 4) help in attracting high-quality applicants to the program. This award has partly supported 20 PhD students. Notably, The UMBC IGERT program has achieved significant attraction of minority (28%) and female students (70%).

SECTION 2: PROJECT DESCRIPTION

Integration of biogeophysical and social systems remains a challenge for the environmental sciences (Kingsland 2005, Alberti et al. 2003, Andersson 2006). In the proposed third phase of the Baltimore Ecosystem Study (BES III) urban LTER, we will 1) improve our knowledge of human-natural system interactions, and 2) examine the mechanisms by which the social and the biogeophysical components of the Baltimore ecosystem can adjust to ongoing or future changes. BES III exploits the growing interest in sustainability in urban systems and the recognition that integration between social and biogeophysical components underlies adaptive strategies and processes that control the resilience of coupled socio-ecological systems in a changing world. The research, education, community engagement, and outreach we propose builds on our watershed-based, spatially explicit, and geographically extensive social and biogeophysical studies, but extends into newly developing exurban lands, adds locational choice as a socio-economic modeling approach, and enhances the interaction among our complementary social, ecohydrological, and ecological models.

In the sections that follow, we will define and justify the use of sustainability and adaptive processes as organizing concepts, present hypothetical feedbacks between social and biogeophysical processes based on ecosystem services of water and carbon budgets, and relate these to local policies in the Baltimore region. To further enhance integration, we will present three theoretical areas new to BES, and present the main research questions that emerge from them or cut across our concerns with the history and condition of adaptive processes, future scenarios of adaptation, and the role of information exchange and education in adapting metropolitan Baltimore to internal, policy, and global changes.

2.1 BACKGROUND AND JUSTIFICATION: URBAN CHANGE AND ADAPTATION

Urban socio-ecological systems (SES) are undergoing vast changes globally (Folke et al. 2002, Grimm et al. 2008). Changes in economic and commercial strategies, human migration, land conversion, density patterns, household structure, lifestyles, sea level, and global climate are among the most conspicuous changes in urban systems (Boone & Modarres 2006, UNPF 2007). Such changes provide contrasting conditions that can expose the biogeophysical and social workings of urban ecosystems (Dow 2000, McDonnell et al. 2009). Researchers and managers of urban systems are increasingly concerned to know whether urban areas are capable of adapting to these drastic biological, geophysical, and social changes. A widespread paradigm shift in response to the changes urban areas face is a move toward sustainability (Curwell et al. 2005), which can be defined based on two standards (Symes et al. 2005): 1) the ability to improve the quality of human life while living within the capacity of ecosystem support (IUCN 1991); and 2) the ability to meet contemporary needs without compromising the ability of future generations to meet their needs (Naess 2001). Both definitions invoke three equal facets: social equity, economic viability, and environmental functionality. Ecological knowledge is crucial to advancing sustainability, and sustainability places ecological knowledge in the context of integrated socio-ecological dynamics (Williams 2007).

The paradigm of the “sustainable city” contrasts with the traditional way of managing urban areas through distinct sectors such as transportation, waste, stormwater, planning, education, housing, and recreation (Platt 2006). The sectoral paradigm characterizes the “sanitary city,” organized around separate engineering and managerial tactics to overcome unhealthy conditions for people (Melosi 2000, Johnson 2006, Grove 2009). In contrast, the sustainable city paradigm is a corrective to the unintended environmental and social costs of the sanitary city. Urban sustainability is not an absolute state, but a relative capacity that can be indexed as either improving or deteriorating (Symes et al. 2005, Curwell et al. 2005). Thus, sustainability can be operationalized using concepts of resilience and adaptive processes (Gunderson et al. 2002, Chapin et al. 2003, Pickett et al. 2004, Chapin et al. 2009) especially in an urban setting (Andersson 2006). Sustainability interpreted in this way does not refer to stabilizing current conditions, but rather to maintaining the ability of a complex system to adjust or adapt to changes in any of the three realms of society, economics, and environment (Folke 2006). The direction, magnitude, and persistence of actions that allow urban systems to do ecological, social, and economic work can be measured (Symes et al. 2005, Folke 2006, Grove 2009).

The emerging paradigm of sustainability in urban systems worldwide is signaled by policies enacted by specific cities, counties, regions, and states (e.g., UNEP 2005, Williams 2007). In BES III, the sustainability paradigm is reflected in sustainability plans aimed at adapting to changing environmental, social, and economic conditions in the city, counties, and state we study (i.e., Baltimore City 2009, Baltimore County 2010). Such plans themselves have become part of the changing local and regional context of city-suburban-exurban (CSE) systems, and like climate change, economic globalization, regional and international migration, and other large forcing functions (Grimm et al. 2008, Boone & Modarres 2006), they must be taken into account in understanding CSE systems

2.1.1 Adaptive Processes: A Key to Sustainability

The paradigm of sustainability must be operationalized by specific adaptive environmental, social, and economic actions. Adaptation is the process, action, or outcome in a system in order for the system to better cope with, manage, and adjust to some changing condition, stress, hazard, risk, or opportunity (Smit & Wandel 2006). Such adaptive processes underlie the ability of a socio-ecological system to experience perturbations, shocks, and novel inputs and still remain in a given domain that is functionally viable (Smit & Wandel 2006, Nelson et al. 2007). These processes allow the system to respond to alterations in a way that retains the overall structure, functional processes, and resilience (Folke 2006, Nelson et al. 2007, Chapin et al. 2009). Adaptation and resilience are both evolutionary concepts, which recognize that fixed stability is unlikely in coupled biological and social systems (Gunderson 2000, Holling & Gunderson 2002, Chapin et al., in press).

Adaptation as a process is shaped by the characteristics of CSE systems; the resources and various types of capital accessible to those systems; and the social, economic, institutional, and ecological constraints that limit how a system may respond to endogenous or exogenous shocks. We will investigate both the dynamic processes and the types of resources and capital, i.e., human, social, built, and natural (Ostrom 1990), influencing the breadth and limits of adaptive capacity. We compile a framework for determinants of adaptive capacity incorporating these elements (Fig 1) by combining social components from Yohe and Tol (2002) and Eakin and Lemos (2006) and biophysical processes from Gunderson et al. (2002) and Walker et al. (2004). This framework is consistent with those developed for the LTER Network by Redman et al. (2004) and Collins et al. (2007).

To investigate processes of adaptation to urban sustainability policies and to climate change, it is necessary to ask who adapts; to what; and how (Smit et al. 2000)? Adaptive actions are then characterized by scale, timing, form, purpose, and other dimensions (Smit et al. 1999, expanded by Fussel 2007). Significantly, these adaptive processes entail both planned processes, such as policy implementation, and autonomous processes such as locational choices at institutional and individual levels (Fig 1). In urban areas, these responses are shaped by multiple stresses; environmental, economic and social processes; rapidly evolving scientific understanding; dense infrastructure and technological legacies, and new policy pressures. This transition to greater

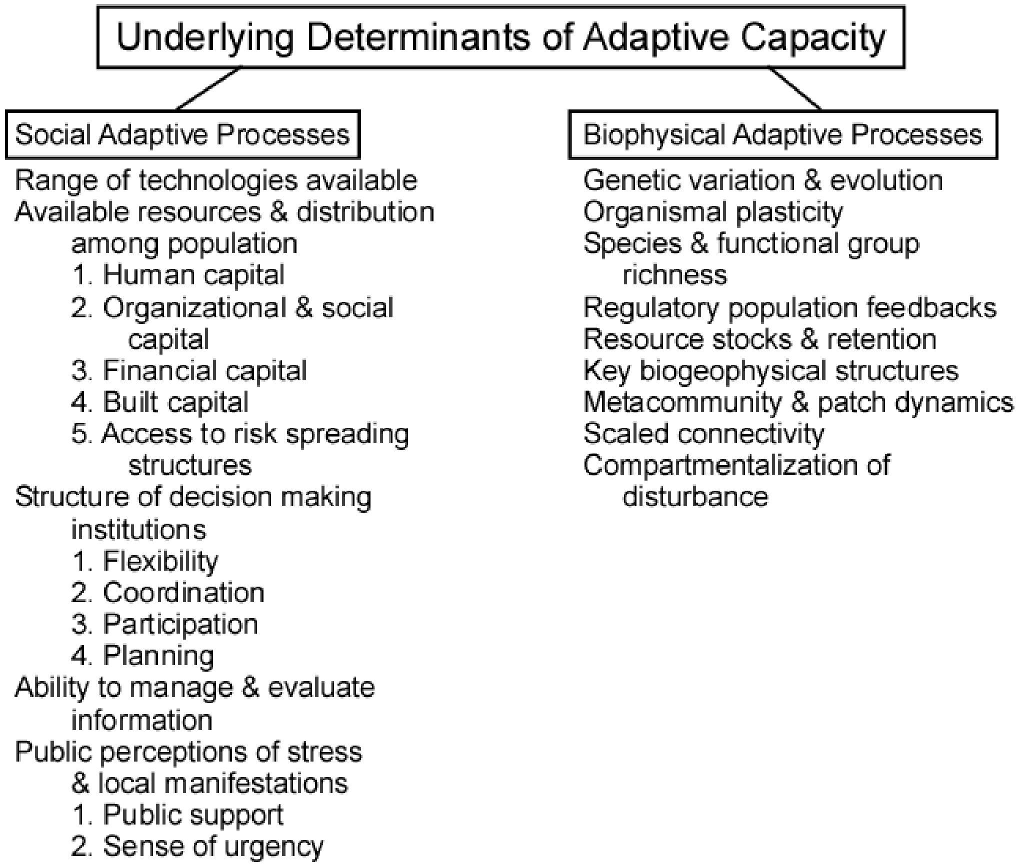


Figure 1. Adaptive processes. Underlying determinants of adaptive capacity, divided into social components (from Yohe and Tol 2002) and biotic components (abstracted from Gunderson et al. 2002, and Walker et al. 2004). Although absolute adaptive capacity can be difficult to measure, assessing whether the underlying processes are tending toward improvement or degradation is more feasible using long-term studies, comparison, or modeling.

sustainability and reduced climate vulnerability is expected to reveal both thresholds and tipping points in systems that constrain or accelerate adaptation (NSF ACERE 2009).

An essential institutional adaptation to address sustainability and climate change may be changes in governance structures and social networks. The last century saw the traditional emphasis on centralized, top-down government management practices increasingly constrained by decentralized, bottom-up management. Initial sustainability and climate change adaptation efforts have focused on learning efforts through multiple networks, e.g., building capacity through generating new information, and the ability to process and to act upon information effectively (Pahl-Wostel 2007, Boesch 2008, Moser 2009, Lowe et al. 2009). As urban systems address these complex and rapidly changing social-ecological issues, sustainable systems may require adaptive management strategies best provided by a hybrid, *polycentric* approach to governance (McGinnis 1999, Ostrom 2005, Kofinas 2009) with an array of interacting institutions having overlapping and varying objectives, authorities, and strengths of linkages (Ostrom 1990). This diversity of interests and perspectives may allow for greater adaptability to promote sustainability and adapt to climate change.

Thus, we ask what are the social and biogeophysical causes that affect who initiates sustainability and climate change adaptations; what are the motivations for these adaptations; and what adaptations result? We ask these questions in a social network context in order to assess how interactions among network actors affect information flows, and in turn, how this information affects social behaviors and outcomes. This leads us to specify the feedback hypothetical models behind our work.

Feedback between Social and Biogeophysical Components. The integration of social and biogeophysical processes can be further facilitated by using a model template for feedback between social and biophysical structures and processes (Collins et al. 2007). We choose this particular model template because it incorporates the general processes and interactions recognized by a variety of conceptual models (Machlis et al. 1997, Collins et al. 2000, Grimm et al. 2000, Redman et al. 2004, Alberti 2008, Pickett & Grove 2009). The conceptual model (Collins et al. 2007) includes coarse scale *external drivers, human outcomes* and *human behaviors*, and *ecosystem structure, ecosystem function,* and *ecosystem services*. We apply this model template to the ecosystem services of clean water provision, regulation of water flow, and net carbon storage in the Baltimore region (Fig 2).

Local Sustainability Plans as an Experimental Platform. For BES III, we take the external policy driver to be the paradigm shift from the sanitary to the sustainable city with its joint concern for social, environmental, and economic vitality and equity. The local and regional instances of sustainability policy are real if evolving components of the Baltimore social-ecological system. We identify major ecosystem services of concern in the Baltimore region to constrain the component variables for our socio-ecological models: water quality and flow, and the ability to reduce contributions to carbon emissions (Fig 2). Each of these major ecosystem services has links to the sustainability policies of Baltimore City (2009) and Baltimore County (2010). These services actually represent bundles (Carpenter et al. 2006, Bennett et al. 2009) of water quality, nutrient retention, stormwater flow, biodiversity, water provisioning, infectious disease regulation, carbon storage, microclimate regulation, and primary production, for example. The feedback models identify the adaptive processes needed to answer our overarching question (Fig 3): –**What are the effects of adaptive processes aimed at sustainability in the Baltimore socio-ecological system**?"

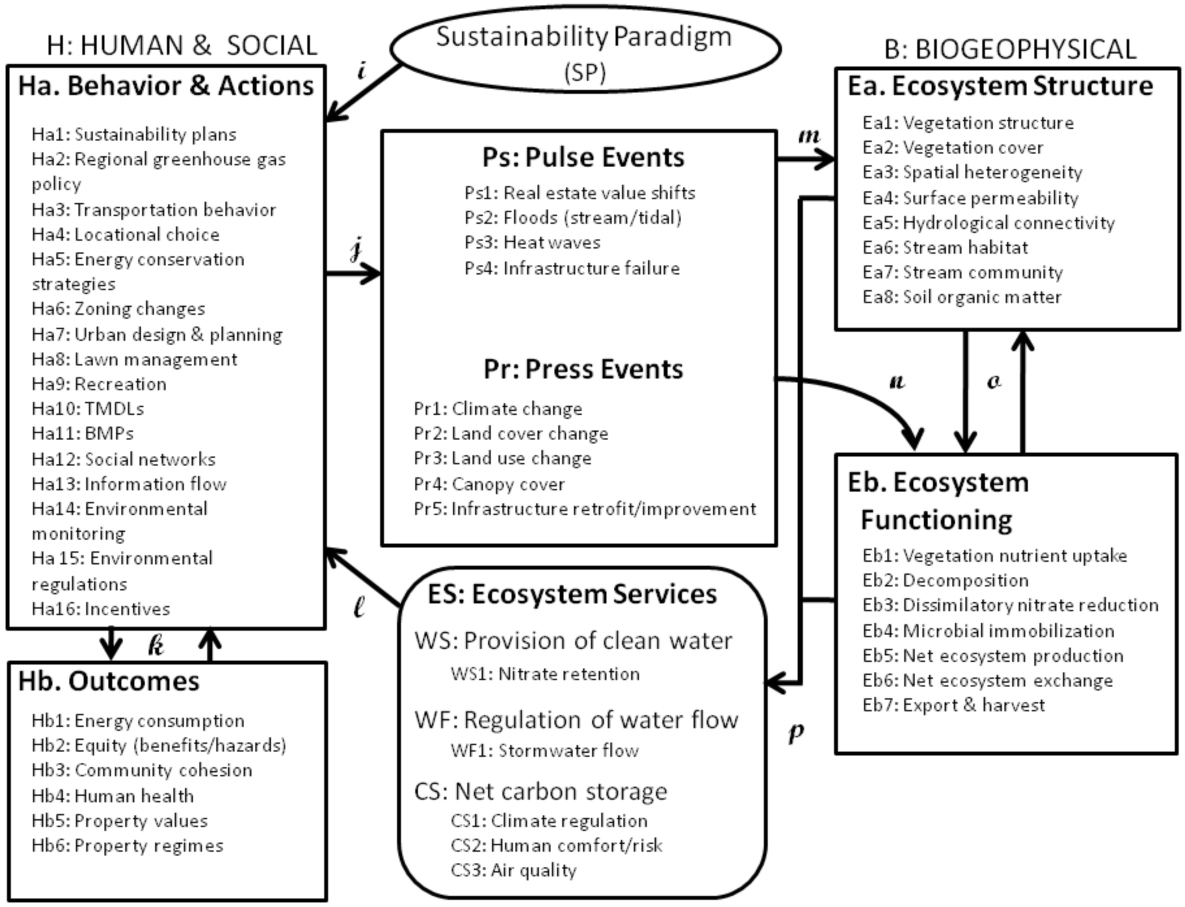


Figure 2. A hypothetical feedback model of social and biogeophysical factors, ecosystem services, and resulting or intervening pulse and press events. The sustainability paradigm, emerging globally, constitutes the external driver. Ecosystem services of water provision and flow, and net carbon storage are chosen for their integrative ability and their significance to local sustainability concerns. The format follows Collins et al. 2007.

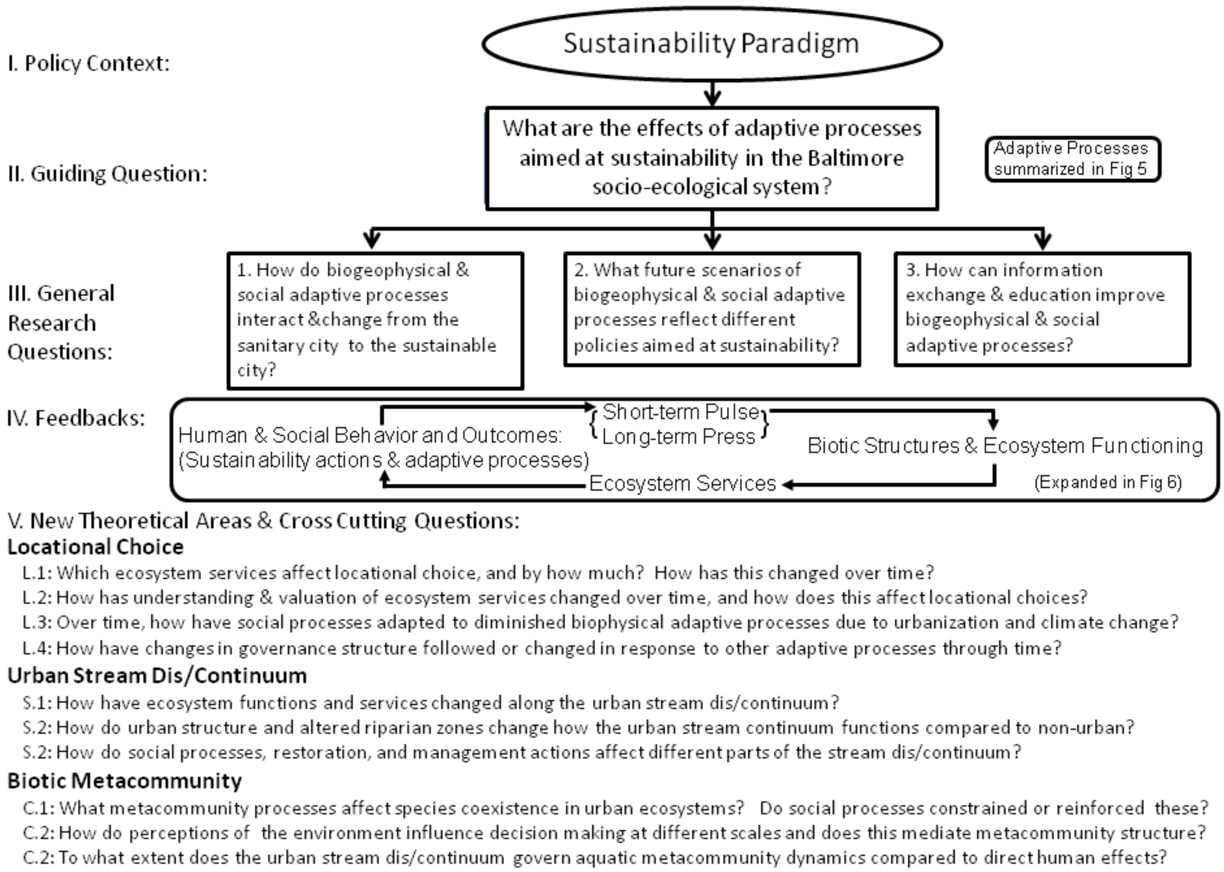


Figure 3. Conceptual structure of BES III. A multifaceted and multilevel approach is required to understand and integrate social and biogeophysical aspects of complex urban systems, including suburban and exurban areas. We focus our efforts within the emerging sustainability paradigm (Level I) because it assumes integration of social, economic, and bioecological system components. The paradigm is being operationalized in Baltimore by specific municipal, state, and community policies and actions that fit within the concept of adaptive processes (Fig 1). This recognition suggests an overarching question (Level II). To answer this overarching question, three, more specific yet still general questions are posed (Level III) that deal with 1) the time course of change in adaptive processes and the integration of biogeophysical and social processes, 2) scenarios of possible future adaptive processes and interactions; and 3) the role of information exchange and education in promoting adaptive processes. Level IV indicates that the specific interactions and processes to be investigated are summarized by a hypothetical feedback model (Fig 2) focusing on water- and carbon-based ecosystem services. A further integrative strategy is the use of three theories new to BES III (Level V). These three areas of locational choice, urban stream dis/continuum, and urban biotic metacommunity theories suggest cross-cutting questions involving both social and biogeophysical system components.

2.1.2 New Theoretical Areas for BES III

Within the context of evolving sustainability policy, we have identified 1) locational choice and land change, 2) the connectivity and dynamics of the urban river continuum and watersheds, and 3) biotic metacommunity dynamics as three major areas of adaptation for empirical and modeling focus. These areas exploit theories new to the project, while connecting with our on-going research. We briefly introduce these areas and indicate cross connections between them and with adaptive processes below.

Locational Choice Theory. The location choices of households and firms and the economic, social, and institutional constraints to these choices are fundamental processes underlying the spatial dynamics of urban socio-ecological systems. Well-established social science theories of location, segregation, and social inequality provide the cornerstones of an interdisciplinary and synthetic theory of locational choice that builds upon previous BES social science research and guides BES III. Location theory (von Thünen 1826, Weber 1929, Christaller 1933, Lösch 1940, Hoover 1948, Isard 1956, Tiebout 1956, Myrdal 1963, Alonso 1964, Krugman 1991) identifies three fundamental economic forces that influence location: (1) natural advantages that attract firms and households; (2) economies of concentration that enhance the productive efficiency of firms that cluster; and (3) transportation and communication costs that spatially differentiate markets and their geographical extent (Hoover & Giarratani 1999). Important extensions of this theory (Graves 1980, Haurin 1980, Roback 1982) have demonstrated the importance of amenities and disamenities to explain the location of population and jobs. These include urban amenities, such as per capita cultural activities (Glaeser et al. 2001, Florida 2005); disamenities, such as crime (Cullen & Levitt 1999); and natural amenities, such as climate (Cragg & Kahn 1997) and coastlines (Rappaport & Sachs 2003, Oliva 2006). Locational choice theory informs land change science (Briassoulis et al. 2000, 2008, Turner et al. 2007) by providing a modeling framework for the demand and supply of land in a particular use at a particular location.

Locational advantages and amenities influence individual location choices of households, but social, economic, and institutional constraints to these choices are critical to understanding the enduring patterns of spatial segregation in American cities. Racial segregation, while still high in the United States, has slowly declined since the 1970s; whereas segregation by socioeconomic status, educational attainment, and political affiliation has steadily increased in recent decades (Massey et al. 2009). Structural theories of segregation and neighborhood differentiation emphasize different social dynamics but share the principle that actions are constrained by forces larger than individual choice, leading to uneven and unequal chances in where people live and work. Examples include the role of capital accumulation (Harvey 1973, 1985); racial and ethnic discrimination (Harris 1992, Orser 1994, Lipsitz 2006); and lifestyle preferences (Logan & Molotch 1987, Weiss 2000).

Theories of location, social inequality, and spatial interaction suggest a range of economic, social, and institutional factors that influence the location of households and economic activity. These are described generally as “push” and “pull” factors, which can be classified as formal versus informal and exogenous versus endogenous (Alonso 1964, Muth 1969, Mills 1979, Harr et al. 1975, Alperovich 1982, Bayoh et al. 2006, Logan & Molotch 1987, Cho 2001, Mieszkowski & Mills 1993). Formal push and pull factors originate from social institutions or policies, e.g., government built roads or public parks; whereas informal factors emerge from social arrangements, e.g., exclusionary practices by neighborhood associations and other social processes. Exogenous factors or “drivers” of the system originate from forces outside the system under study: e.g., an economic or natural disaster or federal policy. Endogenous factors are dynamic feedbacks generated by the cumulative effects of individual location and land use decisions within the system. These feedbacks often reinforce existing patterns by acting as a constraint to some households' location choices while reinforcing the location choices of others. As a result, urban SES's are often path dependent and reflect historical legacies in current outcomes (Boone 2003, Lord & Norquist, in press). Modeling these feedbacks must explicitly account for exogenous and endogenous factors in terms of cross-scale, spatio-temporal interactions that can multiply localized shocks or changes across the larger CSE region.

A novel link between social science theories of locational choice and the social-ecological context of BES III is to connect push/pull drivers with ecosystem services over the long term. This permits an examination of dynamic feedbacks, cross-scale interactions, *and adaptive processes* across social and biophysical systems with an explicit focus on ecosystem services. The following questions are three examples. First, which ecosystem services affect locational choices and by how much over the long term? Do some push/pull drivers become more important over time, while others decline (Bennett et al. 2009, Chapin, in press)? Will the transition from the sanitary to the sustainable city result in an increasing recognition, valuation, or dependence on ecosystem services that will alter push/pull dynamics, location choices, and future policy? Second, do changes in understanding and perception of ecosystem services affect locational choices over the long term? As households, NGOs, and public agencies' understanding and valuation of ecosystem services increase, do interactions between where households and firms choose to locate and the institutional incentives and constraints to those choices change over the long term? Third, do social processes adapt to diminished biophysical adaptive processes due to urbanization and climate change. How have social processes adapted to diminished biophysical functioning such as stream degradation and biodiversity loss in the past through urbanization and how might this change in the future as a result of climate change? Have past practices created path dependencies and legacies which influence or constrain the choices that are available now and in the future?

Urban River Dis/continuum. From the original river continuum concept, the urban form of this theory adopts the idea that it is the interaction between streams and their watersheds that determines the balance between in-stream and allochthonous processes. In particular, stream size and the nature of connectivity to the adjacent terrestrial environment determine stream substrate, temperature, source of carbon and energy, food web structure, productivity, the role of in-stream processing, and biodiversity (Vannote et al. 1980). From an understanding of urban form and from existing data in BES, a modified urban river continuum concept can be developed (Kaushal & Belt, submitted) by recognizing that first order streams have largely been replaced by infrastructure and that the flow regimes of remaining surface streams are modified by leaky sanitary and storm sewers and by runoff from impervious surfaces (Paul & Meyer 2001, Walsh et al. 2005, Cadenasso et al. 2008). Urban ground water dynamics are often disconnected from stream dynamics (Groffman et al. 2003), urban riparian zones and flood plains may be disconnected from the streams (Kaushal et al. 2008b, Klocker et al. 2009, Mayer et al., in press), and organic subsidies of stream food webs are modified by drainage infrastructure and landscape management (Kaushal & Belt, submitted). Stream temperatures reflect urban surface heat budgets (e.g. Nelson & Palmer 2007, Pouyat et al. 2007b). Thus, there is a stream continuum in urban systems, but discontinuities are important because the nature of connectivity is controlled by humans. We adopt the term urban stream dis/continuum to acknowledge the contradictory nature of changes in connectivity in different aspects of urban stream networks that reflect engineering, behavior, and a biotic legacy.

Metacommunity Theory. Urban ecosystems present ecologists with the unique opportunity to study ecological communities in the context of drastic structural and environmental change unprecedented in pristine environments. The consequences of such change have led to novel modifications of species composition, dominance, behavior and dispersal (McKinney 2002). Inherent to these changes are the complex relationships between human behavior and decision-making, spatial structure of the landscape, and the natural processes involved in determining local species richness and composition (Fig 4). By embracing space explicitly in the context of metacommunity theory, the interaction and feedback with human systems can be integrated to understand patterns of species diversity and composition in urban ecosystems (Swan et al., in press). Metacommunity theory distinguishes the relative roles of local vs. regional factors as structuring processes into four categories of metacommunity structure: species sorting, neutral processes, mass effects and patch dynamics.

In BES III we will integrate human behavior and decision-making with metacommunity theory to understand patterns of and mechanisms driving species coexistence in urban ecosystems (Fig 8). The major goal is to deviate from methods seeking to explain patterns in biodiversity as a function of disturbance (e.g., Connell 1978) or productivity (e.g., Gaston 2005) by focusing more on understanding community assembly. We cast this shift in focus in light of how humans directly and indirectly influence patterns in coexistence. We will test a) the relative importance of local vs. regional factors and b) human drivers of local factors for four taxa: riparian trees, soil invertebrates, stream invertebrates, and birds. In applying metacommunity theory to urban ecosystems, we distinguish between facilitated communities, where human behavior drives the environmental conditions supporting species composition, and self-assembled communities, where environmental conditions are free of direct human influence (though indirect effects of actions in neighboring patches can be found; Swan et al. in press). If local factors predominate, then community similarity should increase with environmental similarity (Chase et al. 2005) in both facilitated and self-assembled communities. If regional factors predominate, then community similarity should either decline with distance (dispersal limited taxa) or be neutral relative to distance (non-dispersal limited taxa; Chase et al. 2005, Swan et al., in press). Community similarity should decline with distance in facilitated communities when human activities are spatially clumped (Warren et al. 2008). Basic ecological theory cannot completely explain patterns in biodiversity in urban ecosystems. Our new conceptual model of coexistence integrates basic ecological theory with social patterns and outcomes.

An important component of understanding biodiversity in fragmented urban ecosystems relates to organisms that host and transmit disease. To date, the growing fields of urban ecology and disease ecology have developed both independently from each other and through independent field studies among urban centers. A majority of emerging infectious diseases affecting human society in recent decades are caused by zoonotic (non-human reservoir) and vector-borne pathogens (Jones et al. 2008, Wilcox 2005, Childs et al. 1998). The 1999 emergence of West Nile virus (WNV) in North America caused over 1000 human deaths, and perhaps more notably, dramatic population-level declines in the pathogen's primary avian hosts (LaDeau et al. 2007, 2008). Importantly, while many insect vectored and zoonotic diseases affecting humans have historically been more common around rural communities, today's emerging pathogens are increasingly threatening urban populations (Patz et al. 2008, 2004, Morse 1995). This has been true in the case of WNV, where studies have found that avian and human infection may be greatest near urban population centers (Allan et al. 2009, Bradley et al. 2008, Ruiz et al. 2007). West Nile virus is transmitted between avian hosts and between infected birds and humans by mosquitoes. In BES III, we will examine how environmental (e.g., weather, habitat, biodiversity) and social (e.g., land-use) variables define mosquito communities and regulate the abundance of mosquito vectors in a temperate, urban environment.

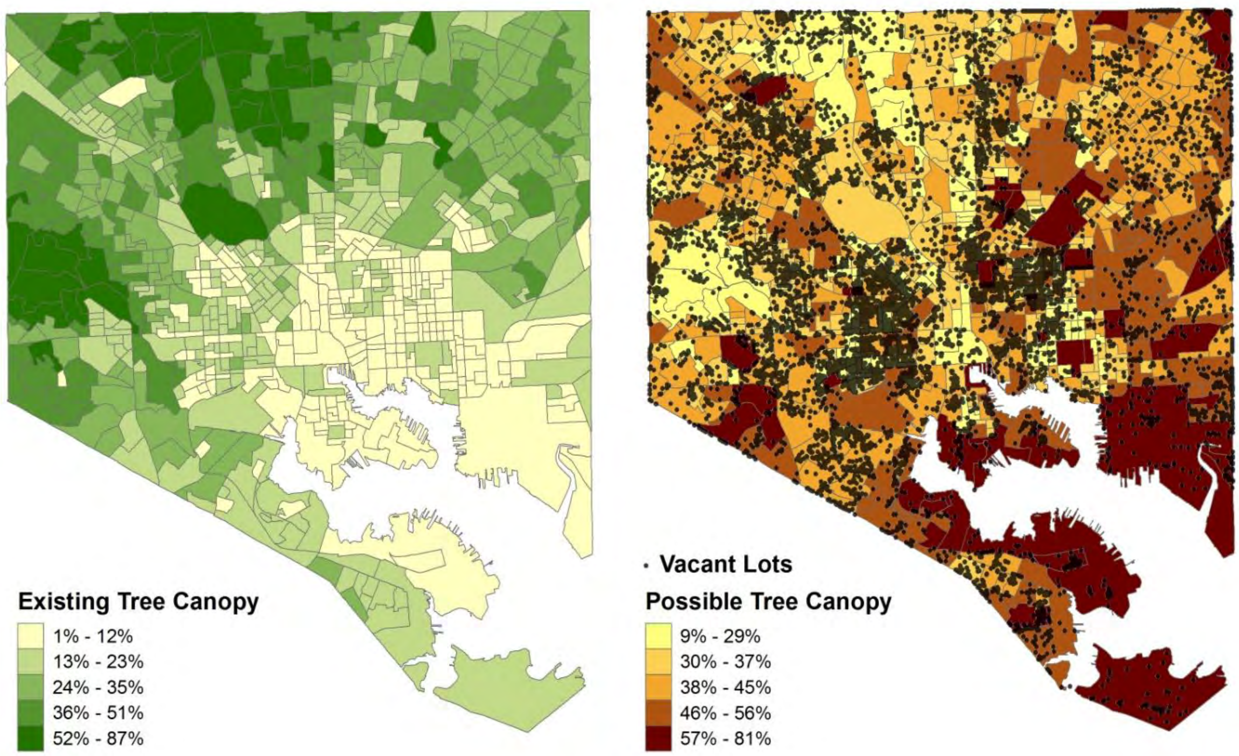


Figure 4. Current existing tree canopy and possible tree canopy along with the location of vacant lots for the City of Baltimore. Possible tree canopy is defined as land where it is biophysically feasible to plant trees.

2.1.3 Integration of Disciplines and Approaches: Structure of the Research

Urban systems are difficult venues for integration due to complicated open boundaries, geomorphic and biotic heterogeneities, multiple institutional structures, diverse property regimes, mosaics of land uses, and generations of infrastructure, which conspire to generate “messy” systems (Alessa et al. 2009). In such systems, social-biogeophysical interactions involve both direct and indirect linkages between human decisions, preferences, and actions and the biogeophysical structures and functions of regional urban aggregations. A variety of approaches together can advance understanding in these complex systems. In this section we indicate how the various research and conceptual strategies for BES III fit together to promote synthesis.

Overarching Question. Actual sustainability policies in place or being developed in the Baltimore region (Baltimore City 2009, Baltimore County 2010) provide a concrete context for the overarching question for BES III:

- **How do biogeophysical and social adaptive processes influence and respond to policies aimed at enhancing sustainability in the Baltimore region?**

Contributing Questions. Three general subquestions (Fig 3) address 1) the current status of adaptive processes and ecosystem services in Baltimore and their historical development; 2) possible scenarios for future adaptive processes and services; and 3) the role of information flow and education in advancing adaptive processes toward sustainability in Baltimore.

1) **How do social and biogeophysical adaptive processes change from sectoral management -- the Sanitary City -- to interdependent and comprehensive approaches -- the Sustainable City?**

1.a: How will a change in focus from maximizing water drainage (sanitary city) to maximizing water retention and quality (sustainable city) affect interactions between biogeophysical and social adaptive processes related to water based ecosystem services (Fig 2)?

1.b: How will a new emphasis on carbon storage (sustainable city) that was absent in the sanitary city affect interactions between biogeophysical and social adaptive processes related to carbon storage and related ecosystem services (Fig 2)?

2) How will scenarios of biogeophysical and social adaptive processes change in response to current and alternative policies designed to achieve sustainability goals in the Baltimore region?

2.a: How might watershed hydrologic properties change under implementation of new stormwater management regulations for the State of Maryland?

2.b: How could patterns of biodiversity change under policies designed to achieve various land management goals, including a doubling of urban tree canopy by 2038 and the creation of community open space and urban agricultural strategies in Baltimore City?

2.c: How could retrofitting of existing development in mature suburbs, new urban designs, the continued enforcement of the Urban-Rural Demarcation Line (Fig 5) in Baltimore County, and the densification of new development and preservation of agricultural areas in Maryland affect Baltimore regional biodiversity and related ecosystem services?

2.d: How could changes in policies related to carbon storage and reduced carbon footprint affect the properties addressed in questions 2a-2c (Fig 2)?

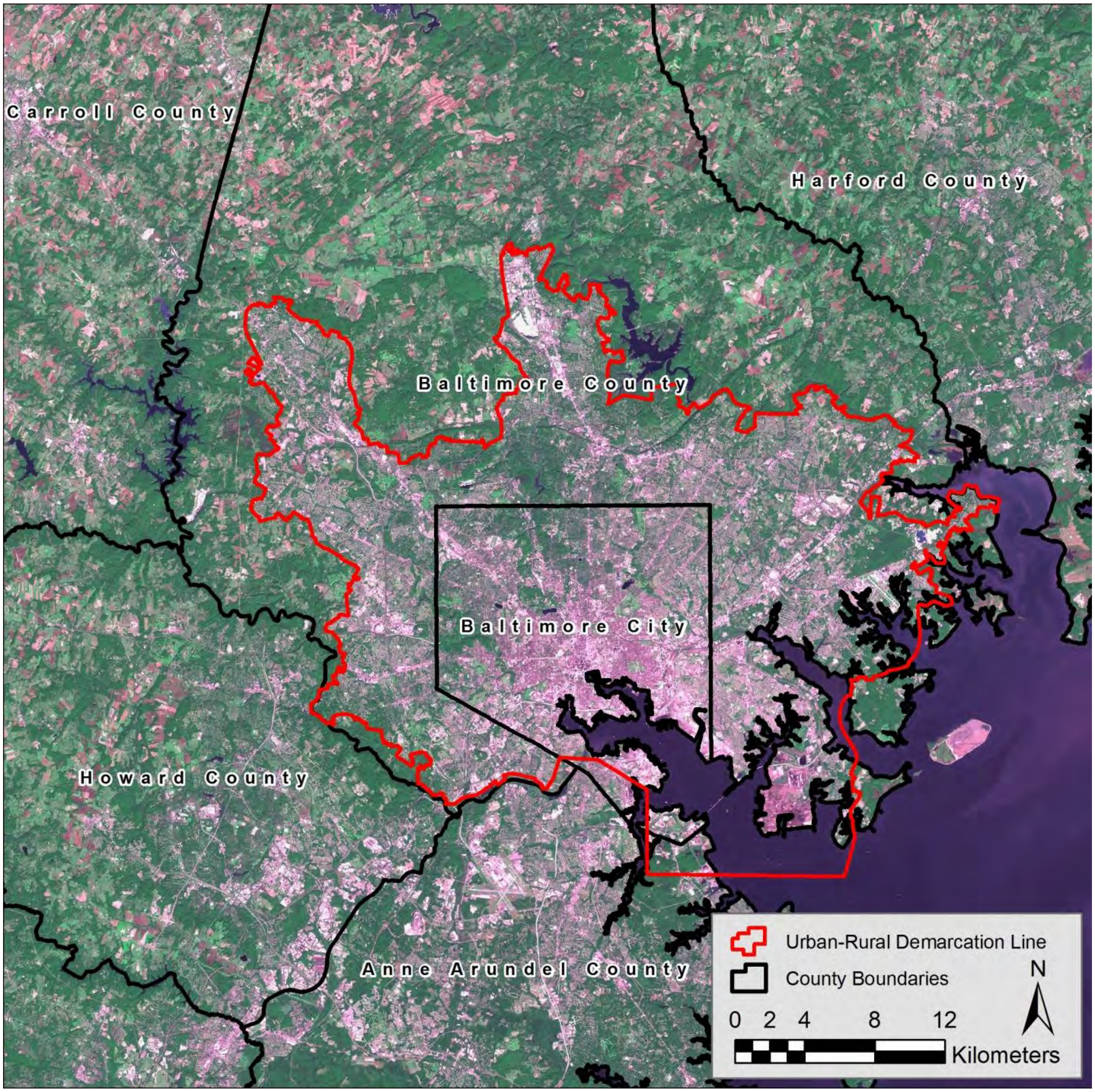


Figure 5. Map showing Baltimore City, Baltimore County and the urban-rural demarcation line (URDL) that was established in 1967 to identify areas of Baltimore County that had or would receive public water and sewer infrastructure, and therefore would accommodate urban residential, commercial and employment development. In the rural areas, reliance on private well and septic systems limited the amount of development that could be accommodated, and thereby helped ensure the area's continued use for agriculture, natural resource protection, and low-density rural residential uses.

3) How can information exchange and education improve adaptive processes?

3.a: Who adapts; to what; and how? In particular, what are the social and biogeophysical causes that affect who initiates sustainability and climate change adaptations (Pahl-Wostel 2007, Boesch 2008)? What are the motivations for these adaptations?
3.b: How do adaptive actions differ by scale, timing, form, purpose, and other dimensions (Smit et al. 1999 expanded by Fussel 2007)?
3.c: Are new social institutions and networks emerging in response to sustainability goals (Moser 2009, Lowe et al. 2009)?
3.d: What are effective strategies, at the teacher/classroom, school system and larger information system scale, for fostering a productive understanding of socio-ecological systems and adaptive capacity?
3.e: What is the relationship between people's understanding of the socio-ecological system and of adaptive processes, and their motivation and capacity to contribute to sustainability?

Synthesis of the Research Plan. A complex and complicated (Alessa et al. 2009) urban system requires multiple tactics to overcome the difficulties and exploit the opportunities for enhanced understanding. Therefore, our conceptual research plan (Fig 3) employs complementary components. First, we use an overarching question that recognizes the significance of the emerging urban sustainability paradigm. We ask more specifically about the nature, changes, future, and informative role of the adaptive processes by which a general sustainability paradigm may be operationalized in Baltimore. We use a hypothetical feedback model (Fig 2), based on key ecosystem service bundles (Bennett et al. 2009), to identify the biogeophysical and social parameters to be measured in Baltimore and to be synthesized using existing and new complementary models. Specific research questions (Fig 3) drive the long-term monitoring, experiments, comparative studies, and modeling described below.

2.2 EXPERIMENTAL PLAN

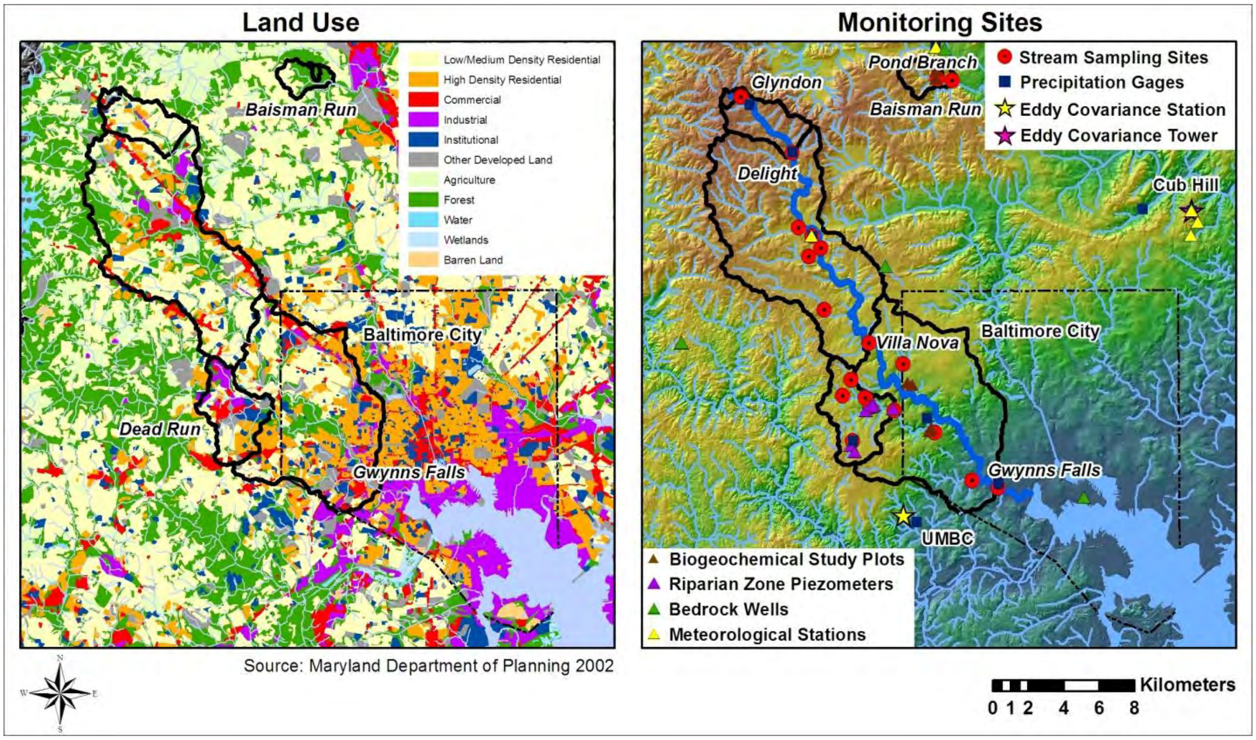
Research in BES is organized around the idea that ecosystem and social-ecological research can be viewed as a table with four legs; long-term monitoring, experiments, comparative analyses and modeling (Carpenter 1998). Below, we describe how each of these approaches have been applied in BES to address our past questions, and more importantly, how we will maintain and/or adjust these approaches to address the new questions that drive BES III. The discussion below also highlights ―hotspots for integration," which we define as specific sites or topics that have been or will be prime opportunities for the integration between biophysical science, social science and education (Table 1).

2.2.1 Long-term monitoring

Stream/watershed monitoring. BES long-term watershed research sites are described in Section 1, Results From Prior Support (Fig 6, Table 2). For BES III we have developed an urban stream dis/continuum theory that focuses on the nature of connectivity between streams and the adjacent terrestrial environment as a determinant of stream and watershed ecosystem structure and function, and propose to modify our long-term data collection accordingly. BES core stream gauging stations are maintained by the US Geological Survey. Weekly water chemistry samples are collected, filtered, and stored in Nalgene bottles. Over the past grant cycle, we installed automated (ISCO) samplers at several of the sites that produce weekly composite samples for comparison with the weekly ―grab" samples. We will continue to install ISCO samplers until all sites have them. Blanks and spikes are processed along with samples

Table 3. Hotspots of integration in the Baltimore Ecosystem Study.

Topic/ location	**Description**
WS 263	• A 364 ha watershed defined by the storm drain network • Prototype for non-point management of storm water in urban systems based on sound science and community participation. • Long-term monitoring of hydrology and nutrients, metals and bacteria in two gaged subwatersheds. • Long-term monitoring of landcover change using UFORE field sampling and hi-res remotely sensed imagery. • Long-term monitoring of social dynamics including secondary social data and BES Household Telephone Survey. • Implementation and evaluation of site-based BMPs. • Impervious surface removal in schoolyards with coupled education program. • After school ecology-based programs.
Lawns	• Very common cover type nationally, can be highly managed. • Previous BES research showed that nitrogen retention was higher and that hydrologic and gaseous losses of nitrogen from lawns were lower than expected. • Lawn management is highly variable along socio-demographic axes. • Monitoring of nitrogen cycling in long-term study plots. • Regional, nested surveys of household and homeowner association lawn management practices, motivations, and by-laws. • Detailed studies of carbon and nitrogen cycle processes in actual residential parcels varying in land use history and other factors. • Development of cross-site comparative studies with CAP, FCE and PIE.
Riparian zones	• Known as hotspots for retention in agricultural and forest watersheds, but do not function as well in urban watersheds due to “urban stream syndrome.” • Watershed and stream restorations attempt to restore riparian processing, reverse urban stream dis/continuum. • Long-term monitoring of riparian water tables and nitrogen cycling processes. • Detailed studies of nitrogen cycling in restored stream corridors. • Long-term monitoring of social dynamics including secondary social data and BES Household Telephone Surveys. • Metacommunity biodiversity analysis of riparian trees, soil invertebrates, stream invertebrates and birds at 84 stream restoration sites. • Design and analysis of stream and riparian restoration projects with City, County and State environmental managers and decision makers. • Analysis of the ability of urban tree canopy goals to create a distributed “riparian effect” in watersheds with degraded riparian processes.
Land change	• Integrated modeling and measurements of land change, both sprawl into outlying counties, and densification of older suburbs will be a major new integrative hotspot. • Addition of new watershed long-term monitoring sites. • Long-term monitoring of landcover change using UFORE field sampling and hi-res remotely sensed imagery. • Extensive spatial data on all land use, subdivisions, zoning and variances, infrastructure for sewers, roads, schools and transportation, parcels, housing price, population and employment variables from 1940 to Present. • Intensive data (e.g., collected via surveys or specialized data sources) on individual landowners, developers, households and other key. • Intensive histories of neighborhood change and stability.



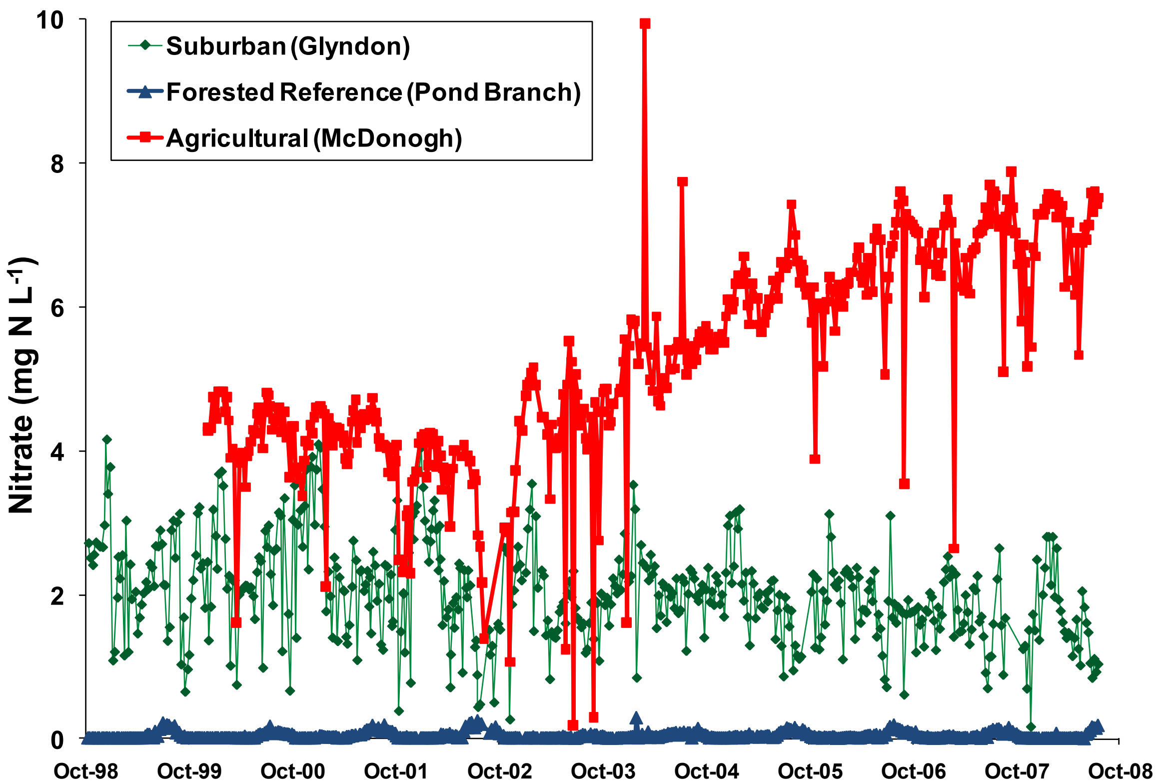


Figure 6. Top – maps of the Gwynns Falls watershed showing predominant land use patterns and the location of BES long-term monitoring sites (described in detail in Table 2). Bottom - weekly nitrate concentrations in forested reference, suburban and agricultural streams sampled by BES from Fall 1998 – Summer 2003. From Groffman et al. (2004) and data posted at beslter.

Table 2. Characteristics of Gwynns Falls main channel watershed reaches and completely forested, agricultural, suburban and urban small and medium size watersheds. From Shields et al. (2008).

Station	Land use/context	Total drainage area	Reach drainage Area	Population density	Land Use (by reach)			
					Forest	Developed	Agriculture	Impervious
----------------	------------------	---- ha ----	--- ha ---	-- per ha --	-----------------------------%	----------------------------		
Main channel reaches								
Glyndon	Suburban	81	81	9.4	19	76	5	19
Gwynnbrook	Suburban	1,065	984	16.4	16	76	8	15
Villa Nova	Suburban/urban	8,349	7,284	12.2	24	66	10	17
Carroll Park	Urban	16,378	6,617	19.7	14	85	1	32
Small and medium watersheds								
Pond Branch	Forested	NA	38	0	100	0	0	0
McDonogh	Agriculture	NA	7.8	0	26	4	70	100
Baisman Run	Suburban/forest	NA	382	1	71	27	2	0.25
Dead Run	Suburban/urban	NA	1414	12.6	5	93	2	31
Other study watersheds								
Rognel	Urban	7	Storm sewer watershed, no natural drainage					
W263:	Urban	364						
Baltimore	Urban	15	Storm sewer watershed, no natural drainage. Site of project for management					
Lanvale	Urban	16	of storm water based on sound science and community participation.					
Maidens Choice	Urban	1,145	Dense urban, natural stream, focus of sanitary sewer improvement efforts.					
Gwynns Run	Urban	647	Dense urban, natural stream, focus of sanitary sewer improvement efforts.					
Jennifer Br.:	Suburban	332	Suburban. USFS/BES micromet flux tower is located in this watershed.					
JBON	Suburban	49	Suburban, subcatchment of Jennifer Branch					
JBHH	Suburban	47	Suburban, subcatchment of Jennifer Branch					

in our laboratory at the University of Maryland Baltimore County (UMBC) each week and are shipped to the Cary Institute of Ecosystem Studies in Millbrook, NY for chemical analysis. A Dionex LC20 series ion chromatograph is used to quantify nitrate, sulfate and chloride, and a Lachat Quikchem 8100 flow injection analyzer (FIA) is used for phosphate. Total nitrogen and phosphorus are analyzed by persulfate digestion followed by analysis of nitrate and phosphate on the Lachat FIA. Dissolved organic carbon is measured on a Shimadzu Total Organic Carbon Analyzer. Watershed nitrogen balances are calculated by comparing streamwater outputs with atmospheric deposition, fertilizer and septic inputs.

For BES III we propose several changes or additions to our long-term watershed monitoring program. We will add additional sampling sites to include:

- An additional *forested referen*ce site for comparison with our long-term site at Pond Branch.
- Additional *exurban* sites not served by sanitary sewers will be added for comparison with our long-term site at Baisman Run and as part of new integrative efforts on locational choice modeling that will focus on exurban areas.
- *Densification* sites in areas of Baltimore County that have been prioritized for high density redevelopment with advanced stormwater controls. These areas will also be a focus of new integrative efforts on locational choice modeling.

New analyses will include:

- Pharmaceuticals and personal care products (PPCPs). Urban waterways contain numerous contaminants that can affect stream-dwelling organisms (Rosi-Marshall 2004). It has become increasingly clear that pharmaceutical and personal care products, such as painkillers, antibiotics and antihistimines, are pervasive in aquatic ecosystems, especially within highly urbanized watersheds. However, the fate and ecological effects of these compounds has not been well-documented. We propose to use the BES long-term monitoring of stream ecosystems to identify and examine the effects of these compounds on stream ecosystem function. In particular, we propose to examine the concentrations of PPCPs in core stream sampling sites and in new exurban watersheds not served by sanitary sewers and in areas being redeveloped with advanced stormwater controls. We will employ methods used previously to measure the fate, transport and effects of nutrients on stream ecosystems (Tank et al. 2006) to study PPCPs in BES streams. We will measure the concentrations of PPCPs along water courses, in combination with conservative tracers to account for changes in discharge, to estimate fate and transport of PPCPs. In addition, we will use pharmaceutical diffusing substrates to directly measure the effects of PPCPs on aquatic ecosystem functions, e.g. primary production, net ecosystem metabolism, and organic matter decomposition.

- In-stream retention. As part of new integrative efforts on the urban stream dis/continuum concept, we will add synoptic sampling campaigns to quantify instream processing of nutrients (Kaushal & Belt, submitted). We will estimate in-stream uptake and transformations of C, N, and P along the Gwynns Falls and Baisman Run stream continuums across the study years and calculate mass balances of nutrients and organic carbon along reaches bounded by BES routine monitoring sites and USGS gauging stations. Our previous work along these stream continuums and tributaries have shown that differences in concentrations and discharge are large enough to detect changes in C, N, and P fluxes to determine instream uptake and transformation (Delaney 2009, Stanko 2009). Mass balance estimates of in-stream C, N, and P retention will be complemented by stream injection experiments to measure uptake rates and whole stream metabolism studies using sondes (Klocker et al. 2009).

- New technology. Over the past six years, non-LTER funds (Table 3) have been used to plan for and partially establish an ―end-to-end system" of field-deployed sensors and sensor

Table 3. Ancillary grants obtained to support Baltimore Ecosystem Study research.

Institutional leveraging	
USFS	Provided over $6 million over the past seven years in personnel and research support in Baltimore (please see attached letter of support in Supplementary Documents).
University of Maryland Baltimore County	Established the Center for Urban Research and Education (CUERE), with core funding from EPA ($3 million) and NOAA ($1 million). CUERE received an NSF IGERT award for $2.9 million under the theme “Water in the Urban Environment (Welty et al.).”
USGS	Over $525,000 in ancillary stream gauging and personnel support for BES.
Parks & People Foundation	Generated over $4 million in grants for their community organizing, educational, and ecosystem restoration programs from a variety of public and private sources.
Individual researcher grants	
Pickett et al.	$1.4 million from NSF Coupled Natural Human Systems to study “Feedbacks between complex ecological and social models: Urban landscape structure, nitrogen flux, vegetation management, and adoption of design scenarios.”
Welty et al.	$1.2 million from NSF, Coupled Natural and Human Systems to study “Dynamic Coupling of the Water Cycle with Patterns of Urban Growth.”
Welty et al.	$405,000 + $481,302from NSF, Hydrologic Science and Environmental Engineering for “Quantifying Urban Groundwater in Environmental Field Observatories (WATERS Testbed, Phases 1 and 2).”
Welty et al.	$894,226 from NOAA for “Integrating Real-Time Sensor Networks, Data Assimilation, and Predictive Modeling to Assess the Effects of Climate Variability on Water Resources in an Urbanizing Landscape.”
Jenkins et al.	$630,000 from NSF Ecosystem Studies to study “Carbon stocks and fluxes in urban and suburban residential landscapes.”
Kaushal et al.	$613,620 from NSF to study “The effects of watershed urbanization on in-stream transformation of organic nutrients within running waters.”
Kaushal et al.	$155,315 from MD Sea Grant for “Investigation of stream restoration as a means of reducing nitrogen pollution from rapidly urbanizing coastal watersheds.”
Kaushal et al.	$125,000 from EPA Chesapeake Bay Program to study “Enhanced Stormwater Monitoring of Toxic Chemicals in the Chesapeake Bay Watershed”
Groffman et al.	$480,000 from EPA for “Quantifying the effects of ecosystem restoration on denitrification activity in riparian groundwater and the hyporheic zone of mid-Atlantic Piedmont stream”
Whitmer et al.	$300,000 from NSF ULTRA-EX for “Urban Sustainability and Push-Pull Drivers of Residential Change: Washington, D.C., Baltimore, Maryland, and the Chesapeake Bay”
Boone et al.	$749,437 from NSF HSD for “A Longitudinal Analysis of the Social Dynamics of Environmental Equity in Baltimore.”
Fraser et al.	$734,506 from NSF HSD for “Exploring the Determinants of Household Environmental Behavior: A Socio-Spatial Analysis of Lawn Care Practices.”
O’Neill-Dunne	$230,000 from U.S. Forest Service for “Multi-State Urban Tree Canopy Assessment”
Moore, Berkowitz et al.	$12.4 million to SGS, BES, KBS, SBC from NSF MSP for “Culturally Relevant Ecology, Learning Progressions and Environmental Literacy”

networks at BES field sites. All existing BES precipitation and long-term stream monitoring gages have been converted to real-time transmission by USGS using satellite communication (Satlink) equipment. A new eddy covariance station has been installed at UMBC that transmits calculated evapotranspiration rates in near-real time; this equipment is outfitted so that it can be deployed on a portable tower and moved around the watershed as needed. A new project is underway to purchase, test, and deploy continuously-recording nitrate sensors (SUNA by Satlantic) and to enable collection and interpretation of high-frequency nitrate data. These sensors will be co-located with BES stream gages to allow simultaneous near-real-time transmission of nitrate data with streamflow. A suite of soil moisture/temperature/soil gas sensors has been deployed at the Cub Hill Tower wirelessly transmitting data in real time. A network of abandoned homeowner wells has been ―adopted" by obtaining permission to install pressure transducers to continuously record groundwater levels in these wells. Recording capacitance probes have been installed in a set of shallow riparian wells for evaluating surface-subsurface exchange near streams. One goal of this effort is to incorporate data into a state-of-the-art data warehousing system, and subsequently assimilate it into predictive models.

Long-term study plots. The BES network of long-term study plots until recently included 8 forest and 4 grass sites that were sampled monthly since 1998 for soil temperature and moisture, soil:atmosphere fluxes of carbon dioxide, nitrous oxide and methane (*in situ* chambers) and leaching fluxes (zero tension and suction lysimeters) of N and P. We also have four riparian sites where we have measured water table depth monthly since 2000. One forest plot and two grass plots were abandoned due to vandalism or management changes.

The long-term study plots have been an essential component of our integrative work on lawns and residential yard management, providing a platform for non-LTER grants (Table 3) for more detailed analyses. For BES III, lawns will continue to be a hotspot of integration as we will seek renewals for these non-LTER grants. The lawn work has also been a platform for cross-site comparative studies with CAP, FCE and PIE (see below).

For BES III, changes or additions to the long-term plot network will include:

- Addition of new sampling sites. We will add two new grass and one forest site to replace those lost to altered management or vandalism and will upgrade the riparian plots to have the same instrumentation as the upland plots. All plots will be outfitted with new temperature and moisture probes. Temperature probes record data every hour and TDR moisture probes have been read every month. Dataloggers for continuous moisture data will be installed at two sites.

- Sampling for productivity and soil organic matter. Tree cores and litterfall will be collected to quantify aboveground productivity. Soil will be sampled to 1 meter depth at five year intervals to quantify soil carbon and nitrogen pools. Soil sampling to 1 meter was done in 2007. Detailed vegetation characterizations were done in 1998 and 2003 and will be repeated during BES III.

- Paleoecology approaches will be used to study the history of vegetation succession in Baisman Run by analyzing sediment cores to trace the history of forests as land use and climate changed. Cores will also be analyzed for nitrogen isotopes to track the history of nitrogen inputs to receiving waters over different periods of land use (Kendall et al. 2007).

Long-term extensive plots. The intensive long-term study plots are complemented by a spatially extensive network of 194, 405 m^2 plots across Baltimore City that were sampled in 1999, 2004 and 2009 to characterize urban forest structure and ecosystem services via the

Urban Forest Effects (UFORE) model (discussed below). UFORE couples vegetation, air pollution, and meteorological data to quantify urban forest effects. These plots are scheduled to be re-measured every 5 years (next in 2014) to monitor changes to urban vegetation and associated ecosystem services. Monitoring data are being used to determine rates of change which will be related to patterns in tree planting and natural regeneration. This information will be used in a new tree population projector (discussed below) to estimate future forest effects and guide urban tree management activities to sustain desirable levels of tree cover.

Long-term extensive remote sensing. The BES remotely sensed data archive contains over 300 GB of high-resolution (5m or better) aerial and satellite imagery, light detection and ranging data (LiDAR), and derived products. While these datasets help to provide answers to a broad range of research questions, three specific applications will be a focus in BES III:

- To examine change in forest patches over a 90-yr period, historical panchromatic aerial photos of the Gwynns Falls watershed were collected for 1938, 1957, 1968 and 1971. Color-infrared digital aerial imagery of the watershed was also acquired for 1999 and 2004. These maps will be used to analyze forest patch change over time in the Gywnns Falls Watershed.
- Measuring structure and productivity. Advances in digital remote sensing technology have permitted BES researchers to examine the structure and productivity of features over broad areas with great detail (Fig 7). From a vegetation mapping standpoint, the near-infrared wavelengths are of great interest as they allow biomass estimates to be computed through the use of equations such as the normalized difference vegetation index (NDVI). LiDAR systems can yield important structural information such as the height of human-made and vegetated features relative to the ground.
- Deriving high-resolution land cover for the Baltimore Metropolitan Statistical Area (MSA). Examining linkages between social and biophysical processes at the property parcel level requires detailed land cover information (Fig 8). Traditional sources of land cover, such as those from the USGS National Land Cover Database (NLCD) are valuable for examining regional trends, but lack the resolution and accuracy suitable for fine scale analysis in heterogeneous landscapes at the parcel level. BES scientists have applied object-based image analysis (OBIA) by distributing the processing load over multiple processing cores to generate high-resolution land cover data for the majority of the MSA.

Long-term socio-demographic data. Long-term socio-demographic data are collected and connected to biogeophysical data using a multi-scale, spatio-temporal data platform that combines extensive and intensive data (Zimmerman et al. 2009; Fig 9). Key units of analysis are the individual property parcel, subdivision, neighborhood, and city or county jurisdictions. Socio-demographic data combine secondary, derived, and primary data. For example, the BES team has invested substantial energies into the acquisition, spatial referencing, documentation, and curation of long term, secondary data, such as Census data at the ward, tract, and block group level from 1900 to the present and environmentally related zoning variances for the City of Baltimore from the 1930s to the present (Lord & Norquist, in press; Fig 10).

Derived, long term socio-demographic data have been created from secondary data. For instance, we used electronic tax assessment records from the State of Maryland to construct a parcel-level mapping of residential and commercial land development from 1900 to 2007 to quantify the suburbanization and exurbanization patterns in three counties within the BES metropolitan study region: Baltimore, Harford and Carroll counties. In addition, unique georeferenced data on residential subdivision development from 1940-present are being created for Carroll and Baltimore Counties using plat data in collaboration with the Maryland State Archives (www.plats.net) in order to better model the process and ―spillover effects" of land development in the CSE. Primary data are collected strategically to leverage secondary

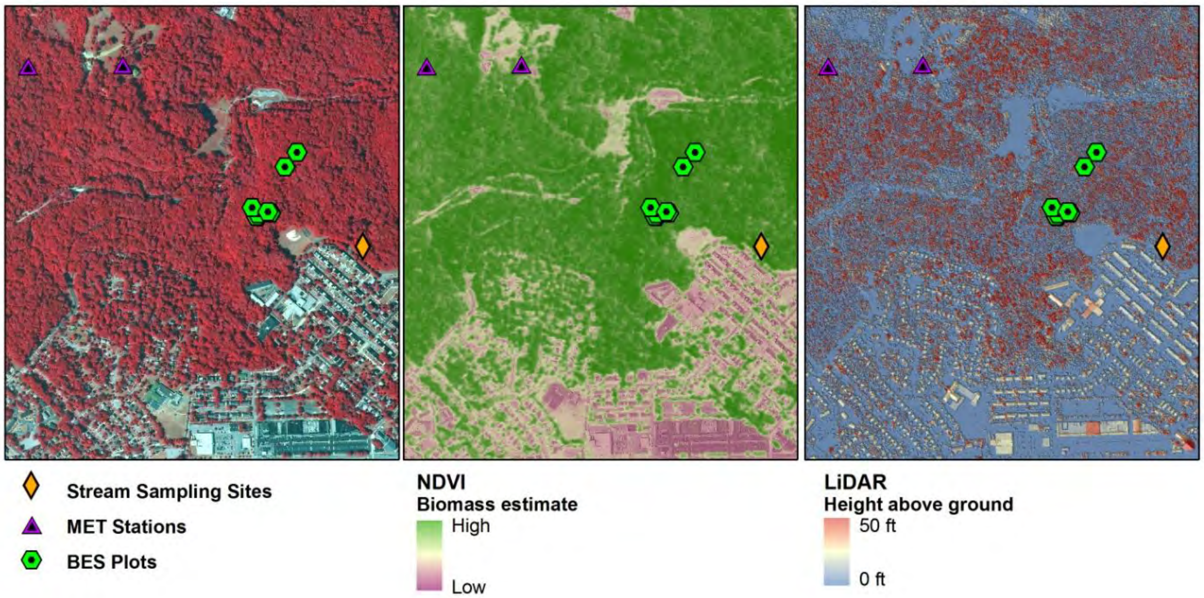


Figure 7. Examples of layers derived from remotely sensed data that can be used to map structure and productivity. Color infrared aerial imagery (left), NDVI derived from the imagery (center), and height of features relative to the ground derived from LiDAR (right) for the Rognel Heights watershed, one of the BES long-term study watersheds.

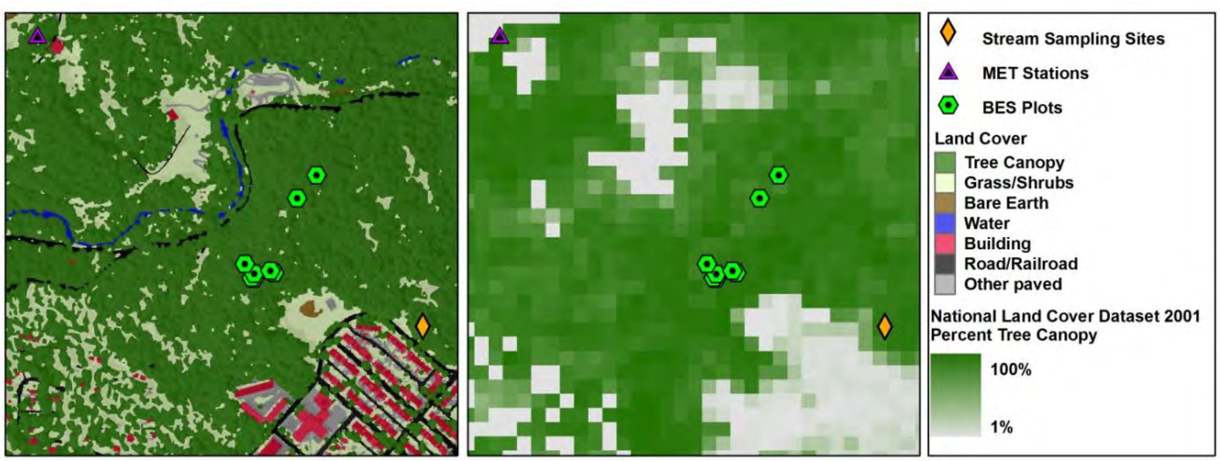


Figure 8. Comparisons between the BES high-resolution landcover dataset (left) and the USGS National Land Cover Database (NLCD). Traditional sources of land cover, such as those from NLCD are valuable for examining regional trends, but lack the resolution and accuracy suitable for fine scale analysis in heterogeneous landscapes.

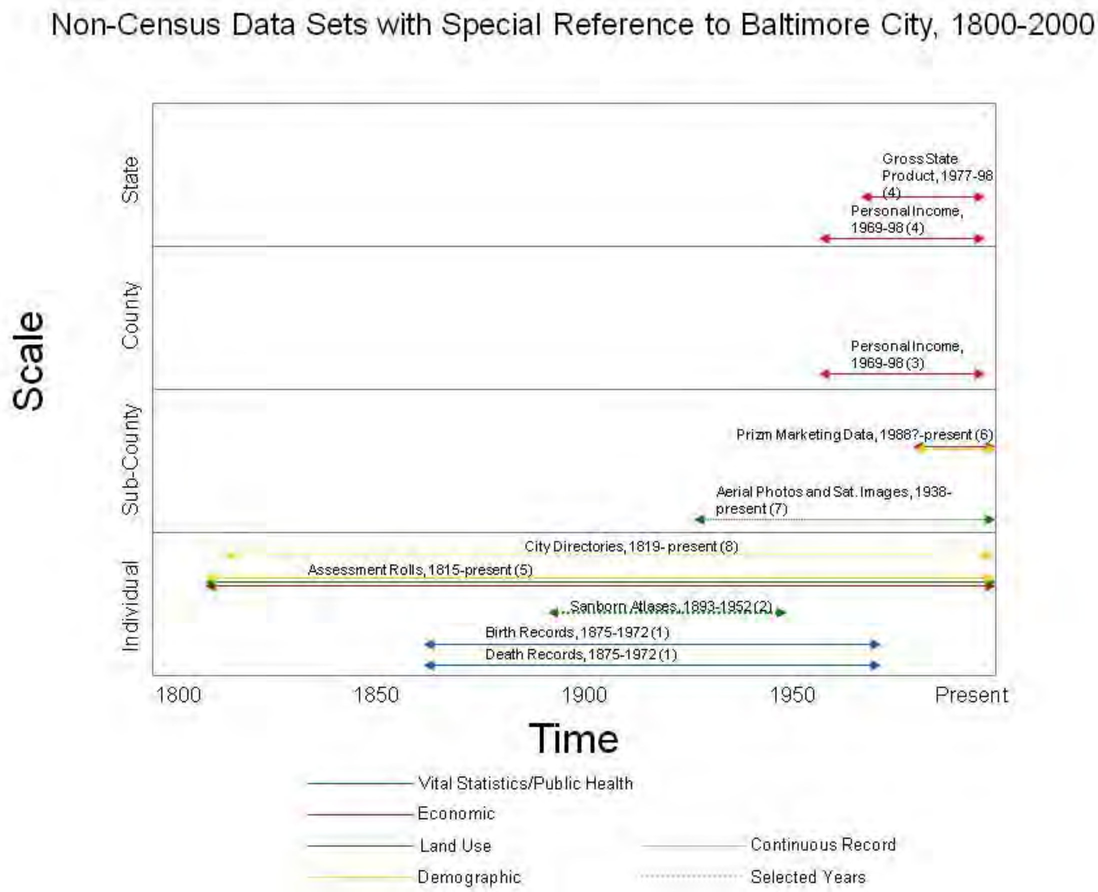


Figure 9. Extensive, long term social science data in BES. Long-term and multi-scale secondary data have been acquired, spatially referenced, documented, and curated.

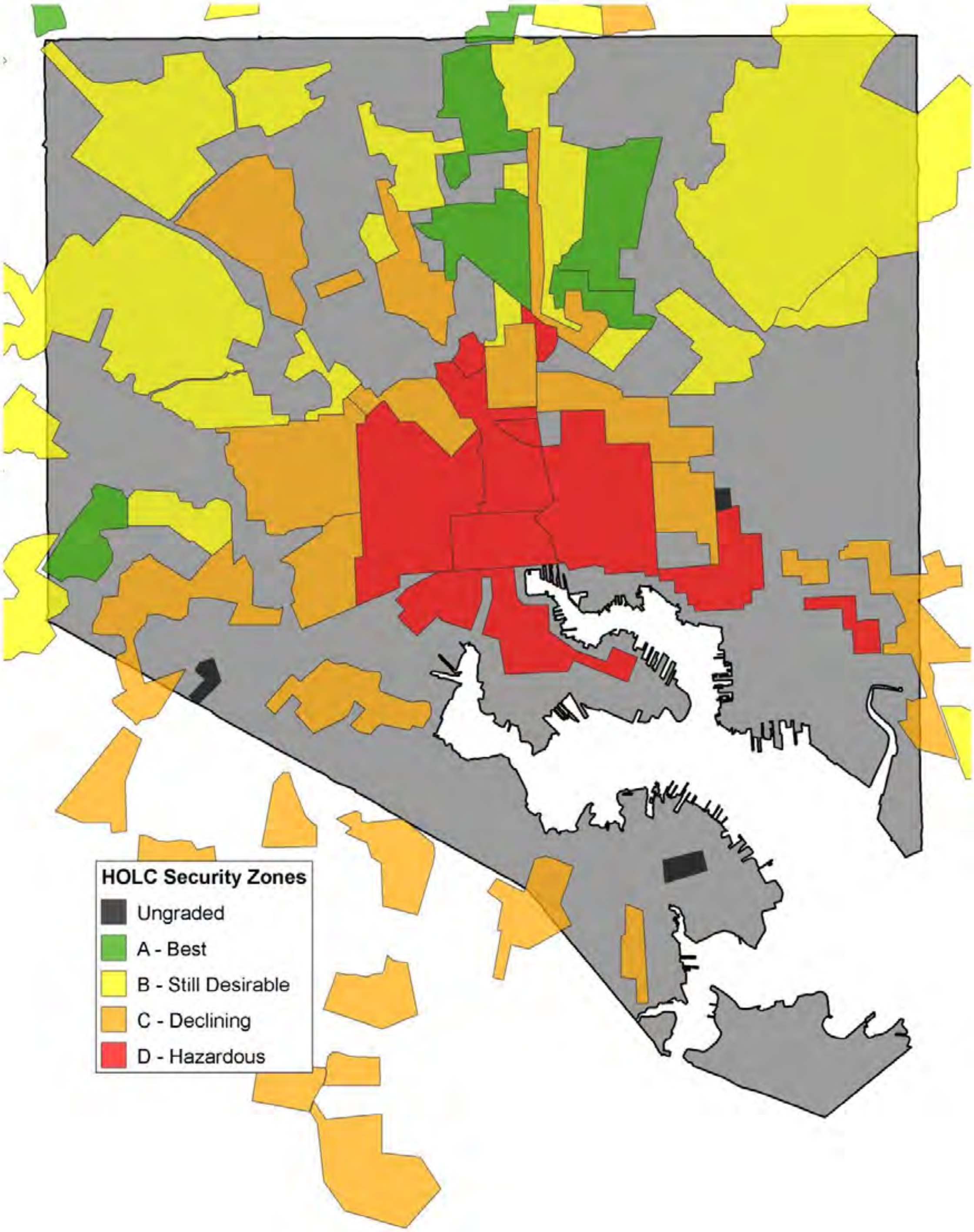


Figure 10. Residential Security Map of Baltimore Neighborhoods produced by the Federal Home Owners' Loan Corporation (HOLC) in 1937. Neighborhoods are delineated by lending hazards from A (best) to D (hazardous). Hazardous residential security zones are highly correlated with percent minority and foreigners, as well as age of housing and proximity to non-residential land uses.

and derived data using a nested approach that includes the residential household telephone survey described in Section 1, Results From Prior Support.

Building upon the existing BES data platform and long term socio-demographic data collection, new data for BES III will focus on enhancing our capacity to model locational choices of households and firms and the economic, social, and institutional constraints to these choices over the long term and at multiple scales—parcel to county—for the entire Baltimore CSE. Our modeling approach relies on explaining the observed meso and macro scale dynamics of land use, land cover, population, employment, housing prices and other key outcomes that are the cumulative result of spatially explicit choices by individual landowners, households and firms subject to economic, policy and other constraints. Thus the fundamental unit of observation is individual agents that make choices across a spatially heterogeneous landscape. This modeling approach will require data on individual decision makers as well as fine-scale spatial data on land use, land cover, housing prices, population and other outcome variables. In addition, data on factors that influence individual land use and location decisions and that adapt to these choices—including roads, utilities, neighborhood and school quality and other local public goods—are needed to fully model agent decisions. Our interest in historical as well as current processes requires extensive time series data. Because many of these historical data are not in electronic or georeferenced format, considerable effort is needed to translate paper or scanned images and tabular data into a georeferenced database that can be used for spatial analysis and modeling.

The types of data needed to support the research efforts are both extensive and intensive. Both types of data are necessary to model spatial behavioral processes and to better understand how location and land use decisions interact with policies and biophysical processes:

(1) Extensive spatial data on all land use, subdivisions, parcels, housing price, population and employment variables from 1940 to the present to estimate reduced form models of landowner land use and household location choices.

(2) Extensive spatial data on current and historical zoning and variances, infrastructure for sewers, roads, schools and transportation.

(3) Intensive data, e.g., collected via surveys or other specialized data sources on individual landowners, developers, households and other key agents, which can be used to estimate more fully specified structural models of these key decision making processes.

(4) Intensive histories of neighborhood change and stability. Extensive data will be complemented with in-depth histories of processes and mechanisms of change. We propose to concentrate our data collection efforts in neighborhoods that best illustrate the broad spectrum of changes Baltimore experienced from ca. 1910 to 2008 to construct a sample of neighborhoods that is demographically, economically, and geographically diverse and that captures the social and environmental stability and instability of the time period. Archival and library collections of non-profit organizations, civic leagues, government agencies, newspapers, and oral histories of residents will be analyzed for these neighborhoods.

A second major area of focus in BES III (specific research questions 3a-c) will be to assess institutional responses to climate change by evaluating changing approaches by four key planning agencies/entities. Research will chart the evolution of the types of adaptation plans and efforts through triangulating interviews and documents from the Baltimore Commission on Sustainable Development, the Baltimore City Planning Commission, the Baltimore County Planning Commission, and the Maryland State Planning Department. A first set of interviews in

2010 will address adaptation actions planned, distribution of burdens and benefits, perceived information priorities, capacity to process new information, flexibility to act, mainstreaming, multiple stresses including relation between adaptation and mitigation, and first efforts prioritized for implementation. In order to capture the dynamics of adaptation, the interviews will be conducted in 2012 and 2014 with an effort to interview the same individuals.

Agency interviews will be conducted in conjunction with the replication and enhancement of an existing survey and methods for assessing governance and social networks associated with natural resource stewardship and sustainability (Dalton 2001). Using 1999 BES data on organizations (Dalton 2001) and relevant long-term social and ecological datasets, we will examine changes to and the effectiveness of polycentric networks in the Baltimore CSE. We will seek to understand how network relationships form and adapt in response to changing social and ecological conditions, how information is transmitted among network actors, and whether network structure affects social and ecological outcomes.

2.2.2 Experiments

Traditional manipulative experiments are difficult to carry out in urban watersheds due to concerns about environmental justice and constraints on human subjects research (Grove & Burch 1997, Cook et al. 2004). However, spatial variation in the nature and extent of land cover, i.e. the urban-rural gradient, provides numerous opportunities for experimental variation of factors controlling biophysical and social parameters. In addition, management initiatives such as efforts to improve sanitary sewer infrastructure (Fig 11), stream restoration projects, Baltimore City's Urban Tree Canopy Goal and conversion of abandoned lots to community managed open space represent experimental opportunities. These management efforts provide strong opportunities for integration of biophysical and social sciences and for education and outreach.

Urban flux tower. The USFS 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. Depending on wind direction, the tower footprint samples a variety of land use intensity, from predominantly forested to predominantly urban (Fig 12). Temporal variation (weekday versus weekend, day versus night, growing versus dormant season) facilitates experimental evaluation of human and natural influences on carbon fluxes.

Over the next six years, work is planned for annual net ecosystem exchange (NEE) comparisons with nearby rural Ameriflux towers to understand carbon dynamics associated with land use change, management, and disturbance. We will integrate isotopic and radiotracer studies using transplant gardens to study the contribution of anthropogenic CO_2 versus biological sources on urban forest productivity. We will initiate a climate change, pollen, and human health study funded by EPA using this gradient for studying increased quantity and potency of pollen allergens. We have established partnerships with new urban towers in Orlando, FL, and Syracuse, NY, and with the AsiaFlux network for studying anthropogenic influences on the regional carbon cycle. We will begin ozone and passive nitrogen monitoring at the tower as part of the Forest Service Experimental Forest Synthesis Network.

Metacommunity Methods.

We focus on four taxonomic groups – riparian trees, soil invertebrates, stream invertebrates and birds. The work on soil and bird communities will build on long-term monitoring established in BES II. The rationale to focus on riparian tree communities and stream invertebrates stems from the extensive work on riverine ecosystems thus far in BES, and the increasing role stream

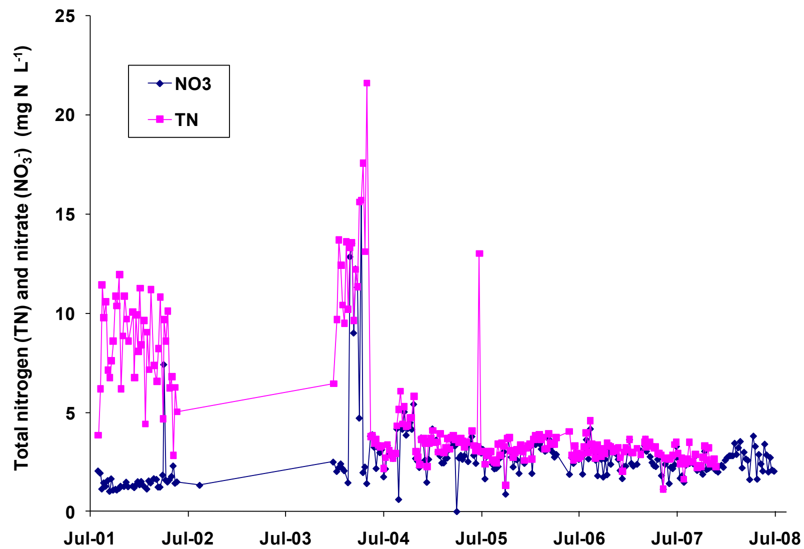


Figure 3. Total nitrogen and nitrate in Gwynns Run, a small tributary to the Gwynns Falls. Sanitary sewer infrastructure improvements in April 2004 led to a marked decline in obvious sewage contamination to this stream.

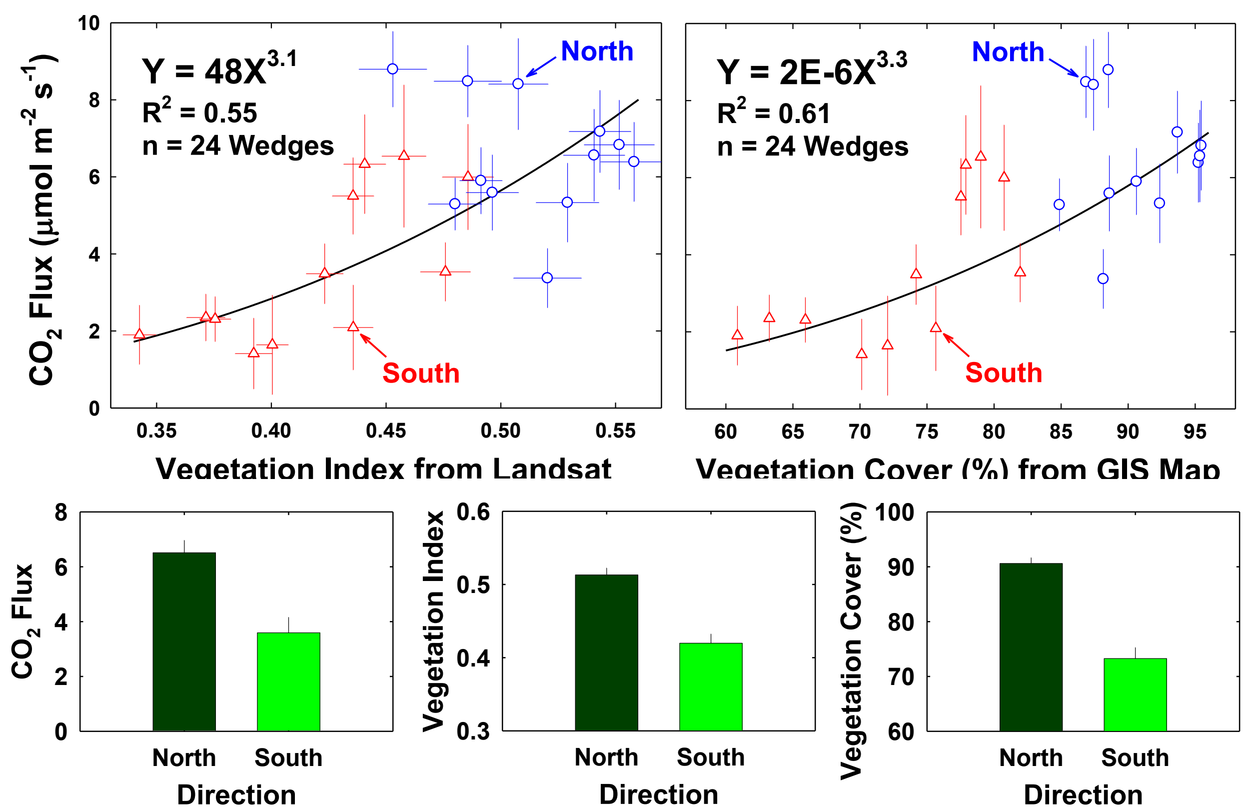


Figure 4. Carbon dioxide flux (F_{CO2}) during daytime as a function of Normalized Difference Vegetation Index (NDVI) from Landsat-TM (Thematic Mapper) and percent vegetation cover from land use classification. Symbols (mean±SE) in the top panels represent 24 footprint wedges (or wind sectors) at 2 km radius around the Cub Hill tower, and bar charts in the lower panels represent the mean±SE, n=12 sectors each for North and South. Positive F_{CO2} values denote CO_2 uptake by the ecosystem (Saliendra et al. unpublished data)

restoration is playing in the management of freshwater resources in the region. Both taxonomic groups are directly manipulated (e.g., riparian reforestation) or managed indirectly (e.g., in-channel habitat restoration) by humans for multiple purposes. In effect, these large scale manipulations reflect a significant human driver of urban biodiversity and are in themselves experiments. Furthermore, years of research at BES on nutrient cycling and urban hydrology have focused on these activities. Understanding urban metacommunity structure in the context of restoration integrates this new direction with current and proposed BES research.

Restoration practice, such as geomorphic restructuring of the river channel and riparian reforestation, is a manipulation of local factors designed to confer a specific pattern in local species composition (Bond & Lake 2003). These facilitated communities (Swan et al., in press) are hypothesized to be a different subset of the regional species pool relative to communities that self-assemble in response to the harsh environmental gradient present on the urban landscape. Furthermore, location of restored sites within a drainage network will influence connectivity to the regional species pool (Brown & Swan, in press). Our goal is to understand community composition relative to potential colonists. We propose to survey existing restoration projects within BES, measure temporal patterns of species composition, and determine the extent to which local community structure reflects local environmental conditions imposed by restoration activity, or dispersal limitation from the regional species pool.

Working with the Baltimore County Department of Environmental Protection & Resource Management, 84 stream restoration sites have been located and described with respect to position within the riverine network and landuse. We hypothesize that for stream invertebrates, position within the river network will determine the extent to which local conditions, driven by restoration activity, determine local community composition (Brown & Swan, in press). Low-order sites are the more isolated locations in the river network, and therefore local composition should reflect local conditions – i.e., community similarity between ―restored" communities and adjacent, unmanaged communities should be very low. However, high dispersal in lower reaches should reduce influence of restoration on conferring changes in community structure, increasing community similarity between restored and adjacent reaches. Therefore, the extent to which humans, via restoration action, facilitate the establishment of riverine invertebrate communities is hypothesized to interact with a significantly important spatial feature of the landscape, network structure of the river drainage.

Riparian restoration involves substantial soil preparation and planting of tree communities. Such efforts result in substantive changes to the environment, and we classify the communities assembling there as facilitated by human intervention. As such, they should exhibit very low community similarity with adjacent communities. However, over time, these communities change, and so management of restoration sites post-planting will be used as a variable to understand coexistence through time. By surveying patterns in tree species composition across restoration sites and adjacent, non-restored riparian forests, we have an opportunity to place the type of riparian management in the context of urban community ecology.

For birds, we will continue annual monitoring of the breeding bird communities at 82 sites drawn from the 194 UFORE plots in Baltimore City and 50 sites drawn from the more intensive UFORE sampling in WS263. Co-location of bird monitoring with these plots will facilitate use of other BES data on local environmental features and household- and neighborhood-scale management by humans collected from the same sites. Previous BES research has identified at least 4 distinct urban bird communities in Baltimore, including two communities associated with distinct residential landscape types: mature trees and open-but-shrubby neighborhoods (Nilon et al. 2009). The presence of each community type is significantly correlated with local factors such as urban tree canopy cover, management of decaying wood (e.g. dead tree branches), and horticultural decisions (e.g. amount of shrub versus lawn cover). In BES III, we will expand on this work to address whether neutral processes (extinction and colonization) are also contributing to the distribution of bird species among sites of the same community type. Through spatial analysis of long-term monitoring data, we will test whether community similarity declines with distance, indicating that regional factors dominate, versus whether community similarity increases with environmental similarity, indicating that local factors dominate. We hypothesize that for the urban bird community associated with mature tree cover, regional factors such as patch size and isolation dominate (Donnelly & Marzluff 2004) but that local factors also play a role, such as tree care practices that affect dead and decaying wood. By contrast, the urban bird community associated with shrub-dominated residential areas is expected to be more actively human-facilitated, e.g. effects of gardening, bird feeding, pet ownership. Thus, we hypothesize that for the open-but-shrubby community, environmental similarity rather than distance predicts community similarity. We will use the HERCULES urban classification system (Cadenasso et al. 2007) to identify patches of mature forest cover around bird sampling locations and street side transects to characterize dead and decaying wood. Questions on bird-related behaviors such as pet ownership, bird feeding, and gardening will be incorporated into the BES telephone survey. Socio-demographic predictors of actions that affect birds will be drawn from US Census and PRIZM datasets (cf. Grove et al. 2006b). Prior BES research shows that tree canopy cover is correlated with median income, but that the presence of dead wood in live trees is not. By contrast, poverty status, race, and college education are predictors of abundance of selected bird species. This information is used to develop spatial models for bird species.

Urbanization and the spread of zoonotic and vector-borne diseases.

New work in BES III will define how urbanization influences mechanistic relationships among disease vector and host community diversity, vector and host population abundances, pathogen amplification, and human disease risk. We will sample mosquito communities weekly from April-September from standardized containers set-up at established BES stream gradient sites in the Gwynns Falls watershed and at the forested reference site. Dark containers initiated with a standard amount of water are a proven way of assessing ovipositing adult populations of several mosquito species (Leisnham et al. 2007). Weekly water sieving will ensure that these containers do not contribute to adult populations. This fine-scale dataset will allow us to examine the temporal variability in species diversity and West Nile virus (WNV) vector abundance along a common stream channel extending from rural to urban habitat. The sites described above and at least four other sites (distributed to capture wealthy-urban, wealthy-rural, poor-urban and poor-rural communities within Baltimore and Baltimore County) will be more thoroughly sampled on a monthly basis (April to September) to quantitatively evaluate the larval mosquito and macro-invertebrate communities. These data will be used to construct food webs and evaluate how mosquito populations are regulated in space throughout the season. Adult mosquito presence will be evaluated using CDC light traps deployed at each of the full macro-invertebrate sampling sites (for one night each in June, July and August).

Water-borne pathogens are also a risk in urban centers. We will continue long-term studies of upland-stream connections of pathogenic E. coli (Higgins et al. 2005, Belt et al. 2007) by sampling soils and runoff from upland hot spots (gutters, rooftops, storm drains, etc.) and the riparian areas of their receiving waters (riparian pools, hyporheic flows, soils, etc.). The corresponding laboratory and in-situ survival characteristics will also be quantified so that more accurate models can be constructed of pathogen dynamics in urban stream ecosystems.

Stream/riparian restoration projects. Stream and riparian restoration studies will continue to function as a hotspot of integration in BES III. Comparison of restored streams with degraded and forested reference streams has been a major experimental effort in BES, with non-LTER funding coming from several sources (Table 3). This work has contributed to efforts to restore denitrification –hot spots" in surface stream sediments (Groffman et al. 2005), riparian and hyporheic zones (Kaushal et al. 2008b), stream channels (Klocker et al. 2009), and along stream networks. We plan to continue this work with a combination of LTER and non-LTER funds, e.g., renewal of existing grants. The USFS has led an effort to build a long-term temperature database to quantify the modulating effects of urbanization on long-term benefits of riparian buffers. These data will be used to evaluate the effectiveness of forestry restoration efforts to mitigate the effects of urbanization on stream and surface runoff temperatures.

Neighborhood greening projects. Watershed 263 will continue to be a hotspot for integration in BES III (Fig 13). The –headwater" storm drains of two 15 ha, 70 % impervious cover residential subcatchments have been the sites of intensive baseflow and runoff sampling. These will be supplemented in the future with upland surface sampling of stormwater BMPs integrated with tree plantings to track alterations in flow volumes, water quality constituents, temperature and organic matter. This will permit the characterization of source areas and runoff fluxes and storage within the engineered stream system as well as outputs to Chesapeake Bay.

2.2.3 Comparative studies

Given the novelty of urban ecosystems within the LTER network, there has been great interest in conducting comparative studies with non-urban sites within the network. Our long-term watershed monitoring and participation in the EcoTrends project has been ideal for these comparisons. There has also been great interest in comparisons with CAP (the other urban LTER site) and other sites that encompass human-dominated landscapes (KBS, PIE, FCE, CWT, and NTL). These comparisons have developed over the past few years with the expansion of many LTER sites to address the human-dominated ecosystems surrounding their sites, the emergence of coupled socio-ecological approaches in environmental science, and the new Urban Long-Term Research Areas-Exploratory (ULTRA-Ex) network. In particular, the District of Columbia-Baltimore City ULTRA-Ex is a close comparative expansion that should in turn facilitate cooperation with other ULTRA-Ex sites around the country.

<u>Within the Baltimore CSE.</u> For BES III a major new integrative hotspot will be locational choice modeling, which will be supported by studies comparing the socio-ecological dynamics of exurban areas in the rapidly developing counties adjacent to Baltimore County as well as redevelopment densification areas that are a focus of land use planning efforts in Baltimore City and County. In BES III, we plan to expand our long term data efforts to facilitate comparisons among the six jurisdictions (Baltimore, Howard, Carroll, Harford, and Anne Arundel Counties, Baltimore City); and within jurisdictions in terms of zoning, neighborhoods, and social groups.

On the biogeophysical side, we have focused on neighborhoods with different methods of sewage disposal -- sanitary sewers versus onsite septic systems -- within the Baltimore metropolitan area. These comparisons foster integration with social science and with management, urban design, and decision making as the method of sewage disposal is determined by the location of the Baltimore County URDL, i.e. all septic outside the boundary. Watersheds served by septic systems have surprisingly high nitrate concentrations in streams given their low population density and impervious surface (Groffman et al. 2004, Kaushal et al. 2008b, Shields et al. 2008) because septic systems discharge waste directly into the subsurface where it mineralizes, nitrifies and moves to streams. In BES III we plan to sample more watersheds served by septic systems, and to further integrate with social sciences, management and decision making in the context of new land change measurement and modeling studies.

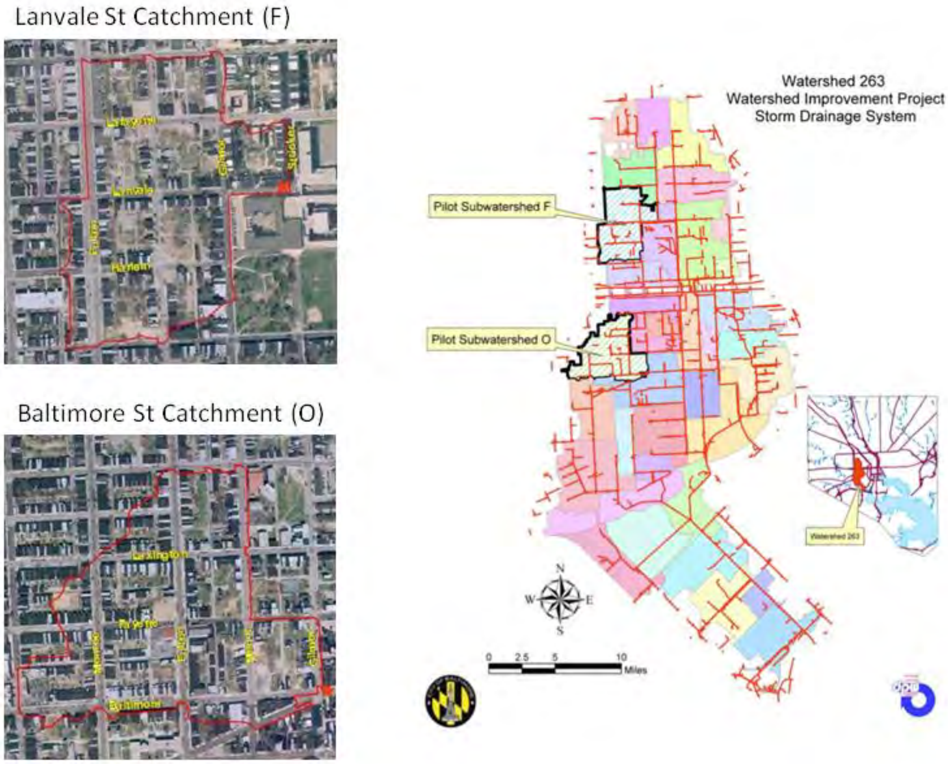


Figure 13. Study design for the 364 ha Watershed 263 project showing two nested sub-watersheds (Lanvale, Baltimore) that have been monitored since 2004. Lanvale and Baltimore St. storm drain runoff sampling locations (at points on right of the photos) and their subcatchment drainage boundaries (photos on left). These drainage areas have ca. 70% impervious cover and are ca. 15 ha in size. The right side figure shows the whole Watershed 263 storm drains and the location of the two sampled subcatchment boundaries (on the left side of the catchment).

With Phoenix. Early comparisons of urban climate and heat island effect between Phoenix and Baltimore (Brazel et al. 2000, Brazel & Heisler 2009) have developed into a wide range of comparative analyses. Both projects have calculated nitrogen balances (Baker et al. 2001, Groffman et al. 2004, Kaushal et al. 2008a) and have looked for nitrogen retention and denitrification in unique urban wetlands (Groffman & Crawford 2003, Zhu et al. 2004) and in lawns (Hall et al. 2008, Groffman et al. 2009, Hall et al. 2009). In BES III, we plan to develop a cross-site comparison of residential landscapes with CAP, FCE and PIE. This work, which is being developed in cross-site proposal writing efforts, will address ideas about socio-ecological homogenization associated with residential land use and its effects on social and ecological variables. Critical to this effort has been BES's collaboration with CAP, FCE, and PIE to share, standardize, and replicate sampling protocols, survey instruments, QA/QC, training, and computational capacities for quantifying landcover structure and condition and characterizing land management practices, motivations, and condition for residential landscapes.

With other LTER sites. Given the centrality of the watershed approach in BES, significant effort has been made to develop comparisons with other watershed-based LTER sites, especially HBR, CWT and AND. The dominant venue for these comparisons has been the EcoTrends project, which is a compendium of long-term datasets from LTER and other long-term research sites. EcoTrends has also developed a platform for socio-demographic cross-site analyses. BES co-pi's Groffman and Grove are on the EcoTrends Steering Committee and will continue to lead efforts to compare BES with the less intensively human-managed ecosystems that dominate the LTER network.

UFORE and Urban Tree Canopy Comparisons with other Cities. Baltimore's urban forest has been assessed using field plots and tree cover change monitored using aerial photographs. To aid in comparing urban forest structure and ecosystem services, a standard data collection and analysis approach has been developed through the UFORE model discussed previously. Based on this approach, dozens of other cities have been assessed with new cities being assessed each year.

With other ILTER sites. For the past three years, BES scientists have participated in and taken a leadership role in developing collaborative opportunities with the French Zone Ateliers sites associated with the Centre National Recherche Scientifique (CNRS). Areas of collaborative focus in BES III will be remote sensing in urban environments, urban hydrology and biodiversity, and the social-ecological dynamics of residential landscapes.

2.2.4 Modeling and Synthesis

To answer our questions about how biogeophysical and social adaptive processes influence and respond to policies aimed at enhancing sustainability in the Baltimore region, and to identify additional data and theory needs, we will make use of and extend existing comprehensive models we have developed to represent and explore the feedbacks between human activity and urban ecosystem processes (Fig 14). A long-term goal of social and biogeophysical modeling activities in the Baltimore region is to establish an ‒end-to-end system” of models and observational instruments to gather and synthesize information on social and biogeophysical components of the ecosystem. The objective of this synthesis is an understanding of how individual and institutional behavior, the urban landscape and infrastructure, ecosystem services and other push/pull factors and climate interact to affect water and biogeochemical storage and flux in the urban hydrologic cycle, terrestrial and aquatic carbon and nutrient cycling and storage, and the regulation of surface energy budgets. We are using biogeophysical models to

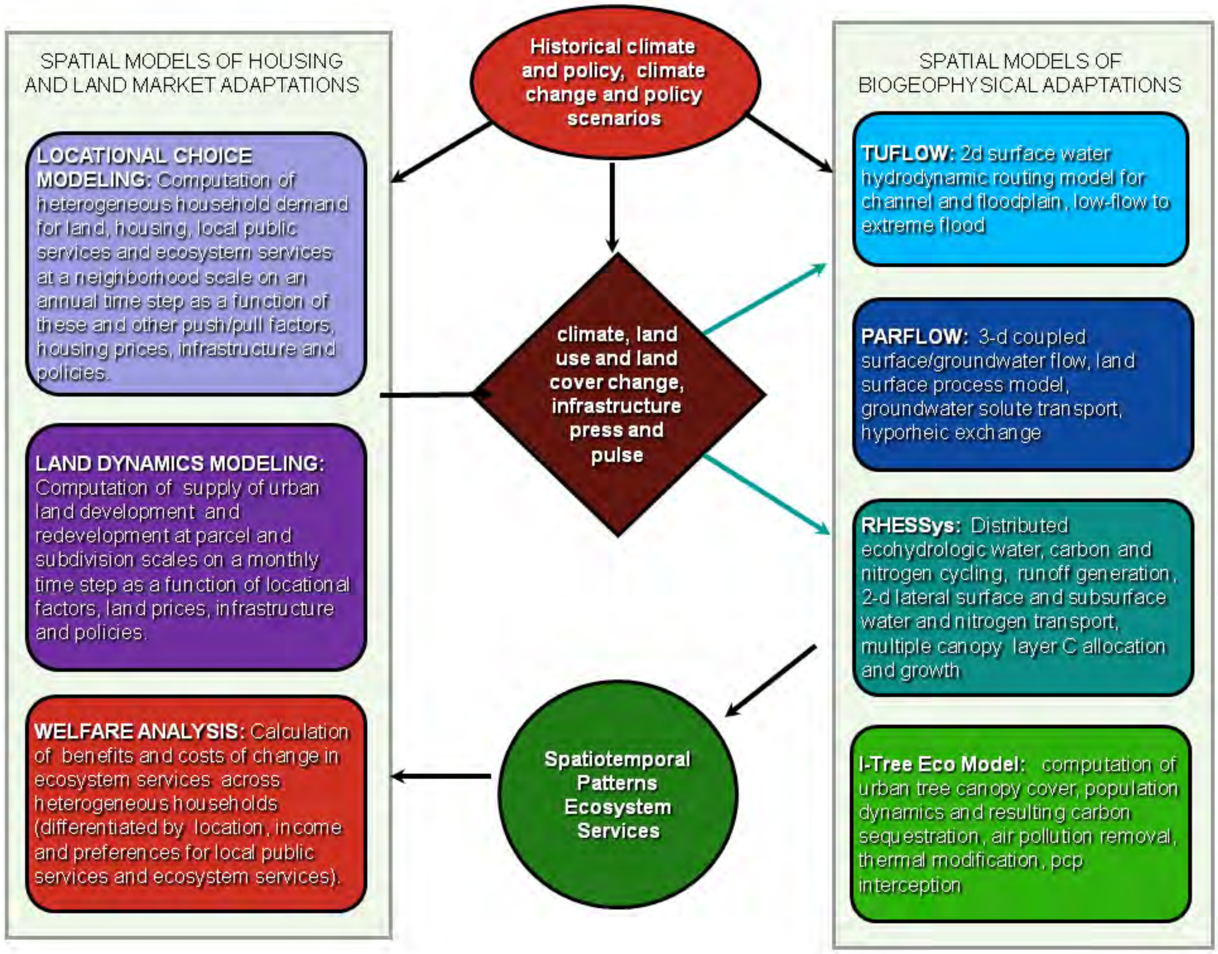


Figure 14. Function and interaction of BES model components coupling social and ecosystem adaptive processes within the context of the ISSE framework. Spatially explicit human locational choice and land use conversion represent social processes directly modifying ecosystem structure, and combined with models (right hand side of figure) are colored in a gradient of ―blue water" to ―green water" (e.g. Falkenmark and Rockstrom 2006) representing a shift from more purely hydrologic to ecohydrological models. The models on the right hand side act as ecosystem production functions which feed back to the human/social processes. In order from the top, TUFLOW will focus on urban flooding, ParFlow on coupled surface water/groundwater interactions and land surface processes, RHESSys on ecosystem cycling and growth along hydrologic flowpaths, and I-Tree on ecosystem services of urban tree canopy. The welfare implications for heterogeneous households of changes in ecosystem services are evaluated using general equilibrium welfare analysis.

simulate water, carbon and nitrogen cycle processes and econometric and structural models to simulate locational choices, land development and patterns of land change at multiple scales across the CSE. Coupling of these models will produce a first effort to develop a predictive understanding of the feedbacks between environmental quality, ecosystem services, locational choice, land development and redevelopment. Specific policy scenarios from the Baltimore sustainability plan related to water quality and carbon sequestration will drive the coupled modeling and synthesis activities.

Integrated Hydrological-Land Dynamics Modeling: Existing ecohydrological models (described below) that simulate coupled water, carbon and nutrient cycle processes at multiple spatial and temporal scales will be integrated with new parcel-level models of land change to simulate changes in runoff production and water quality under alternative land use and management policies and practices. Predictions of spatially explicit land changes under alternative policy scenarios are based on econometric land use change models and empirical structural models of locational choice and land development. These model outputs are used as inputs into the ecohydrological models, which generate predictions of changes in ecosystem services and their spatial distribution. These changes may induce additional locational choice and land adjustments. Simulation of repeated rounds of these model linkages is necessary to capture the transitional dynamics and interactions of the coupled system across multiple spatial and temporal scales. This modeling framework provides the means by which we will investigate the hypothesized linkages among land use and land cover change, ecohydrological processes and ecosystem services, i.e. specific research questions 1a and 2a.

Integrated Urban Forest Ecosystem Services-Locational Choice Modeling: New urban forest ecosystem models being developed as part of the i-Tree (www.itreetools.org) modeling suite, described below, use local field and environmental data to assess urban structure and ecosystem services, e.g., air pollution removal, carbon storage and sequestration, and building energy use (Nowak et al., 2008). In BES III, we will integrate these new models of urban forest ecosystems with household locational choice models (see below) that account for the influence of urban tree amenities and local tree planting policies on locational choices. By explicitly accounting for homeowner demand for urban tree cover and the costs of tree planting, we can estimate the benefits of various tree planting scenarios, the effects of tree planting on land and housing markets and the opportunity cost of policies that commit land to trees. Given predicted changes in locational choices and land use under alternative scenarios, we can estimate changes in ecosystem services due to projected changes in tree population and cover, i.e. address specific research questions 1b and 2b – d. The detailed models that will underlie these integrative analyses are described below:

RHESSys is a distributed ecohydrological model that will operate at neighborhood to catchment scales with a computational grain of processes at the sub-parcel level (Tague & Band 2004). The model simulates fully coupled water, carbon and nutrient cycles, with prescribed land cover and infrastructure from empirical records or simulated by the locational choice and land use change models. Individual and institutional parcel scale land management, including vegetation choice, management, irrigation and fertilization, is also input as developed through our household surveys or as scenarios, and transient evolution of canopy and soil properties along hydrologic flowpaths are simulated. The spatially distributed model will provide an ecosystem service production function at the scale of parcels through watersheds. The model uses a mixed time scale ranging from sub-daily to seasonal, with short to long time domains that can encompass long, transient simulations of historical development and scenarios under climate, land use and infrastructure change. The model makes use of a hierarchical representation of the landscape including progressively nested catchments, hillslopes, patches, and strata (Band et al. 2000). Strata can include natural or built land cover forming patches with multiple understory and overstory species. The spatial structure of RHESSys at the patch level is fully compatible with the HERCULES (Cadenasso et al. 2007) land classification system. Patch scale balances of water, carbon and nitrogen are embedded within 2-d surface and subsurface hydrologic flow fields, such that upslope to downslope transport and subsidy of water and nutrients can be represented, including redirection of drainage by infrastructure, such as sewers and curbs. 3-d groundwater flow is not depicted by RHESSys, but is provided by ParFlow, described below.

i-TREE. The i-Tree Eco model (formerly UFORE) uses local field and environmental data to assess urban structure and ecosystem services, e.g., air pollution removal, carbon storage and sequestration, building energy use (Nowak et al. 2008). Various new models are in development that integrate field and environmental data with high resolution cover maps to help determine the optimal locations for tree cover in terms of ecosystem and human health services. New models in development include: a) an air pollution dispersion and deposition model to determine locations of relatively high pollution concentrations and pollution removal within cities (Hirabayashi 2009), b) an air temperature mapping program to determine how tree cover locations affect local air temperatures (Heisler et al. 2007, Ellis 2009), c) a semi-distributed hydrology model to model tree effects on hourly stream flow (Wang et al. 2008), d) a tree population projector that simulates future tree species, size distributions and ecosystem services given annual planting, natural regeneration and mortality rates (based on Nowak et al. 2004), and e) a GIS-based tree canopy cover projector that simulates tree cover distribution based on outputs from the population projector model. As air temperature affects many ecosystem services, modeled hourly air temperature GIS layers will be integrated with the i-Tree Eco model components for hydrology and pollution dispersion or deposition.

ParFlow. We are using ParFlow to simulate water cycle processes at multiple spatial scales. In contrast to the 2-d subsurface flow fields in RHESSys, ParFlow is a three-dimensional groundwater flow code (Ashby et al. 2001, Jones & Woodward, 2001) that has been modified to include fully coupled surface and subsurface flow (Kollet & Maxwell 2006) and energy and plant processes at the land surface (Maxwell & Miller 2005, Kollet & Maxwell 2008). The code enables seamless simulation of water flow through aquifers and the vadose zone, over land, in streams, as well as via land surface processes related to the energy budget (evaporation, transpiration). The code is optimized for parallel computing applications so that it can be used for large-scale, high-resolution simulations. Calculation of three-dimensional flow fields enables prediction of, for example, contaminant plumes emanating from septic systems, by coupling the flow model with an appropriate transport algorithm (e.g. Maxwell & Thompson 2006). Work is in progress on applying Parflow at varying degrees of spatial resolution: (1) Dead Run (14 km^2) (Bhaskar et al. 2009a); (2) the Gwynns Falls (171 km^2); (3) the Baltimore metropolitan region (5000 km^2) (Bhaskar et al. 2009b); and (4) the Chesapeake Bay watershed (166,000 km^2). High-quality input data (e.g., spatially distributed precipitation) that have been assembled for the past 10 years are being used as model input. Predictions into the future (stream flow, aquifer levels) can be run using any desired hypothetical input scenarios of precipitation (and temperature, if energy budget forecasts are desired). The high performance computing (HPC) facility at UMBC is being used to carry out simulations requiring parallel processing.

TUFLOW is a two-dimensional, depth-averaged finite-difference surface flow hydrodynamic model that incorporates mixed 1-d and multiple-grid-scale 2-d flow domains with algorithms for urban infrastructure elements including culverts, bridges and subsurface pipes. The model is used to simulate flow patterns in streams and over adjacent floodplain surfaces (Syme et al. 2004, TUFLOW Users' Manual, 2008). With separate funding from NSF we are currently using

TUFLOW to support hydraulic analysis of streamflow patterns along selected reaches in urban drainage networks in the BES study area, covering the range of conditions from baseflow to extreme floods. Input data to support modeling efforts are derived from high-resolution LiDAR supplemented with total-station field surveys. Model results are used to simulate changing lateral and longitudinal patterns of flow depth and velocity, flow paths and residence times; to analyze the influence of urban infrastructure on flow patterns and on flood-wave inundation and propagation; and to support stage-discharge relationships at stream-gauge sites (Lindner & Miller, 2009 a, b; Miller & Lindner, 2009).

Locational choice will be modeled using structural econometric models of housing and neighborhood demands of households distinguished by differences in income and preferences. Primary and secondary data on household and location characteristics will be used to estimate these models and identify the locational demand parameters. The general equilibrium framework accounts for the influence of endogenous local public services and ecosystem services on location choices (Bayer et al. 2009, Sieg et al. 2004). When simulated over time, this approach can be used to trace the dynamic feedbacks between location choices and neighborhood change, including changes in location-specific ecosystem services, diverse social, demographic, economic and institutional variables, and cross-scale interactions from parcel level to multi-county using long time series of spatially disaggregated data.

Land dynamics will be modeled using reduced form and structural econometric models estimated with data on parcel and subdivision development and urban redevelopment at a monthly time step over several decades. Supply of urban land is modeled as landowner decisions to sell land and developer decisions to purchase ―raw" land for subdivision (Chen et al. 2009) or urban land for redevelopment. Spatially explicit variables hypothesized to influence the net returns to the location and intensity of land development are included as explanatory variables in reduced form econometric models (Irwin & Bockstael 2002, 2004, Irwin et al. 2003, Wrenn and Irwin 2010). These models uncover correlations between land development and spatial landscape variables, including driving time to urban centers, availability of public sewer and water, zoning constraints and other land use regulations, and suggest testable hypotheses. Using additional data on costs and production technology, structural supply models of landowner and land developer profit functions will also be estimated to capture dynamic feedbacks. Spatial simulation of the structural empirical models of locational demand and land supply will then be used to generate spatial simulations of predicted land dynamics under alternative policy scenarios. Policy modeling will address specific research questions 3a – c.

Welfare analysis of the net benefits of a change in ecosystem services will be conducted using the structural models of locational demand and land supply that can account for market and non-market feedbacks (Smith et al. 2004). By simulating individual and market responses to the changes in ecosystem services that are predicted under alternative policy scenarios, the costs and benefits of a policy change can be calculated (Walsh 2007). Examples of costs of policy changes include higher housing prices or the opportunity cost of an increased land use constraint, while benefits across different households are exemplified by the change in ecosystem services that results from the policy.

SECTION 3: SITE MANAGEMENT

Institutional Arrangements. The Baltimore Ecosystem Study LTER is administered by the Cary 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 and a subcontract, UMBC/CUERE maintains 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, while a Project Facilitator resides at the Cary Institute. The USDA Forest Service, Northern Research Station provides $810,000 of in-kind support per year, including staff time for research in biogeophysical and social sciences; for administration, education, and outreach; and for the Cub Hill eddy flux tower. The Forest Service manages a subcontract to support social science research. The US Geological Survey maintains the stream gaging stations, and contributes staff time for research. Subcontractors include: the Parks & People Foundation (PPF) for community engagement, outreach, non-formal education, and training; Johns Hopkins University for paleoecology, vegetation, and biodiversity research; the University of Missouri for biodiversity studies; the University of North Carolina for hydrologic modeling; Ohio University for social science, historical geography, and a GIS for social databases; the University of Vermont for social science, GIS for social science databases, landcover, and spatial analysis; Ohio State University, and the University of South Carolina for social science and modeling; the University of California, Davis for land cover and heat island research; the University of Maryland Center for Marine and Environmental Studies for stream ecology; and UMBC for groundwater, stream geomorphology, social science, biodiversity, and land use research. Cary Institute research includes stream chemistry, land change, soil microbial ecology, vegetation, infectious disease ecology, and education. Training of graduate students has been conducted through the universities above plus Rutgers.

Personnel. The Project Facilitator, Ms. Holly Beyar, based at the Cary Institute, is the contact for project participants, the public, and persons considering involvement in BES. She is responsible for project reporting, arrangements for the BES research meetings, and editing the BES Bulletin. This 60% time position is funded by the Cary Institute. The full time BES Information Manager, Mr. Jonathan Walsh, is located at the Cary Institute. He coordinates data acquisition from BES researchers and outside sources, enforces metadata standards, and interacts with LTER information management systems. He maintains the BES web site, the BES data portal, and the data back up site. Ms Beyar will devote more time to updating the website as a contribution to BES information management. The Education Coordinator, Ms Bess Caplan, is funded by the BES grant and leveraged support. She is stationed at PPF in Baltimore, and is responsible for linking with the community, in-school, summer, and after-school programs of PPF and other partners, including the educational activities of CUERE at UMBC. Dr. Mary Washington, the Associate Director of Great Parks, Clean Streams & Green Communities at PPF, is responsible half time to BES to facilitate interactions with communities, government agencies, and community groups for research, education, and outreach. She provides a conduit to the press, to 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 Dr. Washington reports to Co-PI Ms. Jackie Carerra, Director of PPF. These supervisors are members of the BES Project Management Committee.

The project is characterized by racial and gender diversity. Of 45 PI's, five are African American and 41% are women. Of 27 graduate students, 13 are women, 3 are African American and one is Asian. Of 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 (http://www.esa.org/seeds/) diversification program. UMBC now hosts a SEEDS Chapter. 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. We have added 5 new, funded Co-PIs to the project (Shannon LaDeau, Elena Irwin, Emma Rosi-Marshall, Sujay Kaushal, Chris Swan).

Administration. BES is administered by a Project Management Committee, which meets monthly (Fig 3-1). Minutes are posted to the internal BES web site to promote communication. A graduate student representative, elected to a two year term by the graduate students in the project, sits on the PMC. Once a year, we convene a Steering Committee, including all Co-PIs, the graduate representative, and staff members. 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 key subcontracting institutions and all project activity areas. It includes an annual rotating position to ensure breadth of viewpoint and to familiarize as many project members as possible with the management process. Other committees include those for Information Management, Research and Annual Meetings, Community Open House, and the BES Bulletin Editorial Board.

Research decisions are shaped by discussions at the quarterly research meetings, which update researchers on progress and explore changes or new projects. Linkage between projects and sharing of project resources are considered at these meetings. Potential collaborators, users, and interested communities attend these meetings.

Fiscal Procedures. The Project Director is for budgetary decisions. Subcontract allocation takes into account the input from science meetings, and the productivity and adherence of subcontractors to the project goals. Suggestions for supplement requests are gathered through the PMC.

Logistic Issues. Regular communication in this distributed project is crucial. All hands are encouraged to attend four meetings per year in Baltimore, 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 activities and write new proposals. Extraordinary effort is devoted to smooth, reciprocal interactions between BES, local communities, and government agencies.

Transition in Leadership. Although we propose that the project directorship remain unchanged in Phase III, we have actively engaged new Co-PIs in the project with the intention of bringing a new generation into positions of responsibility within the project, exposing them to the operation and philosophy of the LTER Network, and to identify a new project director during the next six years.

The table below shows BES members, their insitutions, roles, and funding stream. Red = funds from BES, green = in-kind support, and black = an investigator brings their own support. PMC refers to members of the Project Management Committee.

Participant Name	Institution*	Management Role**	Project Activity
Pickett, Steward T A	Cary Institute	Project Director, PMC	Landscape; Synthesis
Bain, Daniel J	U Pittsburgh		History
Band, Lawrence E	U North Carolina		Hydrological modeling
Belt, Kenneth E	Forest Service		Streams, water quality
Berkowitz, Alan R	Cary Institute	PMC, Education Lead	Education
Boone, Christopher G	Arizona State U		Social sciences
Brush, Grace S	Johns Hopkins U		Paleoecology
Buckley, Geoffrey L	Ohio University		Historical geography
Cadenasso, Mary L	UC Davis	PMC	Landscape ecology
Carrera, Jacqueline M	Parks & People	PMC	Community relations
Dalton, Shawn E	U New Brunswick		Social sciences
Doheny, Edward J	USGS		USGS Liason, Stream gaging
Dow, Kirsten	U South Carolina		Social sciences, scenarios
Elliott, Emily M	U Pittsburgh		Ecosystem ecology
Ellis, Erle C	UMBC		Social geography
Groffman, Peter M	Cary Institute	PMC, Budget Admin.	Ecosystem ecology
Grove, J Morgan	Forest Service	PMC, Soc. Sci. Leader	Social sciences
Holifield, Quintaniay	Forest Service		Soil science, education
Hom, John L	Forest Service		Atmospheric science
Irwin, Elena G	Ohio State U		Social sciences, modeling
Kaushal, Sujay S	UMCES		Ecosystem ecology, streams
LaDeau, Shannon L	Cary Institute		Disease ecology
Law, Neeley L	Ctr. Watershed		Watershed ecology, policy
Lord, Charles P	Urgent Vent. Dev.		Environmental law
McGrath, Brian P	Parsons School		Urban design
Miller, Andrew J	UMBC		Geomorophology, streams
Neff, Robert J	UMBC		Social sciences
Newcomer, Tamara	UMBC	PMC	Graduate stutend rep, streams
Nilon, Charles H	U Missouri		Biodiversity
Nowak, David J	Forest Service		Vegetation, modeling
O'Neil-Dunne, Jarlath	U Vermont		Spatial data & analysis
Parker, Tommy S	U Louisville		Biodiversity
Pouyat, Richard V	Forest Service		Soils, heavy metals
Rosi-Marshall, Emma J	Cary Institute		Streams, organic contaminants
Swan, Christopher	UMBC	PMC	Biodiversity
Szlavecz, Katalin	Johns Hopkins		Biodiversity
Tague, Christina L	UC Santa Barbara		Hydrology
Tennenbaum, David E	U Mass Boston		Hydrology, land modeling
Troy, Austin R	U Vermont		Social sciences, spatial analys.
Twery, Mark J	Forest Service		Technology transfer, modeling
Vermuri, Amanda W	Vermuri Assoc.		Social sciences
Walsh, Jonathan M	Cary Institute	PMC, Information Mgr.	Information management
Warren, Paige S	U Mass Amherst		Biodiversity
Washington, Mary L	Parks & People	PMC	Community relations, soc. scis.
Welty, Claire	UMBC	PMC	Hydrology, UMBC laiason
Whitlow, Thomas H	Cornell U		Vegetation
Whitmer, Ali C	Georgetown U		Education

* See CVs for institutional details.

** PMC = Project Management Committee;

SECTION 4: INFORMATION MANAGEMENT

Highlights: 1) BES has signature long-term data sets posted online, including 10 years of weekly stream chemistry, historical social science datasets, and GIS coverages. 2) The BES website serves as a nexus for project activities - research content, data, sharing documents, meeting announcements, and Director's Corner. Data on the BES website are available via the LTER MetaCat system. 3) The BES Information Manager is involved in all aspects of the project - serving on the Project Management Committee, attending all research meetings, and working with scientists, graduate students and support personnel to make Information Management an integral part of the project.

Description of the system: The BES Information Management System conforms to LTER best Practices. Data are stored in non-proprietary format whenever possible, even if the original format is proprietary. The original format is also preserved to assist in format migration. Metadata are expressed in Ecological Metadata Language (EML). Extensible Markup Language (XML) Stylesheets (XSLT) and scripts are used to present the data in both human and machine readable formats.

Data and metadata, website and FTP servers are backed up continually using software that senses and backs up changed files automatically. The target drives are retired after a year or any indication of impending failure. Backed up data are also moved to offsite storage every 6 months and onsite storage includes a fireproof safe, satisfying Underwriters Laboratories Classification 125, for disaster protection.

Since BES is an urban study, sensitive data such as addresses and incomes are collected. These data are carefully protected by design. Before such data are collected the database structure is planned to provide for public view of only the non-sensitive components.

BES participates fully with the LTER Information Management Committee in the collaboration of information management system design. All program code, ideas, and techniques are freely shared with LTER Network members.

The system is well documented in case of personnel turnover. Program code contains comments describing any difficult passages to aid in future revisions. In addition to an up-to-date online list of current and completed projects, BES has worked with other sites (BNZ, CAP, GCE, AND) to create an online collaborative database of all LTER sites. This database is called ProjectDB (c.f. databits.lternet.edu/node/33).

A yearly review of the system is performed by a selected group of PI's in addition to the Information Management Committee.

Website: The BES website (beslter.org) conforms to all LTER guidelines. The main criterion of its design is ease of use in accessing the project data and publications. The BES website is part of a significant number of collaborative, experimental, and educational efforts put forth by and with the other LTER site Information Managers. BES regularly collaborates with other sites to develop innovative ways of improving these systems.

Contents: In addition to the data and metadata, the BES Information System includes the database of BES publications. Currently the BES publication collection consists of over 850 items. The database is presented with an online interface which is searchable and filterable. The database is updated continually.

BES has a physical archive of filtered stream water samples that have been taken weekly since fall 1998 in a climate-stabilized room at the Cary Institute. These samples have been used as new investigators have measured new analytes, e.g., heavy metals, nitrogen and oxygen isotopes.

Access: All data and metadata are made available online. BES has very large datasets involving maps and Geographic Information Systems (GIS) data. These data are held on the BES web server and available to the public; however for most users the files are too large to be retrieved online. The BES server has available online 51.4 gigabytes of spatial data in 4,913 files (see http://beslter.org/geodatabase_SAL). To make these data readily available, scientists are asked to send a portable hard drive which is remitted with the requested geodatabase.

Tracking: Data access is tracked by means of a form which must be passed through before a file can be downloaded. The contents of this form are optional to facilitate access, but the date, time, and dataset identification of a request are logged. Additionally, the IP address of the requestor is logged so the location of the requestor is known. Since the inception of tracking in April, 2004, there have been approximately 2500 requests. To date, 1900 of those requestors filled in their affiliation and reason for downloading the data. By excluding IP ranges likely to be affiliated with BES, it is estimated that 1400 of the requests were from parties not directly associated with BES.

Integrity: The online BES data are protected by an access level control system and cannot be altered by non-trusted parties.

Mechanism: PI's create metadata records that describe datasets they generate as part of their research. This information is entered into the metadata database. This is done using either an online form, a spreadsheet template, or in the case of GIS data, semi-automatically as part of the ESRI ArcGIS software used to create the data.

A script is run against the metadata database that creates one file for each record in Ecological Metadata Language (EML). Additionally, the script creates one file for each metadata record in human-readable html and one file that lists all the metadata records with links to each EML file and each datafile and each html file. Lastly, a file called harvestlist.xml is created and contains the URL location of every EML file. This file enables the LTER Network Information System to find the EML files so that they can be retrieved via the LTER MetaCat system along with links to the datasets. BES metadata meet the requirements of EML-compliant level 2 (discovery) in accordance with EML best practices for LTER sites. There is a page on the BES website which enables users to browse and retrieve the metadata with links to the data and also to search for records using the keyword, title, or abstract fields.

Certain data are collected via an online database which allows PI's in disparate locations to work on the same data together. These include the BES Bird Survey and the Stream Chemistry data. Certain GIS data are kept in the form of a Geodatabase which allows datasets to be checked out, worked on, and checked back in to the database.

How is IM involved in design of research projects? The IM participates in all BES Research Meetings, helps individual PIs plan the structure of the data storage system that will be used for their particular collection, meets with PIs upon creation new projects to determine hardware, software and programming needs, and helps the PI insure each new project will be supported by the information management system for the entire project life cycle, from early data collection to final archiving. The IM also meets with all new Graduate students to help plan the data component of their work and to ensure the creation of metadata and other elements of proper information stewardship. Improvements to the information management system that are suggested by these interactions with researchers, and which can be made to facilitate research and to make effective use of the information systems in place are carried out. The involvement of the IM with research design enables intimate knowledge of all ongoing projects and in turn, understanding of the information involved.

The IM chairs the BES Information Management Committee which meets bi-monthly and is a member of the BES Project Management Committee and Steering Committee.

What mechanisms are in place to get PI's to contribute their data? Sharing of data is a requirement for BES project membership. It is one of the BES subcontract requirements. Reminders to submit data are made regularly and especially at the annual meeting and as part of the instructions for the BES project annual report.

How quickly are data made available to other researchers? Most datasets become available to BES PI's immediately. The Geodatabase makes new data available to others as soon as it is created. Stream chemistry and flow data are compiled weekly and upon request unqualified data can be made available within a day. The only data that are not quickly available are those that fall under the category of either original measurements or special long-term data collected by individual scientists as described below.

What criteria are used to limit or provide access to LTER data for other researchers? BES especially promotes data access to potential collaborators, policy makers, students, and educators. Every effort is made to make access to BES data as convenient as possible. These data are protected by the scientist's privilege to sufficient time to publish the data. Such embargos are permitted for students, post-docs, and junior faculty, but are queried periodically to encourage timely data publication. The period of such protection is two years and in very rare cases, longer. The BES information release policy is online at beslter.org/dm_policy.html.

How often are data sets updated on web? Qualified stream and soil data are posted to the WWW yearly. Data are committed to the stream chemistry database as they are collected. Some stream gauge data are available on a continual basis using a web interface to the recorder. Many datasets are single collections and not updated. The metadata are automatically scanned for changes on a daily basis and any new or changed data are automatically collected by the LTER Metacat system.

What major changes are necessary? More help for Information Management is needed. This is being facilitated by expanding the budget for the Project Facilitator to help with the website and the publications database.

Clarity of data access on website is being facilitated by replacing the manually generated data access pages with a single data browsing/searching component.

Network Involvement: BES participates in network Information Management activities. Participation includes but is not limited to participation in all IM committee meetings, Service on the IM Executive Committee, ProjectDB, ClimDB, LTERmaps, Web Services Development, All Site Bibliography, development and support of EML, various training workshops, and hosting of visiting Information Managers from the US LTER and abroad.

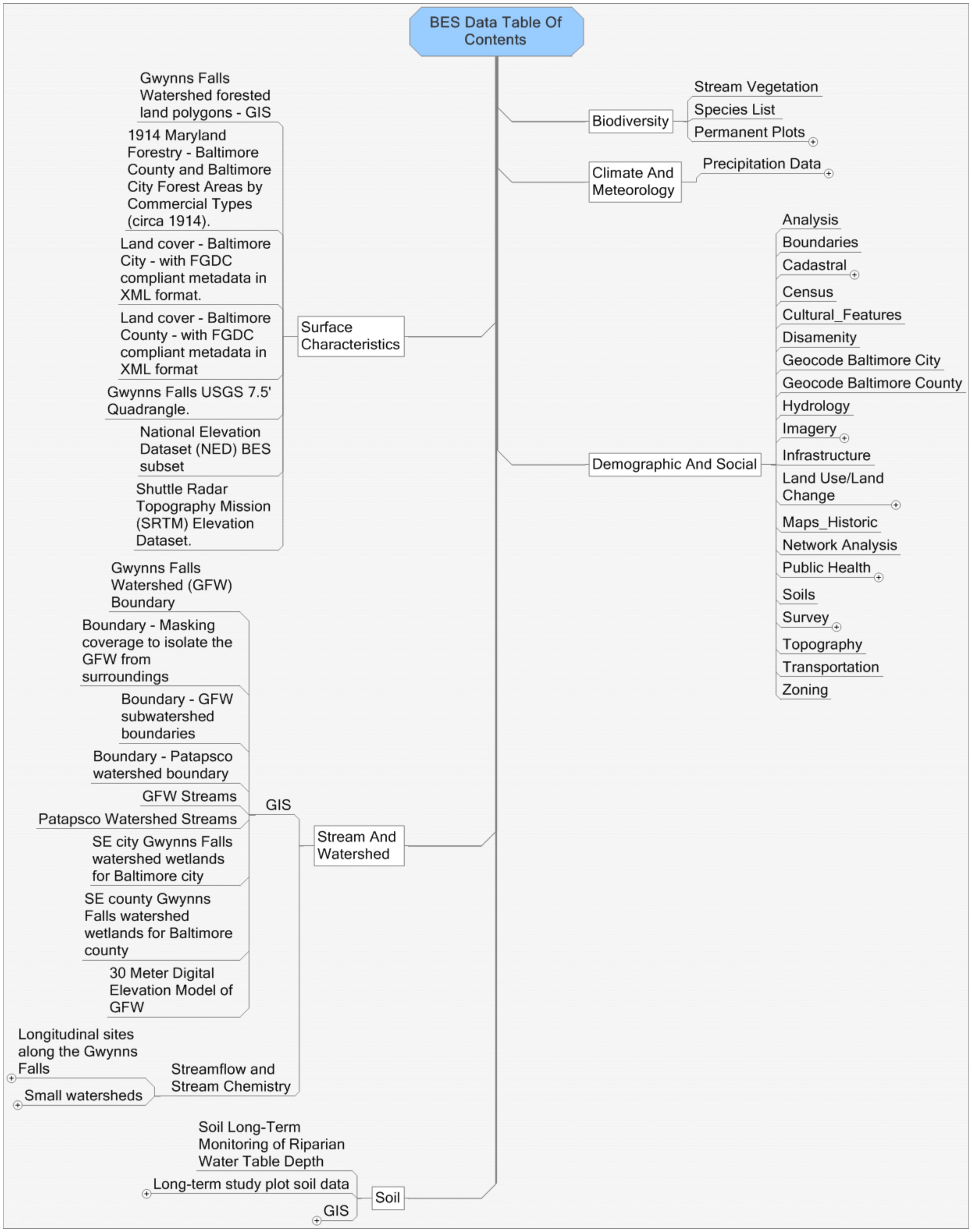


Figure 4-1. A high level table of contents of BES data available on via the project website. A complete list appears in the supplemental documents of this proposal.

SECTION 5: EDUCATION AND OUTREACH

We strive for a seamless interplay between our research, teaching, learning and information flow. Sustainability and adaptive processes are both a topical focus and an outcome for our work. We seek to understand how schools and other information systems adapt to global change and rising societal interest in sustainability. The BES Education Committee (Table 5.1) works with the full BES community on 9 activities enumerated below and aimed at key pivot points in the socio-ecological education system (Figure 5.1). These are described here by type of activity: A) Education Research, B) School and Informal Programs, C) Programs for the Public and Targeted Groups, and D) Career Development Programs.

A) Education Research

❶ Define and measure socio-ecological literacy in the Baltimore urban context. *What should high school graduates know and be able to do? What are the patterns of literacy among students, teachers, targeted groups and the general public across the metropolis and over time?* We will build on frameworks from the Culturally Relevant Ecology project to develop measures of socio-ecological literacy, emphasizing urban sustainability and adaptation. With leveraged funding we will establish long-term comparative studies of students, teachers and others. We also will add socio-ecological literacy items to the social science research efforts of BES III.

❷ Describe socio-ecological teaching and learning, focusing on sustainable urban ecosystems and adaptive processes. *How do students learn about ecosystems and adaptive processes? What pedagogies, teaching practices and experiences are most effective at developing interest and understanding?* We will periodically assess ecology teaching practices used in Baltimore Schools using the 2005 Ecology Teaching Study as a baseline. Careful assessment of our curricula and professional development (PD) efforts will continue to shed light on the best practices for fostering teacher effectiveness and student learning.

B) School and Informal Education Programs

❸ Develop instructional materials to foster socio-ecological literacy. *What activities, resources and investigations foster learning? What is needed for materials to be adopted by schools and used effectively by teachers?* We will continue to add new units to the Investigating Urban Ecosystems curriculum which include BES datasets, protocols and background information for teachers and students. The BioComplexity curriculum will be completed and disseminated. We will develop a new curriculum that schools can use to gage ecosystem services and sustainability of their schools, and to make comparisons with other schools in Baltimore and across the LTER/iLTER networks.

❹ Train and support teachers to be effective in fostering socio-ecological literacy. *What skills, motivation, self-efficacy and resources do teachers need? How do the context and communities that teachers participate in constrain or support effective teaching?* Schools in the Baltimore Partnership for Environmental Science Literacy (BPESL), comprising K-12 schools, Towson and other BES partners, have committed to support and participate in our research and PD programs. Schools will be encouraged to make a longer-term commitment by providing PD to other schools, and to facilitate student-run research on their schools and neighborhoods. Through our collaboration with the DC/BC ULTRA-Ex, we will expand to include schools in DC. For teachers interested in more intensive PD, we will continue to offer Research Experiences for Teachers and Teacher in Residence Fellowships supported by other grants.

❺ Develop useful assessments to support socio-ecological literacy in schools. *How can we gauge student learning to improve teaching? Can assessment promote a focus on socio-ecological literacy within the education system?* Good assessments help teachers attend to student thinking, and we will expand our contributions as our work to describe socio-ecological literacy bear fruit. We will continue working with the Maryland State Department of Education to assure alignment of the new state Environmental Literacy standards with current science.

❻ **Support informal education programs in socio-ecological teaching and engagement.** *What contributions can out-of-school and museum programs make in fostering understanding of urban ecosystem sustainability and adaptation? What resources, training and support are needed?* Informal education providers have tremendous capacity, but need training and support in ecology and pedagogy. BES and PPF will continue to collaborate in after-school and summer programs for elementary (KidsGrow), middle (Project BLUE) and high school (BRANCHES) youth in urban neighborhoods. BES will complete the My City's An Ecosystem! curriculum, and will work with PPF and USGS partners to develop a water unit where students learn about hydrologic processes in the city, and about adaptive responses to environmental changes. Finally, BES will continue to work with the Maryland Science Center to provide support for their citizen science programs on the urban heat island and climate change in Baltimore.

❼ **Help improve schoolyards and provide access to the environment for all children.** *How can we "Leave No Child Inside"? What changes in schools and their grounds foster socio-ecological literacy and environmental citizenship?* BES and partners in the state's Environmental Literacy Initiative and the City's Sustainability Office share a commitment to provide meaningful outdoor experiences to all children. PPF and other organizations are working to enhance schoolyards in a broader effort to cast schools as centers of community revitalization, research, and education. We will contribute expertise in socio-ecological research and monitoring, and in methods to assess impacts on participants' knowledge and interests.

C) Programs for the Public and Targeted Groups

❽ **Make BES knowledge, data and expertise available directly to managers, decision makers, community activists, and the general public.** *What are the most effective ways to reach broad audiences? How can we engage diverse groups in two-way sharing of questions and expertise?* BES, PPF and other partners offer programs and produce informational materials for managers, decision makers and the general public. These are disseminated on the web, in publications, and through the media. We now are working with the Maryland Science Center to produce an exhibit to share BES results with their visitors. The public is welcomed to BES Quarterly and Annual Meetings and Open House. PPF and BES offer tours of BES research sites to interested parties. BES has strong, collaborative relationships with key public agencies (e.g., the City's Sustainability Office and Department of Public Works) and with communities where our research is done (e.g., Watershed 263 Council). PPF and other interface organizations play important roles in fostering engagement with these groups. The Urban Ecology Collaborative and LTER/ ILTER provide networks for broader engagement.

D) Career Development Programs

❾ **Help recruit, retain and train a diverse workforce of urban ecosystem researchers, educators and managers.** *What knowledge, skills, and dispositions does the next generation of socio-ecological scientists need and how can we deliver this in our training programs? How can we bring the full diversity of the Baltimore community into the profession?* PPF, with BES, CUERE and others, is building a coordinated Green Career Ladder to encourage interest in environmental and scientific careers for urban youth. The Urban Resources Initiative (URI) will continue to give a diverse group of interns experiences in community-oriented research and education. Collaboration with the DC/BC ULTRA-Ex and REU positions will involve students in BES. BES faculty will continue to develop undergraduate and graduate courses using BES data and one of the BES quarterly science meetings in the next 3 years will focus on teaching. UMBC BES collaborators at CUERE are hoping to continue their highly successful IGERT program. The website's Resources for Educators will be expanded beyond K-12.

Table 5.1 The BES Education Committee provides ongoing guidance, support and connections between BES and broader communities in Baltimore and the field as a whole. All are confirmed and active members, and are willing to send letters of support upon request.

BES Education Committee	
1. Dr. Anila Asghar, Johns Hopkins University. *Science education*.	2. Ms. Becky Bell, Maryland State Department of Education. *School system needs and adoption.*
3. Dr. Susan Blunck, University of Maryland Baltimore County. *Secondary education*	4. Ms. Jackie Carrera, Parks and People Foundation. *Baltimore NGO networks.*
5. Dr. Katya Denisova, Baltimore City Public School System. Office of Science. *School system needs and adoption.*	6. Ms. Monica Elser, Arizona State University. CAP Education Coordinator. *LTER education.*
7. Dr. Cindy Hmelo-Silver, Rutgers University. *Science education research.*	8. Mr. Rick Hobbs, Irvine Nature Center. *Informal environmental education*.
9. Mr. George Newberry, Baltimore County Public School System. Office of Science. *School system needs and adoption.*	10. Mr. Jim O'Leary, Maryland Science Center. *Informal science education*.
11. Dr. Mary Rivkin, University of Maryland Baltimore County. *Early childhood education.*	12. Dr. Jane Wolfson, Towson University. *Undergraduate education*.

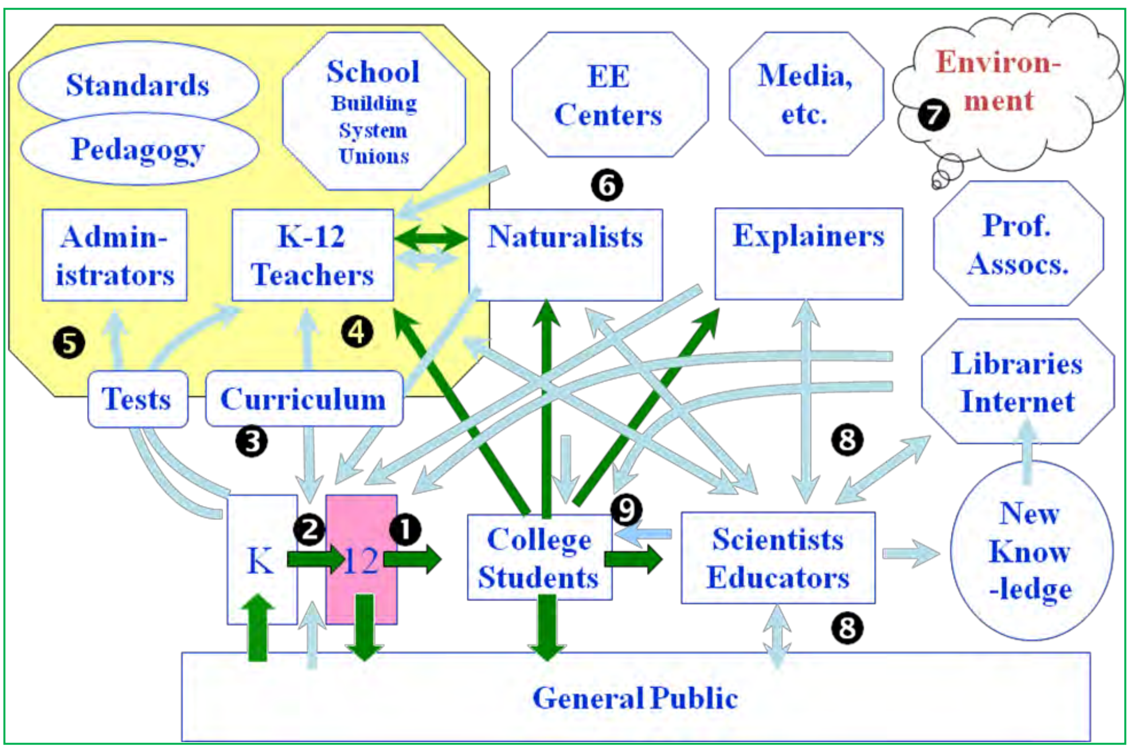


Figure 5.1. The Baltimore Socio-Ecological Education ―System." The framework focuses on the question, ―What determines the socio-ecological literacy of a student graduating from high school (pink 12 box)?" It depicts the interplay between the flow of people through stages and roles (rectangles and green arrows, e.g., students from grades K to 12), key institutions (octagons), resources (rounded rectangles), ideas (ovals, circles) and the flow of information (blue arrows). Many more actors and processes are involved beyond the formal school system (yellow octagon). Numbers in black circles indicate processes and activities that form the core of the BES III Education, Engagement and Outreach Plan and are discussed in Section 5.

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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 Cary Institute of Ecosystem Studies (CIES), 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 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 CIES for chemical analysis. The 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 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 fleet of CIES 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.

Under support of NSF and NOAA, a data analysis and visualization laboratory has recently been completed at CUERE. Included in the hardware for this laboratory are 1 Dell PowerEdge 2950 server connected to a Dell PowerVault MD1000 SATA disk array with 6.5 terabytes of fully mirrored storage, 12 Dell T7400 workstations – each with dual 22 inch widescreen monitors, one HP DesignJet T1000 MFP large format plotter/scanner, and an array of 8 Viewsonic CD4620 46 inch monitors covering approximately 64 square feet and containing approximately 16.6 million pixels. CUERE also houses a Spatial Analysis Laboratory. The laboratory is equipped with a Dell PowerEdge 2550 File/ArcSDE Server connected to a Dell PowerVault 220 SCSI Storage Device, Dell PowerEdge 2950 ArcGIS Server, a Dell PowerVault 120T DLT 7000 Tape Autoloader, 7 high performance 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 Desktop™, ArcGIS Server™ and ArcSDE™. Other spatial analysis products include ERDAS Imagine 8.7 for image analysis, TerraScan™ for LIDAR point classification and analysis and eCognition image analysis software that incorporates object oriented classification techniques.

Analytical facilities at the Cary Institute are state-of-the-art and make possible a wide variety of new as well as ongoing research programs. The Cary Institute's Rachel Carson Analytical Facility is serviced by a Laboratory Information Management System (LIMS) and a Laboratory Document Management System (LDMS). Instrumentation includes a Perkin-Elmer Analyst 300 atomic absorption spectrometer with graphite furnace; Leeman Labs Profile inductively coupled plasma emission spectrometer; CE Elantech Flash EA1112 Elemental Analyzer; Two Dionex ICS-2000 ion chromarographs, one Dionex DX500 ion chromatograph; two high quality Shimadzu UV-visible dual-beam spectrophotometers; a Lachat QuickChem 8000 FIA Ion Analyzer, a Lachat QuickChem 8500 FIA Ion Analyzer and a Milestone Ethos EZ microwave digestion system. General use equipment includes a Shimadzu TOC-V carbon analyzer; Perkin-Elmer LS-50 Luminescence Spectrophtometer and plate reader; Beckman LS6500 scintillation counter; a Turner Designs fluorometer; leaf area meter; optical microscopes; inverted microscope; fluorescence microscopes; glove box; an image analyzer; ultra centrifuge; freeze dryer; drying ovens; rotary evaporator; laminar flow hood; incubators; walk-in cold room; muffle furnace; soil processing equipment; sonicator; temperature baths; turbidimeter; platform shakers; electronic balances (including microbalances); pH meters and electrical conductivity meters.

Additional instrumentation includes a Waters HPLC system with controller, photodiode array detector, auto-sampler and Millenium chromatography analysis software; four Shimadzu model GC-8 gas chromatographs, a Shimadzu model 14A gas chromatograph with thermal conductivity, flame ionization and electron capture detectors and Tekmar-Dorhmann auto-sampler 7000; a Shimadzu model 14A gas chromatograph with TC detector and an additional Lachat QuickChem 8000 FIA Ion Analyzer and Milestone Ethos EZ microwave digestion system.

Postdoctoral Mentoring Plan

M.L. Cadenasso, UC Davis

The subcontract from UC Davis includes 10% support for a Postdoctoral researcher in the first three years of the funding cycle to be based in the Cadenasso lab. Dr. Cadenasso maintains a vibrant lab of graduate and undergraduate students, post-docs, and research technicians. Aside from individual regular meetings with Cadenasso, the lab also meets as a group each week to discuss new journal articles, critique manuscripts in preparation, discuss sampling designs for new experiments, practice upcoming presentations, and encourage and challenge members in the development of their own projects. The lab mentoring philosophy is one that recognizes the integrated and interdisciplinary nature of ecological understanding. Consequently, collaboration is encouraged while at the same time the need to develop focused and rigorous scholarship and skills is reinforced.

Dr. Cadenasso will work with and mentor the postdoctoral researcher. Postdocs are encouraged to develop new research that builds on their existing expertise and skills. Collaborative research development and proposal writing accomplishes this goal. In addition Cadenasso supports participation in local, regional, national and international meetings that can provide opportunities to present research, gain visibility, and interact with potential future collaborators and employers. Opportunities to attend seminars, participate in skill specific workshops, and interact with scholars across disciplinary fields is abundantly available on the UC Davis campus and, when appropriate, participation is encouraged by Cadenasso. The UC Davis Office of Research runs a Responsible Conduct in Research program that holds sessions on a variety of topics (http://www.innovationaccess.ucdavis.edu/home.cfm?id=OVC,10,1622). Attendance will be monitored and completion of the program is recognized by a certificate.

Publications of the Baltimore Ecosystem Study (2004 – 2009)

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http://beslter.org/data_http/biodiversity/vegetation/2003_raw_height.txt	Baltimore Ecosystem Study Permanent Plot Vegetation Sampling, 2003 Height Data
http://beslter.org/data_http/biodiversity/vegetation/2003_raw_sapling.txt	Baltimore Ecosystem Study Permanent Plot Vegetation Sampling, 2003 Sapling Data
http://beslter.org/data_http/biodiversity/vegetation/2003_raw_seedling.txt	Baltimore Ecosystem Study Permanent Plot Vegetation Sampling, 2003 Seedling Data
http://beslter.org/data_http/biodiversity/vegetation/2003_raw_shrub_and_vine.txt	Baltimore Ecosystem Study Permanent Plot Vegetation Sampling, 2003 Shrub and Vine Data
http://beslter.org/data_http/biodiversity/vegetation/2003_raw_trees.txt	Baltimore Ecosystem Study Permanent Plot Vegetation Sampling, 2003 Tree Data
http://beslter.org/data_http/biodiversity/vegetation/2003_spp_list.txt	Baltimore Ecosystem Study Permanent Plot Vegetation Sampling, 2003 Species List
http://beslter.org/frame7-page_1e.html	Baltimore Ecosystem Study Long-Term Study Plot Research Overview
http://beslter.org/frame7-page_1g.html	Baltimore Ecosystem Study Stream Flow and Chemistry Overview
http://beslter.org/frame7-page_1p.html	Baltimore Ecosystem Study Meteorology Overview
http://beslter.org/geodatabase_SAL *	1904 Parks, Baltimore City
	1914 Forest Areas, Baltimore City and
	1915 Forest Areas, Anne Arundel
	1938 Wehling LULC, Gwynns Falls
	1938 Wehling LULC, Gwynns Falls
	1957 Wehling LULC, Gwynns Falls
	1957 Wehling LULC, Gwynns Falls
	1971 Wehling LULC, Gwynns Falls
	1971 Wehling LULC, Gwynns Falls

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL *	1999 high-resolution Land Cover Dataset for Gwynns Falls watershed, MD
	1999 high-resolution Land Cover Dataset for Gwynns Falls watershed, MD
	1999 Wehling LULC, Gwynns Falls
	1999 Wehling LULC, Gwynns Falls
	2004 High-Resolution Land Cover Dataset for Gwynns Falls watershed, MD
	2004 High-Resolution Land Cover Dataset for Gwynns Falls watershed, MD
	Agriculture Land Preservation Foundation Lands
	Agriculture Land Preservation Foundation Lands
	Anne Arundel County Land Use/Land Cover, 2002
	Anne Arundel County Land Use/Land Cover, 2002
	Archeological Sites for Baltimore City
	Archeological Sites, Anne Arundel County
	Archeological Sites, Baltimore County
	Archeological Sites, Carroll County
	Archeological Sites, Harford County
	Assessments and Taxation Database, MD Property View 2004, Anne Arundel County
	Assessments and Taxation Database, MD Property View 2004, Baltimore City
	Assessments and Taxation Database, MD Property View 2004, Baltimore County
	Assessments and Taxation Database, MD Property View 2004, Carroll County
	Assessments and Taxation Database, MD Property View 2004, Harford County
	Baltimore City Land Use/Land Cover, 2000

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL *	Baltimore City Land Use/Land Cover, 2000
	Baltimore City Land Use/Land Cover, 2002
	Baltimore City Land Use/Land Cover, 2002
	Baltimore City Liquor Licenses
	Baltimore City Liquor Licenses
	Baltimore City Parks, Mayor's Office of Information Technology
	Baltimore City Parks, Mayor's Office of Information Technology
	Baltimore City/County DOQs
	Baltimore County Land Use/Land Cover,
	Baltimore County Land Use/Land Cover,
	Baltimore County Parcels, 2007
	Baltimore Land Use/Land Cover, 2002
	Baltimore Land Use/Land Cover, 2002
	Brownfields, Baltimore City
	Building Footprints, Baltimore County
	CAMA Baltimore County, MD, 2007
	CAMA Data, Baltimore City County, MD
	Carroll County Land Use/Land Cover, 2002
	Carroll County Land Use/Land Cover, 2002
	Carroll County Land Use/Land Cover, 2002
	Carroll County Land Use/Land Cover, 2002
	Chesapeake Bay Land Cover Analysis, 1984
	Chesapeake Bay Land Cover Analysis, 1984
	Chesapeake Bay Land Cover Analysis, 1989
	Chesapeake Bay Land Cover Analysis, 1989
	Chesapeake Bay Land Cover Change Analysis 1984 to 1989
	Chesapeake Bay Land Cover Change Analysis 1984 to 1989

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL *	Computer Assisted Mass Appraisal (CAMA) Database, MD Property View 2004, Anne Arundel County
	Computer Assisted Mass Appraisal (CAMA) Database, MD Property View 2004, Baltimore City
	Computer Assisted Mass Appraisal (CAMA) Database, MD Property View 2004, Baltmore County
	Computer Assisted Mass Appraisal (CAMA) Database, MD Property View 2004, Carroll County
	Computer Assisted Mass Appraisal (CAMA) Database, MD Property View 2004, Harford County
	Computer Assisted Mass Appraisal (CAMA) Database, MD Property View 2004, Howard County
	County Parks for the State of Maryland
	County Parks for the State of Maryland
	Crime Risk Database, MSA
	DNR Lands
	DNR Lands
	Drug Centers, Baltimore City
	Emerge 2004 Index, Baisman Run
	Emerge 2004 Index, Baltimore City
	Emerge 2004 Index, Gwynns Falls
	Emerge 2004 Index, Jennifer Branch
	Emerge 2004 Orthophotos Comprehensive Index
	Emerge 2004 Orthophotos Raster Catalog
	Emerge CIR Orthophotos, 1999
	Environmental Trust Lands
	Environmental Trust Lands

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL *	False Natural Color Landsat ETM+ Image, 05 Oct 2001
	Federal Lands
	Forest Legacy Easements
	Garden Survey, Baltimore City
	GDT Roads
	Geocoded Baltimore City Liquor License
	Green Infrastructure
	Green Infrastructure
	Greenways
	Greenways
	Greenways_BACI
	Greenways_BACI
	Gwynns Falls Watershed Land Use, 1973
	Gwynns Falls Watershed Land Use, 1973
	Gwynns Falls Watershed Land Use, 1981
	Gwynns Falls Watershed Land Use, 1981
	Gwynns Falls Watershed Land Use, 1990
	Gwynns Falls Watershed Land Use, 1990
	Gwynns Falls Watershed Land Use, 1997
	Gwynns Falls Watershed Land Use, 1997
	Health Organizations, Baltimore City
	HERCULES Boundary, Baismans Run
	HERCULES Boundary, Baismans Run
	HERCULES, Glyndon
	HERCULES, Glyndon
	HERCULES, McDonogh
	HERCULES, McDonogh
	HERCULES, Rognel Heights

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL *	HERCULES, Rognel Heights
	HERCULES, Watershed 263
	HERCULES, Watershed 263
	Highways, Baltimore City
	Historical Imagery for Gwynns Falls, 1938 Index
	Historical Imagery for Gwynns Falls, 1938 Index
	Historical Imagery for Gwynns Falls, 1938 Index
	Hospitals, Baltimore City
	Housing Statisics by Block Group for Baltimore City and Baltimore County
	Housing Statisics by Block Group for Baltimore City and Baltimore County
	Howard County Land Use/Land Cover,
	Howard County Land Use/Land Cover,
	IKONOS Image (Pan-Shapened, False Natural Color), Baltimore City
	IKONOS Imagery (Pan-Shapened), Baltimore City
	IKONOS Multispectral Imagery (4m), Baltimore City
	Imperviousness, NLCD 2001
	Imperviousness, NLCD 2001
	Infant Mortality, Baltimore, MD; Circa 1880
	Infant Mortality, Baltimore, MD; Circa 1880
	Inventory of Historic Properties, Harford County
	Inventory of Historic Properties, Howard County
	Land Management, MSA
	Land Use by Parcl, Baltimore City

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL *	Land Use for Baltimore City; 1876
	Land Use for Baltimore City; 1876
	Landmarks, Baltimore City
	Landsat ETM+ Image, 05 Oct 2001
	Landsat TM Image, 16 May 1987
	Lawn Expenditure Survey Data, 2003
	Lawn Expenditure Survey Data, 2004
	Lawn Expenditure Survey Data, 2005
	Lawn Expenditure Survey Data, 2007
	Libraries, Baltimore City
	Light Rail Stations, Baltimore City
	Light Rail, Baltimore City
	Light Rail, Baltimore City
	LULC Change: 1970s NALC to 1990s
	LULC Change: 1970s NALC to 1990s
	Major Roads, Baltimore City
	Major Roads, Baltimore City
	Multi-Resolution Land Characteristics (MRLC), 1990s
	Multi-Resolution Land Characteristics (MRLC), 1990s
	Museums, Baltimore City
	National Elevation Dataset (NED) - 10m
	National Elevation Dataset (NED) - 30m
	National Land Cover Data (NLCD), 1992
	National Land Cover Data (NLCD), 1992
	National Land Cover Database (NLCD)
	National Land Cover Database (NLCD)
	National Register of Historic Places, MD
	Newcomer Hotspots, Baltimore City

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL *	North American Landscape Characterization (NALC), 1970s
	North American Landscape Characterization (NALC), 1970s
	Ordinance_master
	Ordinance_parcels
	Ordinance_unmatched
	Parking Facilities, Baltimore City
	Parking Facilities, Baltimore City
	Police Districts, Baltimore City
	Private Conserved Lands
	Private Conserved Lands
	PRIZM data for the MSA, 2003
	PRIZM NE data for the Baltimore MSA,
	Property Parcel Boundaries, 2003 Edition, Baltimore City
	Property Parcel Boundaries, 2003 Edition, Baltimore County
	Property Parcel Boundaries, 2004 Edition, Baltimore City
	Public Right-of-Way Land, 2003, Baltimore City
	Railroads_GDT_MSA
	Recreational Centers, Baltimore City
	Religious Organization Parcels, Baltimore
	Rural Legacy Areas
	Rural Legacy Areas
	School Parcels, Baltimore City
	Schools, Baltimore City
	Street Boundaries, Baltimore City
	Street Centerlines, Baltimore City

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL *	Subway Route, Baltimore City
	Subway Stations, Baltimore City
	SUFA LULC, Baltimore City
	SUFA LULC, Baltimore City
	TIGER Road Network
	Topographic Slope in Degrees (30m)
	Topographic_Map_of_Baltimore_1894_1of6.img
	Topographic_Map_of_Baltimore_1895_index.img
	Topographic_Map_of_Baltimore_1914_index.img
	Tree Canopy, NLCD 2001
	Tree Canopy, NLCD 2001
	Urban Historical Boundaries, 1792
	Urban Historical Boundaries, 1801
	Urban Historical Boundaries, 1822
	Urban Historical Boundaries, 1850
	Urban Historical Boundaries, 1850
	Urban Historical Boundaries, 1878
	Urban Historical Boundaries, 1878
	Urban Historical Boundaries, 1900
	Urban Historical Boundaries, 1900
	Urban Historical Boundaries, 1925
	Urban Historical Boundaries, 1925
	Urban Historical Boundaries, 1938
	Urban Historical Boundaries, 1938
	Urban Historical Boundaries, 1953
	Urban Historical Boundaries, 1953
	Urban Historical Boundaries, 1966

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL *	Urban Historical Boundaries, 1966
	Urban Historical Boundaries, 1972
	Urban Historical Boundaries, 1972
	Urban Historical Boundaries, 1982
	Urban Historical Boundaries, 1982
	Urban Historical Boundaries, 1992
	Urban Historical Boundaries, 1992
	Ward Boundaries for Baltimore City; 1876
	Ward Boundaries for Baltimore City; 1876
	Zoning, Baltimore County
	Zoning, Harford County
	Zoning, Howard County
http://beslter.org/geodatabase_SAL/Boundaries/Boundaries.mdb *	Baltimore City Limits (not coincident with MSA boundary)
	Counties, MSA
	Counties, MSA
	Highways, Baltimore City
	Legislative Districts, Baltimore
	Long Term Sampling Grid, 100 Meters, Baltimore MSA
	Long Term Sampling Grid, 300 Meters, Baltimore MSA
	MSA Boundary
	Neighborhoods, Baltimore City
http://beslter.org/geodatabase_SAL/Cadastral/Cadastral_Planimetric.gdb *	AT_2003_BACI_1
	Buildings_BACI
	CAMA_2003_BACI_1
http://beslter.org/geodatabase_SAL/Cadastral/Housing_Stats.mdb *	BACI2003_ACRES_Stats
	BACI2003_CONSIDR1_A_Stats

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL/Cadastral/Housing_Stats.mdb *	BACI2003_SQFTSTRC_Stats
	BACO2003_ACRES_Stats
	BACO2003_CONSIDR1_A_Stats
	BACO2003_SQFTSTRC_Stats
	Federal Lands
	Forest Legacy Easements
	Garden Survey, Baltimore City
	GF_2004_6cls.lyr
	Urban Historical Boundaries, 1801
	Urban Historical Boundaries, 1822
http://beslter.org/geodatabase_SAL/Census/Census.mdb *	1940 Age Census Data for Baltimore, MD
	1940 Ancestry Census Data for Baltimore,
	1940 Dwellings Census Data for Baltimore, MD
	1940 Education Census Data for Baltimore, MD
	1940 Employment Census Data for Baltimore, MD
	1940 Population Census Data for Baltimore, MD
	1950 Age Census Data for Baltimore, MD
	1950 Ancestry Census Data for Baltimore,
	1950 Dwellings Census Data for Baltimore, MD
	1950 Education Census Data for Baltimore, MD
	1950 Employment Census Data for Baltimore, MD
	1950 Income Census Data for Baltimore, MD
	1950 Marriage Census Data for Baltimore,

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL/Census/Census.mdb *	1950 Population Census Data for Baltimore, MD
	1960 Age Census Data for Baltimore, MD
	1960 Ancestry Census Data for Baltimore,
	1960 Education Census Data for Baltimore, MD
	1960 Employment Census Data for Baltimore, MD
	1960 Household Census Data for Baltimore, MD
	1960 Housing Census Data for Baltimore,
	1960 Income Census Data for Baltimore, MD
	1960 Marital Status Census Data for Baltimore, MD
	1960 Population Census Data for Baltimore, MD
	1960 Race Census Data for Baltimore, MD
	1960 Residence Census Data for Baltimore, MD
	1970 Age Census Data for Baltimore, MD
	1970 Ancestry Census Data for Baltimore,
	1970 Census Data; Education
	1970 Census Data; Employment
	1970 Census Data; Income
	1970 Marriage Census Data for Baltimore,
	1970 Population Census Data for Baltimore, MD
	1980 Census Data; Employment
	1980 Census Data; Income
	1980 Census Data; Population
	1990 Census Data; Employment
	1990 Census Data; Income

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL/Census/Census.mdb *	1990 Census Data; Population
	1990 Census; Age
	1990 Census; Education
	2000 Census; Age
	2000 Census; Education
	2000 Census; Employment
	2000 Census; Income
	2000 Census; Population
	Census Data for 2000 from Geolytics
	Census_Age_1980
	Census_Baltimore_CBSA_BG
	Census_Education_1980
	Census1960table1
	Census1960Table2
	Census1960table3
	Census1960table4
	Census1960table5
	Dwelling Age Statistics by Block Group, Residential Properties, 2005, MSA
	Environmental Behaviors, BES Household Telephone Survey, 2003
	Environmental Improvements, BES Household Telephone Survey, 2003
	Environmental Problems, BES Household Telephone Survey, 2003
	Environmental Satisfaction, BES Household Telephone Survey, 2003
	Geocoded Baltimore City Telephone Survey 2006
	Geocoded Baltimore County Telephone Survey 2006

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL/Census/Census.mdb *	Social Capital for the MSA, 2003
	Social Indices, MSA
http://beslter.org/geodatabase_SAL/Cultural_Features/Cultural_Features.mdb *	A&T DATA, Baltimore City County 2007
	Archeological Sites, Howard County
	Assessments and Taxation Database, MD Property View 2004, Howard County
	AT DATA, Baltimore County, 2007
	Inventory of Historic Properties, Anne Arundel County
	Inventory of Historic Properties, Baltimore County
	Inventory of Historic Properties, Carroll County
	Parks for Baltimore City (Parks & People Foundation)
	Street Tree Data
	SUFA Vegetation, Baltimore City
	Urban Historical Boundaries, 1792
http://beslter.org/geodatabase_SAL/Disamenity/Disamenity.mdb *	Environmental Health Complaints, Baltimore City
	Housing Complaints, Baltimore City, 01/2001
	Housing Complaints, Baltimore City, 02/2001
	Housing Notices, Baltimore City, 01/2001
	Housing Notices, Baltimore City, 02/2001
	HousingComplaintCodes
	HousingNoticeCodes
	Transportation Complaints, Baltimore City, 01/2001
	Transportation Complaints, Baltimore City, 02/2001
	Trash Complaints, Baltimore City, 01/2001

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL/Disamenity/Disamenity.mdb *	Trash Complaints, Baltimore City, 02/2001
	TrashCodes
	Water_SewerComplaintCodes
	Water-Sewer Complaints, Baltimore City, 01/2001
	Water-Sewer Complaints, Baltimore City, 02/2001
	Watersewer_Complaints
	ZBA_parcels
	ZBA_point
	ZBA_unmatched
http://beslter.org/geodatabase_SAL/Disamenity/Ordinance.mdb *	Ordinance_point
http://beslter.org/geodatabase_SAL/lulc/lulc.mdb *	Community Grants, 1996 - 2002
	GF_2004_6cls.lyr
	Parks for Baltimore City (Parks & People Foundation)
	Street Tree Data
	Wehling_Integrated_Codes
	Wehling_Integrated_Codes
	Wehling_Meld_Codes
	Wehling_Meld_Codes
	Wehling_Topology
	Wehling_Topology
http://beslter.org/geodatabase_SAL/lulc/lulc/mdb *	Community Grants, 1996 - 2002
http://beslter.org/geodatabase_SAL/lulc/sufa_veg2r_baci.img *	SUFA Vegetation, Baltimore City
http://beslter.org/geodatabase_SAL/Maps_Historic/Balimore_topo_1914/Topographic_baltimore_1n4w_1914.img *	Topographic_Map_of_Baltimore_1914_2of7.img

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL/Maps_Historic/Balimore_topo_1914/Topographic_baltimore_1s3w_1914.img *	Topographic_Map_of_Baltimore_1914_3of7.img
http://beslter.org/geodatabase_SAL/Maps_Historic/Balimore_topo_1914/Topographic_baltimore_2s1w_1914.img *	Topographic_Map_of_Baltimore_1914_4of7.img
http://beslter.org/geodatabase_SAL/Maps_Historic/Balimore_topo_1914/Topographic_baltimore_2s-2w_1914.img *	Topographic_Map_of_Baltimore_1914_5of7.img
http://beslter.org/geodatabase_SAL/Maps_Historic/Balimore_topo_1914/Topographic_baltimore_2s3w_1914.img *	Topographic_Map_of_Baltimore_1914_6of7.img
http://beslter.org/geodatabase_SAL/Maps_Historic/Balimore_topo_1914/Topographic_baltimore_3s1and2w_1914.img *	Topographic_Map_of_Baltimore_1914_7of7.img
http://beslter.org/geodatabase_SAL/Maps_Historic/Baltimore_topo_1894_1896/Topographic_baltimore_1n-4w_1895.img *	Topographic_Map_of_Baltimore_1895_2of6.img
http://beslter.org/geodatabase_SAL/Maps_Historic/Baltimore_topo_1894_1896/Topographic_baltimore_1s-3w_1895.img *	Topographic_Map_of_Baltimore_1895_3of6.img
http://beslter.org/geodatabase_SAL/Maps_Historic/Baltimore_topo_1894_1896/Topographic_baltimore_1s-4w_1895.img *	Topographic_Map_of_Baltimore_1895_4of6.img
http://beslter.org/geodatabase_SAL/Maps_Historic/Baltimore_topo_1894_1896/Topographic_baltimore_2s-2w_1895.img *	Topographic_Map_of_Baltimore_1896_5of6.img
http://beslter.org/geodatabase_SAL/Maps_Historic/Baltimore_topo_1894_1896/Topographic_baltimore_2s-3w_1895.img *	Topographic_Map_of_Baltimore_1895_6of6.img
http://beslter.org/geodatabase_SAL/Soils/Soils.mdb *	Soil_Samples_BACI
	Soils, Baltimore County
	SURRGO Mapunit Aggregated Attributes
http://beslter.org/geodatabase_SAL/Topography/LIDAR_BareEarth_Baisman.img *	LIDAR, Bare Earth, Baisman
http://beslter.org/geodatabase_SAL/Topography/LiDAR_BareEarth_GF.img *	LiDAR, Bare Earth, Gwynns Falls

OnlineLinkage	Title
http://beslter.org/geodatabase_SAL/Topography/LiDAR_FirstReturn_Baisman.img *	LiDAR_FirstReturn_Baisman.img
http://beslter.org/geodatabase_SAL/Topography/LiDAR_FirstReturn_GF.img *	LiDAR, First Return, Gwynns Falls
http://beslter.org/geodatabase_SAL/Transportation/Transportation.mdb *	GDT Roads
	Light Rail Stations, Baltimore City
	Railroads_GDT_MSA
	Street Boundaries, Baltimore City
	Street Centerlines, Baltimore City
	Subway Route, Baltimore City
	Subway Stations, Baltimore City
	TIGER Road Network
http://beslter.org/geodatabase_SALMaps_Historic/Balimore_topo_1914/Topographic_baltimore_1n3w_1914.img *	Topographic_Map_of_Baltimore_1914_1of7.img
http://beslter.org/http://md.water.usgs.gov/BES/wxcbhl/index.html	Climate and Meteorology, Precipitation Data, Station Locations, Photographs, Equipment (USGS): Station: Rain Gauge, Cub Hill (CBHL)
http://beslter.org/pub/soil/bes-riparian-water-table-data-for-www.xls	Soil Long-Term Monitoring of Riparian Water Table Depth (Spreadsheet))
http://beslter.org/pub/soil/bes-riparian-water-table-data-for-www-text.txt	Soil Long-Term Monitoring of Riparian Water Table Depth (Text)
http://beslter.org/pub/soil/bes-soil-moisture-data-for-the-www.xls	Soil Moisture Data (Spreadsheet)
http://beslter.org/pub/soil/bes-soil-moisture-data-for-the-www-text.txt	Soil Moisture Data (Text)
	Soil moisture in long-term study plots
http://beslter.org/pub/soil/bes-soil-nitrogen-cycle-data-for-www-text.txt	Soil nitrogen cycle variables
http://beslter.org/pub/soil/bes-trace-gas-collection-file-for-www-text.txt	Soil:atmosphere fluxes of carbon dioxide, nitrous oxide and methane
http://beslter.org/pub/soil/lysimeter-data-for-www-February-2007-text.txt	Soil solution chemistry data from long-term study plots

OnlineLinkage	Title
http://beslter.org/pub/soil/soil_temperature/Hillsdale_1.txt	Soil: Temperature Data - Hillsdale
http://beslter.org/pub/soil/soil_temperature/Leakin_1.txt	Soil: Temperature Data - Leakin 1
http://beslter.org/pub/soil/soil_temperature/Leakin_2.txt	Soil: Temperature Data - Leakin 2
http://beslter.org/pub/soil/soil_temperature/McDonogh_1_1_of_2.txt	Soil: Temperature Data - McDonogh - 2000/07/07 - 2004/11/11
http://beslter.org/pub/soil/soil_temperature/McDonogh_1_2_of_2.txt	Soil: Temperature Data - McDonogh - 2005/08/08 -
http://beslter.org/pub/soil/soil_temperature/McDonogh_2.txt	Soil: Temperature Data - McDonogh 2
http://beslter.org/pub/soil/soil_temperature/Oregon_Ridge_Middle_1.txt	Soil: Temperature Data - Oregon Ridge Middle 1
http://beslter.org/pub/soil/soil_temperature/Oregon_Ridge_Middle_2.txt	Soil: Temperature Data - Oregon Ridge Middle 2
http://beslter.org/pub/soil/soil_temperature/Oregon_Ridge_Upper_1.txt	Soil: Temperature Data - Oregon Ridge Upper 1
http://beslter.org/pub/soil/soil_temperature/Oregon_Ridge_Upper_2.txt	Soil: Temperature Data - Oregon Ridge Upper 2
http://beslter.org/pub/soil/soil_temperature/UMBC1.txt	Soil: Temperature Data - UMBC 1
http://beslter.org/pub/soil/soil_temperature/UMBC2.txt	Soil: Temperature Data - UMBC 2
http://beslter.org/pub/soil/ufore_soil.txt	Soil chemical data for Baltimore City
http://beslter.org/pub/stream/upper_gwynns_falls_tributaries_final_chemistry_for_www_text.txt	Stream chemistry data for Upper Gwynns Falls tributary watersheds
http://hiscentral.cuahsi.org/pub_network.aspx?n=121	CUAHSI Water Data Service: Baltimore Ecosystem Study Precipitation Data
http://hiscentral.cuahsi.org/pub_network.aspx?n=68	Baltimore Waters Test Bed Ground Water Level Data
http://hiscentral.cuahsi.org/pub_network.aspx?n=70	CUAHSI Water Data Service: Baltimore Ecosystem Study Stream Chemistry Data
http://hiscentral.cuahsi.org/pub_network.aspx?n=71	CUAHSI Water Data Service: Baltimore Ecosystem Study Stream Soil Data

OnlineLinkage	Title
http://md.water.usgs.gov/BES/wxcmnc/index.html	Climate and Meteorology, Precipitation Data, Station Locations, Photographs, Equipment (USGS): Station: Rain Gauge, Carrie Murray Nature Center (CMNC)
http://md.water.usgs.gov/BES/wxcpgc/index.html	Climate and Meteorology, Precipitation Data, Station Locations, Photographs, Equipment (USGS): Station: Rain Gauge, Carrol Park Golf Course (CPGC)
http://md.water.usgs.gov/BES/wxcvpg/index.html	Climate and Meteorology, Precipitation Data, Station Locations, Photographs, Equipment (USGS): Station: Rain Gauge at Cromwell Valley Park near Glen Arm, MD
http://md.water.usgs.gov/BES/wxgdes/index.html	Climate and Meteorology, Precipitation Data, Station Locations, Photographs, Equipment (USGS): Station: Rain Gauge at Glyndon Elementary School at Glyndon,
http://md.water.usgs.gov/BES/wxgybk/index.html	Climate and Meteorology, Precipitation Data, Station Locations, Photographs, Equipment (USGS): Station: Rain Gauge near Delight, MD (GYBK)
http://md.water.usgs.gov/BES/wxmcdo/index.html	Climate and Meteorology, Precipitation Data, Station Locations, Photographs, Equipment (USGS): Station: WXMCDO: Weather Station at McDonogh, MD
http://md.water.usgs.gov/BES/wxordg/index.html	Climate and Meteorology, Precipitation Data, Station Locations, Photographs, Equipment (USGS): Rain Gauge at Oregon Ridge, MD (ORDG)
http://md.water.usgs.gov/BES/wxumbc/index.html	Climate and Meteorology, Precipitation Data, Station Locations, Photographs, Equipment (USGS): Rain Gauge at UMBC Campus near Arbutus, MD (UMBC)
http://SoilDataMart.nrcs.usda.gov/	Soil Survey Geographic (SSURGO) database for City of Baltimore, Maryland
http://waterdata.usgs.gov/md/nwis/nwisman?site_no=01583570	Streamflow - Small watersheds - Small Watershed 1. Pond Branch. This is a completely forested
http://waterdata.usgs.gov/md/nwis/nwisman?site_no=01589180	Streamflow - Longitudinal Sites Along The Gwynns Falls - Boundary Station 1. Gwynns Falls at Glyndon

OnlineLinkage	Title
http://waterdata.usgs.gov/md/nwis/nwisman?site_no=01589180	Streamflow - Small watersheds - Small Watershed 4. Glyndon. Boundary station #1 (described above) also serves as a small watershed, draining approximately 96 ha of mixed rural and old suburban land use.
http://waterdata.usgs.gov/md/nwis/nwisman?site_no=01589197	Streamflow - Longitudinal Sites Along The Gwynns Falls - Boundary Station 2. Gwynns Falls at Gwynnbrook/Delight
http://waterdata.usgs.gov/md/nwis/nwisman?site_no=01589238	Streamflow - Small watersheds - Small Watershed 2. McDonogh School. This is a completely agricultural
http://waterdata.usgs.gov/md/nwis/nwisman?site_no=01589300	Streamflow - Longitudinal Sites Along The Gwynns Falls - Boundary Station 3. Gwynns Falls at Villa Nova
http://waterdata.usgs.gov/md/nwis/nwisman?site_no=01589330	Streamflow - Small watersheds - Small Watershed 3. Dead Run at Franklintown. The site samples high density urban residential land use.
http://waterdata.usgs.gov/md/nwis/nwisman?site_no=01589352	Streamflow - Longitudinal Sites Along The Gwynns Falls - Boundary Station 4. Gwynns Falls at Route 1/Carroll Park
http://www.beslter.org/pub/stream/Baismans_Run_final_chemistry_WWW_nov2009.txt	Stream chemistry data for Baisman Run (forested/suburban) watershed
http://www.beslter.org/pub/stream/Carroll_Park_final_chemistry_WWW_nov2009.txt	Stream chemistry for Gwynns Falls at Carroll Park/Route 1 (urban) watershed
http://www.beslter.org/pub/stream/Cub_Hill_sites_final_chemistry_WWW_nov2009.txt	Stream chemistry for Cub Hill (suburban, tower flux site) sites
http://www.beslter.org/pub/stream/Dead_Run_final_chemistry_WWW_nov2009.txt	Stream chemistry data for Dead Run (urban) watershed
http://www.beslter.org/pub/stream/Glyndon_final_chemistry_WWW_nov2009.txt	Stream chemistry for Gwynns Falls at Glyndon (suburban) watershed
http://www.beslter.org/pub/stream/Gwynnbrook_final_chemistry_WWW_nov2009.txt	Stream chemistry for Gwynns Falls at Gwynnbrook (suburban) watershed
http://www.beslter.org/pub/stream/Gwynns_Run_final_chemistry_WWW_nov2009.txt	Stream chemistry for Gwynns Run (urban) watershed
http://www.beslter.org/pub/stream/Maidens_Choice_final_chemistry_nov2009.txt	Stream chemistry data for Maidens Choice Run (urban) watershed
http://www.beslter.org/pub/stream/McDonogh_final_chemistry_WWW_nov2009.txt	Stream chemistry data for McDonogh (agricultural) watershed

OnlineLinkage	Title
http://www.beslter.org/pub/stream/Pond_Branch_final_chemistry_WWW_nov2009.txt	Stream chemistry data for Pond Branch (forested reference) watershed
http://www.beslter.org/pub/stream/Rognel_Heights_final_chemistry_WWW_nov2009.t	Stream chemistry data for Rognel Heights (urban) watershed
http://www.beslter.org/pub/stream/Villa_Nova_final_chemistry_WWW_nov2009.txt	Stream chemistry for Gwynns Falls at Villa Nova (urban/suburban) watershed
http://www.beslter.org/pub/stream/W263_final_chemistry_WWW_nov2009.txt	Stream chemistry for watershed 263 (urban) sites
http://www.ecostudies.org/bes	Research Frontiers and their Applications for Water Resources Infrastructure in Urban Watersheds: Making the connection between human and hydro-ecological
http://www.ecostudies.org/bes/pub/hef_multiscale_policy_inventory.xls	Policy Inventory for Baltimore Maryland USA
http://www.ecostudies.org/pub/bes_206.zip	BES Reference Meteorological Station Data
http://www.ecostudies.org/pub/besgis/gfutm301.zip	Stream and Watershed Studies - GIS - 30 Meter Digital Elevation Model of GFW
http://www.ecostudies.org/pub/besgis/rbdata/gfbaltw2_sp.zip	Soil Studies - GIS - Southeast GFW wetlands in Baltimore County
	Stream and Watershed Studies - GIS - SE county Gwynns Falls watershed wetlands for Baltimore county
http://www.ecostudies.org/pub/besgis/rbdata/gfbaltwe_sp.zip	Soil Studies - GIS - Southeast GFW wetlands in Baltimore City
	Stream and Watershed Studies - GIS - SE city Gwynns Falls watershed wetlands for Baltimore city
http://www.ecostudies.org/pub/besgis/rbdata/gfbnd_sp.zip	Stream and Watershed Studies - GIS - Boundary - Gwynns Falls Watershed (GFW) Boundary
http://www.ecostudies.org/pub/besgis/rbdata/gfbndinv_sp.zip	Stream and Watershed Studies - GIS - Boundary - Masking coverage to isolate the GFW from surroundings
http://www.ecostudies.org/pub/besgis/rbdata/gfcockey_sp.zip	Soil Studies - GIS - Northeast GFW wetlands
http://www.ecostudies.org/pub/besgis/rbdata/gfelicot_sp.zip	Soil Studies - GIS - Southwest GFW

OnlineLinkage	Title
http://www.ecostudies.org/pub/besgis/rbdata/gfpatap_sp.zip	Stream and Watershed Studies - GIS - Gwynns Falls Watershed Streams
http://www.ecostudies.org/pub/besgis/rbdata/gfreiste_sp.zip	Soil Studies - GIS - Northwest GFW
http://www.ecostudies.org/pub/besgis/rbdata/gfwshed_sp.zip	Stream and Watershed Studies - GIS - Boundary - GFW subwatershed boundaries
http://www.ecostudies.org/pub/besgis/rbdata/patstr_sp.zip	Stream and Watershed Studies - GIS - Patapsco Watershed Streams
http://www.ecostudies.org/pub/besgis/rbdata/patwshed_sp.zip	Stream and Watershed Studies - GIS - Boundary - GFW subwatershed boundaries
http://www.ecostudies.org/pub/besveg/riparian.zip	RIPARIAN VEGETATION OF THE GWYNNS FALLS WATERSHED
http://www.ecostudies.org/pub/besveg/upland.zip	UPLAND VEGETATION IN GWYNNS FALLS WATERSHED
http://www.umbc.edu/cuere/BaltimoreWTB/index.html	Baltimore WATERS Test Bed. Center for Urban Environmental Research and Education CUER

* Part of a Geodatabase and requires ESRI ArcGIS software