COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./DUE DATE NSF 15-596 03/04/16	☐ Special Exception to Deadline Date Policy	FOR NSF USE ONLY NSF PROPOSAL NUMBER **1637661**
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
03/04/2016	1	08010000 DEB	1195	781388392	05/05/2016 12:12pm S

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS ☒ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)
223232968	1027188	

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 PRIMARY PLACE OF PERF Institute of Ecosystem Studies	ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE Institute of Ecosystem Studies NY ,125450129 ,US.

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 **LTER: Dynamic heterogeneity: Investigating causes and consequences of ecological change in the Baltimore urban ecosystem**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 6,762,000	72 months	11/01/16	

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)
- ☒ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date 09/17/15
  PHS Animal Welfare Assurance Number A4242-01
- ☒ FUNDING MECHANISM Research - other than RAPID or EAGER
- ☒ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number FWA00013876
  Exemption Subsection ____ or IRB App. Date 05/12/15
- ☐ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
- ☒ COLLABORATIVE STATUS
  A collaborative proposal from one organization (GPG II.D.4.a)

PI/PD DEPARTMENT Cary Institute	PI/PD POSTAL ADDRESS 2801 Sharon Turnpike Box AB MILLBROOK, NY 125450129 United States
PI/PD FAX NUMBER 845-677-5976	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Email Address
PI/PD NAME Emma J Rosi-Marshall	PhD	2002		
CO-PI/PD Peter M Groffman	PhD	1984		
CO-PI/PD J. Morgan Grove	PhD	1996		
CO-PI/PD Steward Pickett	PhD	1977		
CO-PI/PD Claire Welty	PhD	1989		

PROJECT SUMMARY

Overview:

The proposed research addresses three general questions that reflect the synthetic nature of human and urban ecosystems: 1) How do the dynamics of hydrology, biogeochemistry, and social heterogeneity affect watershed nutrient retention and contaminant processing, i.e., ecosystem fluxes; 2) How do the composition and organization, i.e. community organization, of the biotic capital of ecosystems reflect biophysical and social processes; 3) How do the choices that people and institutions make about where to locate and how to manage their land interact with fluxes and biotic community organization? These questions emerge from fundamental theories such as limiting nutrient retention in ecosystems, ecosystem/biodiversity and metacommunity theory, and economic locational choice theory. Long-term data collection has led to a new conceptual framework built around dynamic heterogeneity, which we define as a suite of interacting spatial mosaics in the biophysical and social realms that change over time. Prior research provides evidence that in urban ecosystems causes and consequences of ecological and social change are a result of this dynamic heterogeneity, hence it is the central theme of our proposed research. Research in BES will continue key long-term data sets on stream and watershed function, biodiversity of plants, animals, and microbes, and human resource use and social structure. It will add pulses of spatially extensive field sampling to understand 1) the heterogeneity of watershed/landscape linkages, 2) the role of management and functional diversity in plant and insect communities, and 3) the evaluation of both market and non-market locational decisions. The pulse sampling will be repeated over the long-term. Integration will be enhanced via these spatially coordinated, interdisciplinary field pulses, focus by all disciplines on three shared watersheds, continued refinement of ecohydrological models in social contexts, and novel application of statistical network modeling employing long-term data from our linked disciplines and sites to investigate long-term change.

Intellectual Merit :

Long-term ecological research has improved the understanding of slow and episodic processes in ecosystems. Landscape ecology and land change science have focused on the significance of spatial heterogeneity or patchiness as drivers of ecological processes, rather than a mere methodological nuisance. These usually independent ecological research traditions emphasize time and space, respectively. There is an urgent need to bring these two approaches together to better understand ecosystem structure and function in an era of human-accelerated environmental change and burgeoning regional and global connectivity. Urban systems provide 1) a unique venue to join the study of intensive temporal change and extensive spatial differentiation as a fundamental ecological principle, and 2) an effective platform to explore the reciprocal linkage between ecosystem science and landscape science. BES will investigate how extensive spatial heterogeneity in biophysical and social processes affect one another, and how the interaction generates new patterns that alter the nature and magnitude of social and environmental change over the long-term. Heterogeneity is used as a unifying theme because, in general terms, it can operate as both a cause and a consequence of the interactions in coupled human-natural systems, of which urban ecosystems are the epitome. We employ the shorthand of "dynamic heterogeneity" to reflect the interdisciplinary and long-term nature of spatial differentiation as both cause and consequence of ecological processes.

Broader Impacts :

Broader impacts reside in three areas: 1) Enhanced engagement with local and regional sustainability plans and the agencies implementing them; 2) New formal curricular and teacher-training relationships with a majority African American school system; and 3) Intensive training and mentoring of small groups of students, including a large proportion of underserved groups, in social-ecological research. These intensive programs will focus on two audiences: environmental magnet high and middle schools, and on a broad pool of youth from the entire city for a summer program.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.B.2.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

LTER: Dynamic heterogeneity: Investigating causes and consequences of ecological change in the Baltimore urban ecosystem

INTRODUCTION

The Baltimore Ecosystem Study (BES) began in 1998 with three questions aimed to advance understanding of cities as an ecosystem type. We asked about: 1) Structure: What is the spatial and temporal patch structure of socio-economic, ecological and physical factors in the urban ecosystem; 2) Function: What are the fluxes of energy, matter, capital and populations in the urban ecosystem; and 3) People: What are the choices they make about their environment. We initiated long-term data collection in these areas guided by a conceptual model based on patch dynamics, i.e. that there are coherent relationships among ecological, socio-political, and physical patch structures within an urban ecosystem that control ecological functions related to the fluxes of water, nutrients and carbon, and biodiversity. Long-term data collection has driven the evolution of our ideas from patches to a more general theory of heterogeneity in cities. Heterogeneity is used as a unifying theme because it operates as both a cause and a consequence of the interactions in coupled human-natural systems, of which urban ecosystems are the epitome. This is in contrast to treating heterogeneity as noise or as simply a static outcome of ecological process.

We now propose to investigate how extensive spatial heterogeneity in biophysical and social processes affect one another, and how the interaction generates new patterns that alter the nature and magnitude of environmental change over time. Our past and proposed research are organized around three research focal areas: 1) the flows of materials; 2) community assembly and differential biotic performance; and 3) the choices that people and institutions make affecting the built environment (Fig 1). Research in these focal areas facilitates collection of data that encompasses LTER core areas of research (primary production, population studies, movement of organic matter, movement of inorganic matter and disturbance patterns). In our proposed research, collection, analysis and interpretation of data in these core areas will be driven by three integrative research questions: 1) How does dynamic hydrological, biogeochemical and social heterogeneity influence watershed nutrient retention? 2) How does dynamic heterogeneity in biophysical and social processes across the urban landscape influence biotic community assembly and diversity? 3) How do the choices people make about where they live and how they use and manage their land interact with dynamic heterogeneous ecological conditions?

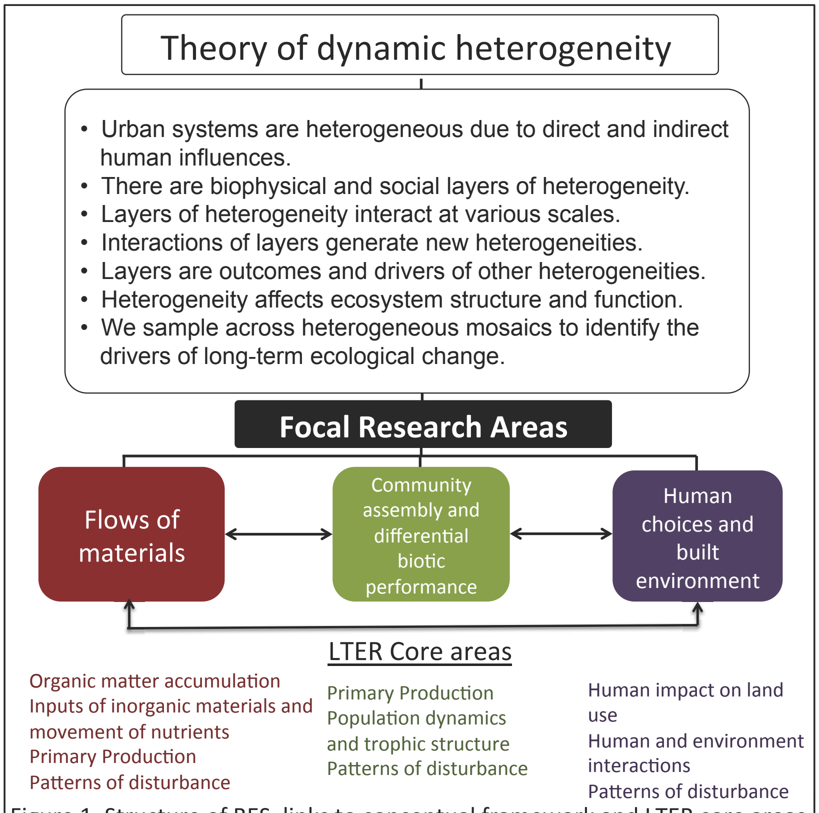


Figure 1. Structure of BES, links to conceptual framework and LTER core areas.

SECTION 1: RESULTS FROM PRIOR SUPPORT

In this section we present our main findings and publications (Table 1) and highlight how long-term data collection, quantitative analysis and modeling of those data have inspired the research we propose to conduct in the next phase of BES. Since 2010, BES LTER research has resulted in ca. 192 journal articles, 47 book chapters and 9 books.

BES Approach to characterizing urban ecosystems: From the beginning, a primary theme of BES has been to characterize the spatial and temporal heterogeneity of the integrated social-ecological system, and investigate how that heterogeneity influences ecological and social processes (Troy et al. 2007, Grove et al. 2015a). We have improved methods for characterizing urban heterogeneity using remote sensing and geographic information systems (Cadenasso et al. 2007, Zhou et al. 2009a, 2010, 2014, Zhou and Cadenasso 2012) and tested how they can improve our understanding of ecological processes and ecological theory (Cadenasso et al. 2008, Smith et al. 2010, Huang et al. 2011, Zhou et al. 2011a, b, Schwarz et al. 2012, 2013). This work has set the stage for dynamic heterogeneity to frame the next phase of BES. We define **dynamic heterogeneity** as *a suite of interacting spatial mosaics in the biophysical and social realms that change over time.* Our prior research provides evidence that in urban ecosystems, causes and consequences of ecological and social change are a result of this dynamic heterogeneity, hence it is the central theme of our proposed research.

Table 1. 10 most significant publications from BES III (2010 – 2016):

- Bettez . et al. 2015. Climate variation overwhelms efforts to reduce nitrogen delivery to coastal waters. Ecosystems **Submitted**.
- Bettez and Groffman. 2013. Nitrogen deposition in and near an urban ecosystem. Environmental Science & Technology **47**:6047-6051.
- Grove et al. 2015. The Baltimore School of Urban Ecology: Space, Scale, and Time for the Study of Cities. Yale University Press, New Haven.
- Hager et al. 2013. Socio-ecological revitalization of an urban watershed. Frontiers in Ecology and the Environment **11**:28-36.
- Kaushal et al. 2011. Tracking nonpoint source nitrogen pollution in human-impacted watersheds. Environmental Science & Technology **45**:8225-8232.
- Pickett et al. 2013. Ecological science and transformation to the sustainable city. Cities **32**:S10-S20.
- Pickett et al. 2011. Urban ecological systems: Scientific foundations and a decade of progress. Journal of Environmental Management **92**:331-362.
- Romolini et al. 2013. Assessing and comparing relationships between urban environmental stewardship networks and land cover in Baltimore and Seattle. Landscape and Urban Planning **120**:190-207.
- Rosi-Marshall and Royer. 2012. Pharmaceutical compounds and ecosystem function: An emerging research challenge for aquatic ecologists. Ecosystems **15**:867-880.
- Zhou et al. 2011. 90 years of forest cover change in an urbanizing watershed: spatial and temporal dynamics. Landscape Ecology **26**:645-659.

1) The flow of materials: BES research on fluxes has been rooted in the watershed approach (Bormann and Likens 1969, Fisher 1992), which allows us to compare urban, suburban and exurban ecosystems with the less human-dominated systems in the LTER network. Watershed studies in BES have used 10 core long-term stream sampling sites (Fig. 20 for map) to represent exurban, suburban and urban watersheds, as well as forested and agricultural reference sites. Since 1998, we have continuous data on stream stage and discharge as part of our collaboration with USGS, and weekly water samples for analysis of nitrate, phosphate, total nitrogen, total phosphorus, chloride, sulfate, turbidity, temperature, dissolved oxygen and pH. Continuous meteorological and energy flux data (Smith et al. 2012, Ramamurthy et al. 2014) support watershed analysis and modeling (Smith et al. 2013).

We have observed distinct differences in streamwater nitrate concentrations (a prime agent of eutrophication in Chesapeake Bay) among streams draining forested reference, suburban, and agricultural watersheds (Fig 2A). While we expected these differences to be driven strongly by variation in impervious surface, climate and nitrogen inputs, controlling factors have proven to

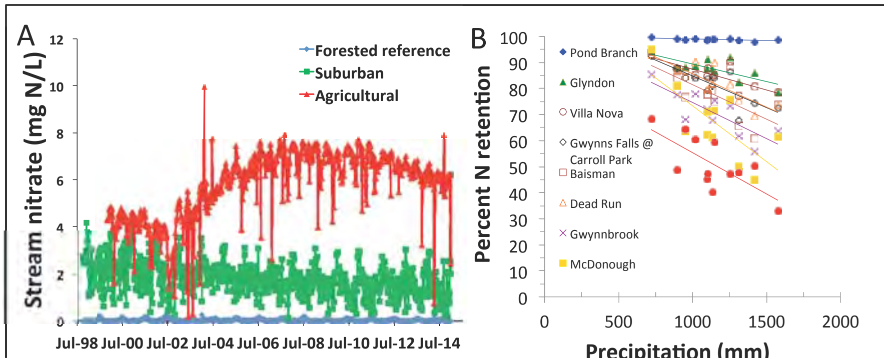


Figure 2. Nitrate concentrations (A) in streams draining forested, suburban and agricultural watersheds sampled weekly from October 1998 through October 2012 and watershed nitrogen retention versus precipitation (B) for forested (Pond Branch), suburban (Glyndon, Villa Nova, Baisman, Gwynnbrook), urban (Carroll Park, Dead Run, Rognel Heights) and agricultural (McDonogh) watersheds in the Baltimore metropolitan area from 1998 – 2011.

be much more complex, motivating our new focus on dynamic heterogeneity (Cadenasso et al. 2007, Kaushal et al. 2011, Schwartz and Smith 2014, Bettez et al. 2015). Long-term estimates of nitrate and total nitrogen export are compared with inputs from the atmosphere, fertilizer, food and other sources to compute watershed budgets and to calculate watershed nitrogen retention. Watershed N retention is generally much higher (often > 70%) than we initially expected, suggesting that vast amounts of anthropogenically-derived N are processed, stored and retained in urban, suburban and exurban watersheds (Fig 2B) (Groffman et al. 2004, Kaushal et al. 2008a, 2011, Duan et al. 2012, Kaushal et al. 2014a, Newcomer Johnson et al. 2014, Pennino et al. 2014, Bettez et al. 2015). The factors controlling this retention, and their heterogeneity, underlie watershed dynamics.

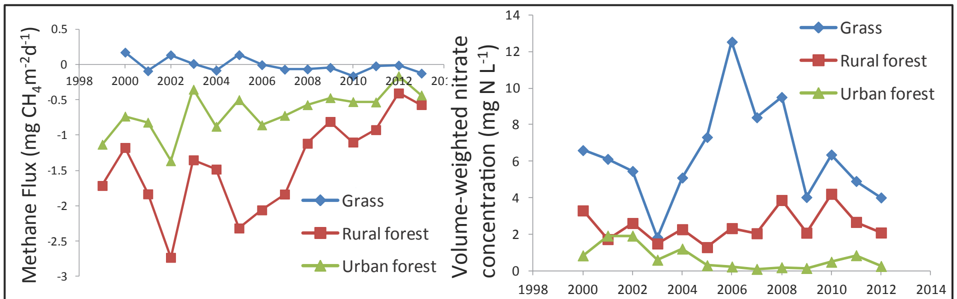


Figure 3. Mean annual (based on monthly sampling) soil:atmosphere CH_4 flux (A) and volume-weighted nitrate concentrations in leaching water from BES long-term rural forest, urban forest and urban grassland plots.

Observations of surprisingly high nitrogen retention have raised questions about the magnitude of key ***sources*** of nitrogen in urban and suburban ecosystems and have influenced the evolution of our ideas about how heterogeneity influences whole watershed retention. We have quantified inputs from the atmosphere (Bettez and Groffman 2013) and used stable isotope analyses of oxygen and nitrogen in streamwater nitrate to determine whether this and other sources of nitrogen (e.g., sewage) move into streams (Kaushal et al. 2011). Water balances of 65 gaged watersheds in the Baltimore metropolitan area (Bhaskar and Welty 2012) showed that there can be large water fluxes exiting watersheds due to infiltration and inflow (I&I) of precipitation and groundwater into sanitary sewers. For two watersheds where I&I were monitored, these fluxes exceeded average annual streamflow.

The high nitrogen retention has led us to discover ***sinks*** for nitrogen in lawns, riparian zones and streams. Combining social survey and biogeochemistry data showed that while fertilizer is a significant input (~15 kg N ha^{-1} y^{-1}) in suburban watersheds as a whole, only ~50% of lawns are fertilized (Law et al. 2004, Carrico et al. 2012, Fraser et al. 2013). Furthermore, retention of added nitrogen is high (Raciti et al. 2008, 2011a, 2011b, 2011c), and leaching losses and nitrous oxide fluxes are relatively low (Groffman et al. 2009, Martinez et al. 2014) (Fig 3). Nitrogen inputs have eliminated methane uptake by lawns (Groffman and Pouyat 2009, Costa and Groffman 2013), a result consistent with those from other LTER sites (Fig 3). Soil functions and threats to human health in lawns also are likely affected by hotspots of lead contamination, which are common in residential areas (Schwarz et al. 2012, 2013).

Long-term data on riparian water tables and nutrient concentrations (Fig 4) show that hydrologic changes associated with urbanization have unexpectedly converted these areas from sinks to sources of nitrogen in the urban landscape. These changes lead to lower water tables in riparian zones, disrupting the interactions among hydrologic, soil, vegetation and microbial factors that control riparian nitrate removal processes (Groffman et al. 2002, Groffman et al. 2003, Gift et al. 2010, Harrison et al. 2011, Bettez and Groffman 2012, Harrison et al. 2012b, Cui et al. 2014, Harrison et al. 2014, Waters et al. 2014).

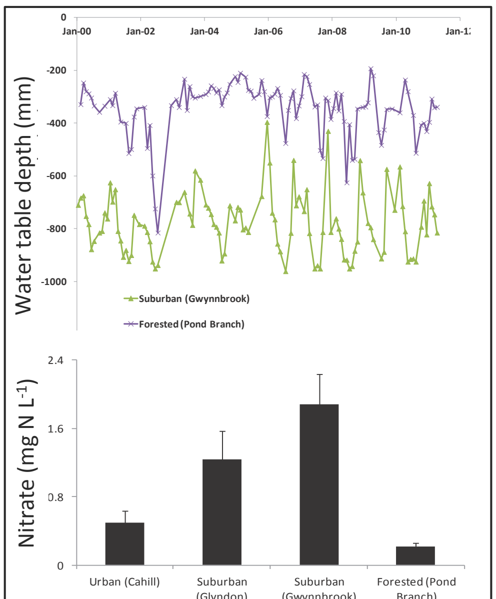


Figure 4. Long-term water table depth and groundwater nitrate concentrations in forest, suburban and urban riparian zones.

The search for nitrogen sources and sinks has also produced surprising results in streams. The physical degradation and burial of urban stream channels suggest that their potential to function as nitrogen sinks is minimal (Elmore and Kaushal 2008, Kaushal and Belt 2012). However, long-term data and detailed studies suggest that there are dynamic transformations and significant potential for nitrogen retention in daylighted urban streams (Kaushal et al. 2008b, Klocker et al. 2009, Mayer et al. 2010, Sivirichi et al. 2011, Harrison et al. 2012a, Newcomer et al. 2012, Duan et al. 2014, Kaushal et al. 2014a, 2014b, Newcomer Johnson et al. 2014, Pennino et al. 2014, Kaushal et al. 2015). We hypothesize that retention is driven by heterogeneity within and among streams and is amplified by stream and riparian restoration.

We have also demonstrated that pharmaceutical and personal care products (PPCPs) occur in suburban and urban streams, providing further evidence for contamination by sewage. More fundamentally, our results suggest that these compounds have significant effects on ecosystem processes and services. We have detected a range of compounds including antibiotics and illicit drugs (e.g. amphetamines, morphine from heroine use; Lee et al. *in review*) and demonstrated that these compounds alter primary production and nutrient cycling in urban streams (Rosi-Marshall and Royer 2012, Rosi-Marshall et al. 2013, 2015, Lee et al. *in review*). These compounds also appear to increase antibiotic-resistant bacteria in urban stream communities and thus may pose a threat to human health (Rosi-Marshall and Kelly 2015).

2) Community assembly and differential biotic performance. Ideas about biotic communities in Baltimore and in cities across the world have evolved markedly over the past 15 years from an assumption that biodiversity is low in urban areas to a realization that these communities are diverse and dynamic and have significant effects on fluxes of water, energy, carbon and nutrients and human well-being (Swan et al. 2011, Szlavecz et al. 2011). In BES, we have investigated community assembly, controls on biodiversity, and the heterogeneity of biota across the metropolitan area. These three processes result from contrasting life history attributes, species distribution, and community composition. The differences in biota across the metropolis can affect ecosystem functioning. We have focused on specific groups of organisms because of their ecological roles: plants and soil fauna because of their effects on production and decomposition, birds as integrators of larger landscape patterns, and mosquito populations as members of foodwebs and as human disease vectors.

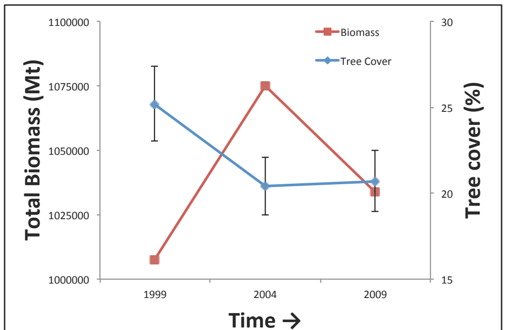


Figure 5. Total tree biomass and percent tree cover for Baltimore City in 1999, 2004 and 2009 derived from sampling of 202 randomly distributed plots using the i-Tree methodology.

The main platform for long-term biotic data collection in BES has been the i-Tree sampling and analysis tools developed by the USDA Forest Service, a key partner in BES. i-Tree uses data from 202 stratified random permanent plots to quantify the structure of the urban landscape, including forest and other land covers. At these plots, the composition and health (Nowak et al. 2008) and primary production of woody vegetation is assessed. This sampling (1999, 2004, 2009, 2014) shows that, similar to other LTER sites, long-term dynamics in tree biomass and canopy cover change over time (Fig 5) and are affected by extreme events, e.g., windstorms, and invasive pests like the emerald ash borer. These analyses have fostered our ideas about heterogeneity as both a driver that motivates human remedial actions, and an outcome that creates variation in climate and air quality of urban forest dynamics and function (Escobedo and Nowak 2009). In addition, long-term i-Tree data facilitates estimation of the value of urban forests for carbon sequestration, air quality and other

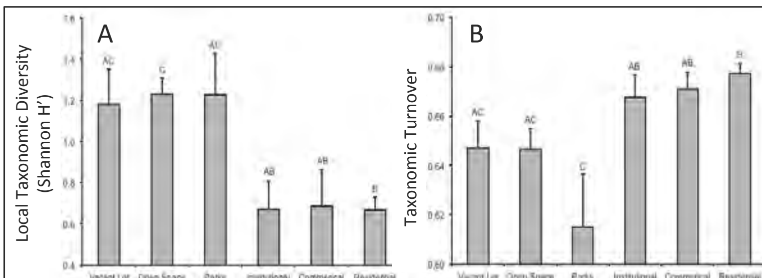


Figure 6. Local diversity (A) and compositional turnover (B) in UFORE urban forest communities occupying different landuse classes in Baltimore, Maryland. Both local diversity and turnover varied significantly with landuse (1-way ANOVA, P<0.002 for both). Bars are the mean + 1 SE. Bars with the same letter are not statistically different following Tukey's HSD (P>0.05).

ecosystem services (Nowak et al. 2013a, Nowak et al. 2013b).

i-Tree data also were used to assess woody plant local diversity and compositional turnover (β-diversity) across different urban land uses, where land use was arranged along a gradient in the intensity with which humans manage species composition at the parcel scale. Local taxonomic diversity varied with land use (Fig 6a) and taxonomic turnover was highest in areas where humans most strongly control composition (Fig 6b) (Swan et al. 2011, Johnson and Swan 2014). For example, diversity was more than two times higher in vacant lots, open spaces, and parks compared to more actively managed plots. These results have also contributed to our ideas about how heterogeneity in land use, even at the small scale of a vacant lot, can act as a driver and outcome of the assembly and diversity of communities. This heterogeneity in turn affects how plant communities influence other ecological variables, e.g. soil fauna and pollinators.

Patterns of heterogeneity may manifest differently in soils because they are a complex, three dimensional patchwork of different land uses, covers, management practices, levels of stress and disturbance histories at several spatial scales (Pouyat et al. 2010, Szlavecz et al. 2011). Cities have been identified as the epicenter of invasions by exotic earthworms that have the capacity to fundamentally alter the cycling and retention of carbon and nitrogen (Bohlen et al. 2004). In the Mid-Atlantic there is particular concern about the recent introduction of *Amynthas* (Megascolecidae) from Asia. Our long-term data from the BES permanent plots indicate that the relative abundance of *Amynthas* is increasing (Fig 7 ; Chang et al. 2015). However, because their populations are highly variable, only long-term studies can reveal whether they persist and affect ecosystem processes.

The i-Tree plots also have been used as a platform for our BES annual breeding-bird surveys since 2004. These surveys have now produced 58,211 observations that allow for analysis of spatial and temporal trends with geostatistical (Rega et al. 2015) and Bayesian (Wu et al. 2015) approaches, and modeling the relationships between bird habitat and occurrence data (Lerman et al. 2014). Again, these types of data emphasize that community assembly and habitat access in cities is an outcome of the heterogeneous nature of urban landscapes, which in turn drives long-term ecological change (Fig 8).

New research on mosquito community assembly and species distribution has discovered potential links between socio-ecological heterogeneity and public health, a link that is especially important given the continued emergence of diseases like the mosquito-borne West Nile and Zika viruses. Weekly sampling of juvenile mosquitoes at ten BES stream sampling sites from 2011 – 2013 revealed higher species richness in the more urban sites. Forested areas had greater

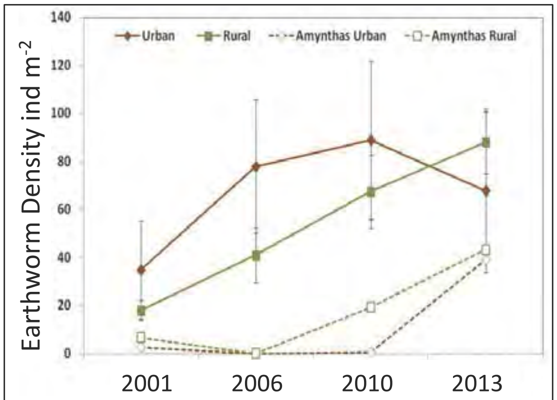


Figure 7. Long term changes in earthworm abundance in BES permanent forest plots. Data for Leakin park (urban, red) and Oregon Ridge (rural, green) are shown. Solid lines: changes in total desnity (mean±SE). Dashed lines: changes in the invasive Asian *Amynthas* sp. (only mean values shown). Years are not to scale.

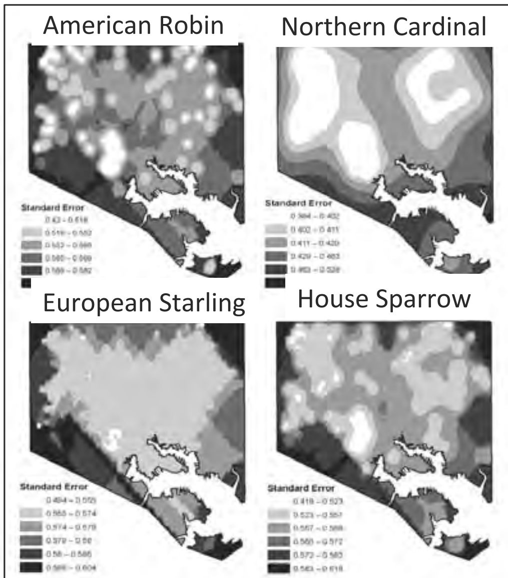


Figure 8. Kriged distributions of American Robin, Northern Cardinal, European Starling in Baltimore City based on sampling of 132 iTree plots. From Rega et al. (2015). Colors indicate standard error

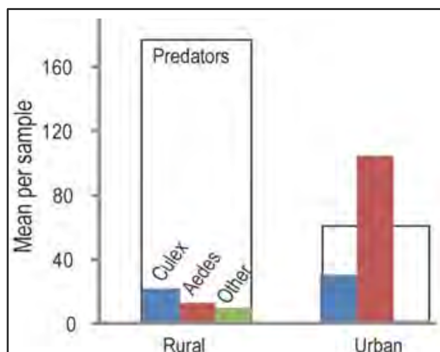


Figure 9. Mosquito and predator abundance in stormwater detention basins in forested (rural) and urban locations.

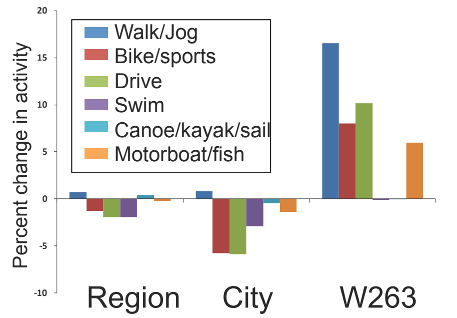


Figure 10. The BES Household Survey found increases in outdoor recreation in poor neighborhoods where there had been ecological interventions (green infrastructure) compared to the rest of the City and the Region. From Hager et al. (2013).

evenness across mosquito genera and higher predator abundance than urban stormwater pools (Fig 9). Likewise, richness and disease vector potential across urban sites varied with neighborhood socio-economic status (LaDeau et al. 2013, Becker et al. 2014), as do people's behaviors and perceptions of mosquito exposure (Bodner 2015).

3) Choices that people and institutions make. We have focused on two kinds of human choices: "Where will I live?" and "How will I manage land?" While these are parcel-scale questions associated with landowners and renters, the factors controlling these questions reflect coarser organizational scales and are both outcomes and drivers of the urban environment.

Since the beginning of BES, we have employed a long-term household telephone survey repeated every 5 years to examine social-ecological dynamics of both locational and land management choices. The survey assesses environmental knowledge, values, and behaviors; how these influence ecosystem structure and function; *and* how changes in ecosystem structure and function may affect people's physical activity, social cohesion, perception of neighborhood desirability, and willingness to move. Importantly, this survey is spatially explicit at the household level, thereby facilitating integration with remotely-sensed and field, administrative, and census data (Troy et al. 2016, Grove et al. 2015a). Variations in canopy cover are positively associated with neighborhood desirability, environmental satisfaction, quality of life, and social cohesion (Vemuri et al. 2011, Holtan et al. 2014). Land management interventions in the urban watershed 263 (WS263) had substantial social outcomes, with increases in neighborhood satisfaction, decreases in willingness to move, and increases in outdoor recreation relative to the entire city and region (Fig 10; Hager et al. 2013).

Surprising heterogeneity in residential yard management, e.g. fertilizer use, that could not be explained by variables such as lot size, housing age and housing value (Carrico et al. 2013, Groffman et al. 2016), led to analyses of how land management choices by private landowners and public agencies that have created spatially heterogeneous distributions of residential land cover over time. We hypothesized that residential trees and lawns can have significant social meanings. We have labeled this "an ecology of prestige," based upon the hypothesis that housing styles and yard characteristics act as social-ecological symbols and reflect the types of neighborhoods where people choose to live. There are three important findings: First, lifestyle factors such as family size and life stage, and ethnicity appear to be stronger predictors of private residential land management than population density or socioeconomic status (Grove et al. 2006a, Troy et al. 2007, Zhou et al. 2009b, Huang et al. 2011, Grove et al. 2015a). Second, different social groups' needs for status and group identity produce neighborhood-based and geographically coherent differences in ecological structures and functions (Grove et al. 2014, Locke and Grove 2014). Finally, there were temporal lags and legacies between changes in neighborhood social characteristics and canopy cover. For example neighborhood lifestyle characteristics in the 1960s were the best predictors of canopy cover existing in the 2000s (Boone et al. 2010, Buckley and Boone 2010, Lord and Norquist 2010, Grove et al. 2015a). These results suggest the need for understanding the heterogeneous legacies of past housing markets and land management on the current spatial heterogeneity of ecological structures and functions, and to make predictions about changes in the future.

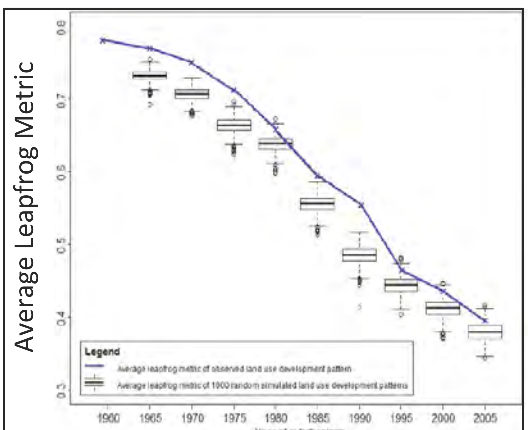


Figure 11. Leapfrog metric is a relative measure for a specific subdivision that quantifies the amount of vacant and developable land that is more accessible to an urban center than the given subdivision; this amount is divided by the total amount of developable vacant land plus all developed land that is more accessible, which bounds the metric between 0 and 1. Leapfrog metric has declined over time from 1960 to 2010 at a rate that is equal to an average decrease of 1% per year.

We have focused on the relationship between the natural and built environment, household locational choices, and land use patterns. We hypothesized that the choices by landowners and households impact ecosystem structures and functions in spatially heterogeneous ways, and that those choices are influenced by spatial patterns of ecosystem services, amenities, and environmental costs. Spatially explicit modeling of household choices and human-induced feedbacks is crucial for understanding these interactions among ecosystem structure and function, housing and land markets and social outcomes (Irwin et al. 2009a, 2009b, Irwin 2010, Brady and Irwin 2011, Chen et al. 2011, Irwin and Wrenn 2012). We used econometric analysis of housing sales since 1960 to examine how ecosystem services and other urban amenities influence households' demand for a particular location and the value of ecosystem amenities (Gnagey and Irwin *in review*, Carrion and Irwin 2010, Irwin et al. *in review*, Livy and Klaiber 2016).

Key findings underscore the importance of the spatial patterns in a landscape (i.e. heterogeneity) that may have social consequences. For example, proximity to a park may have positive or negative effects on housing values depending on the specific features of the park. We also have analyzed the influence of land use policies on the production of spatial heterogeneity (Chen et al. 2011, Newburn and Ferris 2015, Towe et al. 2015, Wrenn and Irwin 2012, 2015, Wrenn and Sam 2014, Zhang et al. *in press*). In particular, we have studied "leapfrog development," where more distant land is developed while land closer to an urban center is left vacant (Fig 11; Carrion and Irwin 2010, Zhang et al. *in press*, Wrenn and Irwin 2015). A key finding is that policies intended to protect natural and rural ecosystems often unintentionally increased exurbanization and land fragmentation, contrary to the original intent of these policies and zoning regulations.

Our work on the long-term dynamics of locational choice has included the role of residential segregation in the production of urban heterogeneity and patterns of environmental inequalities. Lord and Norquist (2010) documented procedural mechanisms and patterns of racial bias in zoning decisions in Baltimore since the 1930s, particularly the long-term legacies of "redlining" of African-American communities. Additional historical research on restrictive covenants and neighborhood improvement associations show that racial discrimination continued long after the redlining maps were produced (Boone 2013). BES research has also examined inequalities associated with the uneven distribution of parks (Boone et al. 2009), current distributions of urban heat islands (Huang et al. 2011), tree canopy cover, and vacant lots (Grove et al. 2015a). These environmental inequalities are closely aligned with neighborhoods that were redlined during the 1930s. While the procedural mechanisms for these racial biases have decreased over time (Lord and Norquist 2010), attempts to remedy these conditions are hindered by legacies of the city, making social ecological redevelopment, the adoption of sustainability practices, and adaptation to future climate scenarios more difficult in neighborhoods of disinvestment (Battagalia et al. 2014).

Finally, we developed a novel social-ecological approach to inventory and map the civic networks that affect environmental management by government agencies, non-governmental organizations, businesses, and community groups. We hypothesized that institutional shifts, focusing on urban sustainability and resilience, would lead to changes in governance, increased involvement of multiple sectors and stakeholders and decentralization of the network (Pickett et al. 2013, 2014). We surveyed the ~390 known stewardship organizations in Baltimore in 1999 and 2011, allowing us to observe the effects of institutional change since the Baltimore Office of Sustainability was established in 2008. Results from these long-term data indicate the substantial institutional shifts and decentralization of networks, confirming our hypothesis and contributing to theories of environmental governance (Romolini 2012, Romolini et al. 2013).

4) Techniques and tools for integration. Our approach to integration across physical, biological and social science research domains has been to bring together long-term data streams using mechanistic simulation models and statistical analysis. Integration has been fostered by focusing on three specific small watersheds within the Baltimore metropolitan area: 1) a dense urban watershed with an underserved population and a significant proportion of vacant lots (WS263; Hager et al. 2013), 2) a high socio-economic status, low density exurban watershed served by septic systems (Baisman Run; Mittman et al. 2012), and 3) an older, denser, suburban watershed (DR5; Linder and Miller 2012, Miles and Band 2015, Smith et al. 2015, Bhaskar and Welty 2015). We have integrated these data streams using RHESSys **(**Regional Hydro-Ecologic Simulation System) and other models (e.g., Parflow, an integrated watershed model to simulate surface and subsurface flows; Bhaskar and Welty 2012). RHESSys is a distributed ecohydrological model that operates at multiple scales: parcel, subdivision, neighborhood and catchment scales (Tague and Band 2004), and can thus examine impacts of different built forms, human behaviors, and canopy conditions.

We have used RHESSys to evaluate changes in water, carbon and nutrient cycles associated with actual and simulated changes in land cover and infrastructure; we have also linked RHESSys to individual and institutional parcel land management, including vegetation choice, management, irrigation, and fertilization (Law et al. 2004, Mittman et al. 2012, Miles and Band 2015; Fig 12). We have used i-Tree Hydro to represent a statistical spatial distribution of runoff producing areas, including both upslope and downslope features that can affect water quantity and quality. In addition, we have integrated land use and locational choice data through econometrically estimated simulation models of the residential housing market (Livy 2015) and residential land conversion (Wrenn and Sam 2014). We also have integrated housing market models with data on water quality and other ecological amenities to examine their influence on housing values and locational choices (Livy and Klaiber 2016, Irwin et al. *in review*). More fundamentally, we have integrated results from our three focal areas of research to produce synthetic products that characterize the multi-dimensional and multi-disciplinary nature of urban ecosystems and helped to bring these ecosystems into the field of ecosystem ecology (McGrath and Pickett 2011, Hager et al. 2013, Childers et al. 2014, Pickett et al. 2014, Tanner et al. 2014, Grove et al. 2015a, Weathers et al. 2016).

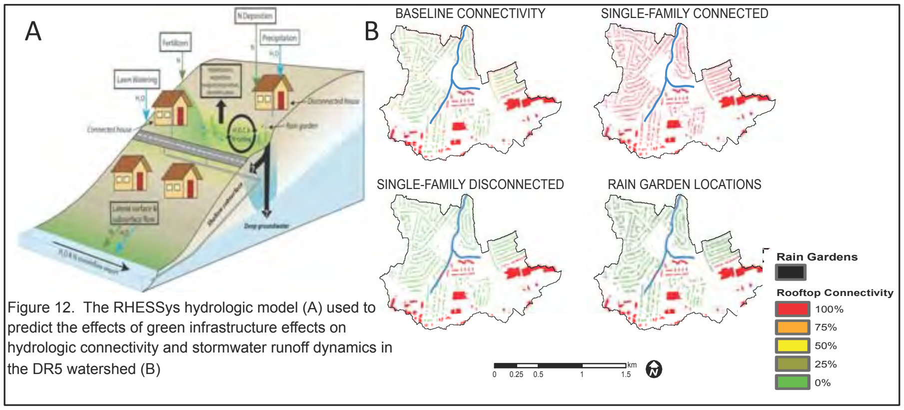


Figure 12. The RHESSys hydrologic model (A) used to predict the effects of green infrastructure effects on hydrologic connectivity and stormwater runoff dynamics in the DR5 watershed (B)

5) Education and outreach activities. Since 2009, we have worked with 91 teachers (including 19 Asian and 15 African American teachers) through 72 days of professional development aimed at increasing understanding, skills, motivation and confidence for environmental science teaching. Major outputs of these programs include research about student learning (Gunckel et al. 2012, Jin and Anderson 2012), and the development of curricular modules on carbon, water, biodiversity, and citizenship (Caplan et al. 2013, Covitt et al. 2013, Harris et al. 2013). A summer citizen science program in mosquito ecology has enrolled 32 adults, with 16 individuals earning citizen scientist certificates. A month-long youth camp has been offered for the past two summers for over 60 children. The annual BES Open House and Community Greening Celebrations generally attract over 200 people. In the policy arena, BES research findings have been used to enhance federal, state and local policy on riparian reforestation, urban tree canopy goals, community greening, stormwater management, and the development of quantifiable goals for sustainability.

6) Response to mid-term review. The 2013 mid-term review identified five areas of concern. Of primary importance was the sense that intellectual links among the project's components were not clear and integration was lacking. Related to this concern was that the roles that theory or broader conceptual frameworks play in guiding the project's research and in formulating research hypotheses were not demonstrated. A third concern was that "few of the research projects described seem to rely on or require long-term data." To address these concerns we have reformulated our conceptual framework to focus on heterogeneity as both a driver and outcome of long-term ecological change in cities, and refocused our data collection to provide tighter linkages between long-term data and our conceptual framework. We propose a new focus on integration where long-term data are used to refine our predictive simulation models and to conduct new statistical analyses. Significant reorganization of project structure and re-budgeting of funds is proposed to facilitate these changes. We have addressed a fourth concern, i.e., that individual research components appear to be chosen opportunistically rather than strategically, in the text above by more effectively communicating how the addition of project components has been driven by our results from long-term data collection. A fifth concern, about the paucity of participants in the project who come from underserved groups, has been addressed in two ways. First, we have added a new summer program involving groups of youth from Baltimore City in BES research. Second, we have expanded our work with the majority-minority Baltimore City School system by initiating a partnership with Green Street Academy (GSA), a public charter school for middle and high school students and Francis Scott Key School. GSA focuses on STEM related sustainability curriculum and programs and is a prime target for connecting with students to work with BES.

SECTION 2: PROPOSED RESEARCH

The Baltimore Ecosystem Study has developed a robust understanding of the spatial and temporal patch structure of physical, ecological, and social factors in the urban ecosystem. Building on these findings, we propose to investigate how the interactions between human activities and the environment create heterogeneous mosaics that are both consequences (outcomes) *and* causes (drivers) of long-term ecological change in urban ecosystems (Pickett et al. *in review*). We propose that interacting patterns of heterogeneity are alternatively a cause and consequence of urban ecosystem functioning and change. Heterogeneity is a key theoretical concept in the discipline of ecology, with the heterogeneous nature of the environment, the distribution of organisms, and ecological processes as key principles underpinning the general theory of ecology (Wiens 2000, Turner and Chapin 2005, Scheiner and Willig 2011). We describe the evolution of our conceptual framework, the specific hypotheses and questions that emerge from this framework and the methods that we will use to collect and integrate long-term data to address our research objectives.

2.1 BACKGROUND AND JUSTIFICATION: DYNAMIC HETEROGENEITY

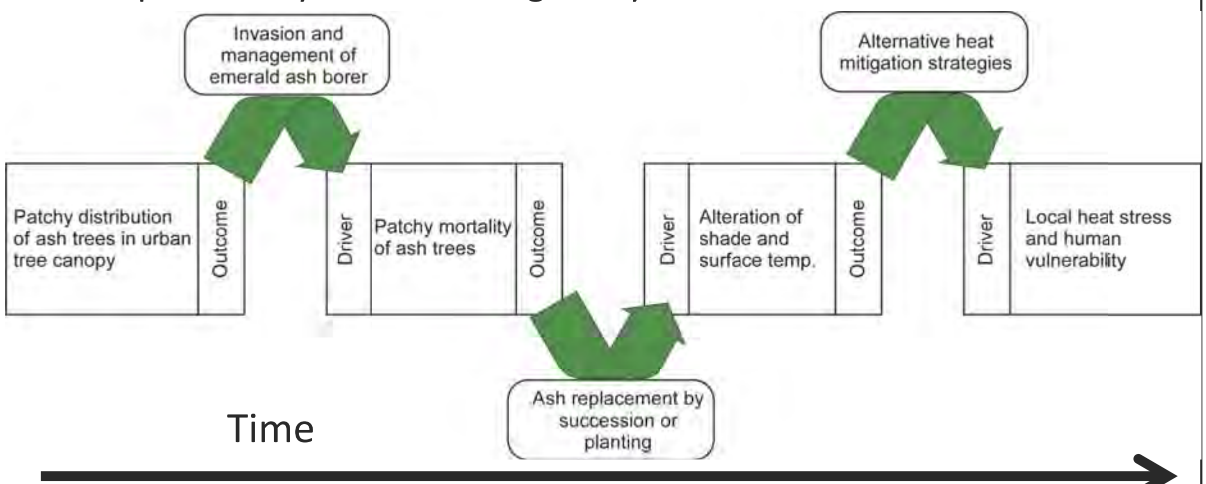
Our long-term research has demonstrated that an urban ecosystem comprises *a suite of interacting spatial mosaics in the biophysical and social realms that change over time*, which we refer to as "dynamic heterogeneity" (Fig 1). We are now poised to make significant advances in examining the extent to which these interacting spatial mosaics and the resulting dynamic heterogeneity drive long-term ecological change in urban ecosystems.

Urban ecosystems have distinctive patterns of heterogeneity that are generated across varying time scales by spatially complex interactions among common physical and biotic ecosystem drivers, as well as by built and human social dynamics (Alberti 2008, Shane 2005, Grove et al. 2015a). Patchy distributions of resources, organisms, and processes are, reciprocally, outcomes and drivers of ecological change in all ecosystems (Wu and Loucks 1995, Zhang et al. 2013, Leibold 2011, Scheiner and Willig 2011). However, in combination, human choices, interventions, and natural landscapes may interact to *amplify* the spatial heterogeneity of urban ecosystems over time (Niemala et al. 2009). Indeed, many human decisions in urban ecosystems intentionally manipulate multiple dimensions of heterogeneity, e.g. the spatial arrangement and distribution of patches, the flow of water through the landscape, while other human decisions unintentionally affect heterogeneity, e.g. the spread of non-native plants, or the distribution of mosquito habitats. Such spatially anchored decision-making and management is superimposed on an already heterogeneous biophysical landscape (Cadenasso et al. 2006). While research demonstrates that urban areas in different biomes are more similar to each other than the surrounding native ecosystems, (i.e. urban homogenization, Niemelä et al. 2009, Groffman et al. 2014), at the within-city scale, research demonstrates high degrees of spatial heterogeneity (Jenerette et al. 2006, McDonnell and Hahs 2009, Pickett and Cadenasso 2009). Moreover, the decisions people make *amplify* heterogeneity in an urban landscape. For example, the emerald ash borer is killing ash trees in forests (both managed and unmanaged) across the Eastern U.S., creating heterogeneity (an outcome) and driving ecological change across the region. In urban areas, this cycle of heterogeneity as an outcome and driver of change is amplified by human actions: removal of dead trees, and selection and planting of new trees (Box 1). Thus a conceptual approach based on dynamic heterogeneity is ideally suited for long-term urban ecosystem research.

We propose that characterizing heterogeneity within and between biophysical and human domains will allow us to develop both descriptive and predictive models of the structure and function of urban ecosystems and that a conceptual framework based on *dynamic heterogeneity will allow us to 1) integrate across ecosystem components, 2) develop general ecological questions that link processes and patterns across levels of organization and temporal and spatial scales, and 3) develop predictive models of changing heterogeneity and social-ecological processes in urban ecosystems.*

Our overarching hypothesis is that: Heterogeneity is an outcome of the patterns and processes that interact at distinct spatial and temporal scales in urban ecosystems and that dimensions of dynamic heterogeneity are then themselves drivers of subsequent ecological patterns and processes. Outcomes and drivers are **amplified** in urban ecosystems by **human choices and interventions** that both respond to and change ecological pattern and process.

Box 1. Spirals of dynamic heterogeneity



Events along the time line in the middle of the diagram all involve some spatially differentiated (i.e. heterogeneous) pattern. Boxes on the green arrows represent urban processes and human responses to the heterogeneous condition (the driver) at the root of each arrow.

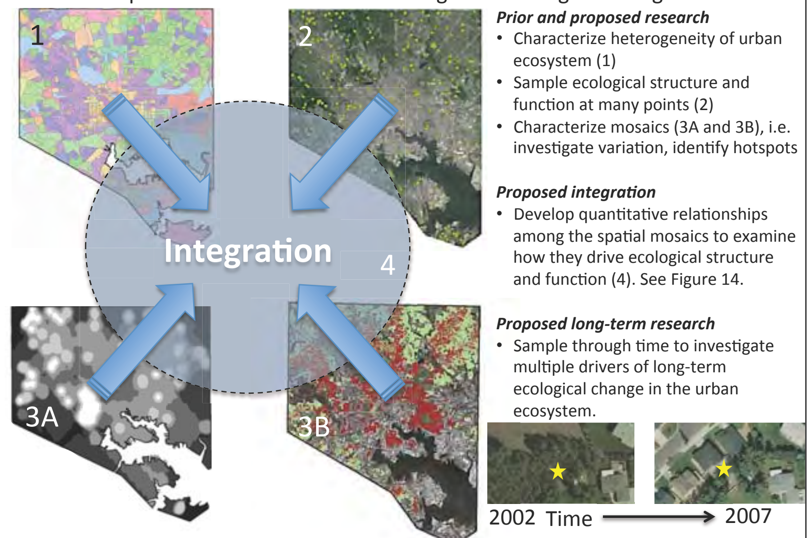
We will investigate our overarching hypothesis by documenting how heterogeneity in key biological, physical, social, and built variables (Pickett and Grove 2009) is an outcome of the ecosystem status quo that interacts with subsequent ecological and social changes to become a driver of ecological processes in an urban ecosystem over the long term (Pickett et al. *in review*). The urban stream syndrome is another example of heterogeneity as both a driver and outcome. Specifically, heterogeneity in flooding was an *outcome* of urban land use change that became the *driver* of the installation of stormwater infrastructure. The installation of this infrastructure created a series of new heterogeneous outcomes, such as stormwater detention ponds. Residents' perceptions of risks or disamenities associated with such ponds became, in turn, a driver of new generations of stormwater management infrastructure.

Although urban areas are manifestly heterogeneous (Shane 2005, Zhang et al. 2013, McGrath 2013), we recognize that not every aspect of urban heterogeneity is a significant driver of ecological function and change. Therefore, **our research seeks to sample across heterogeneous mosaics through space and time to identify the significant social and biophysical drivers that influence ecosystem pattern and process.** A central tenet of landscape ecology is to investigate spatial mosaics in order to understand pattern and process (e.g., McGuire et al. 2014), but these spatial mosaics are often investigated in space, not over time. Investigating the temporal dynamics of spatial mosaics within the context long-term research will offer unique insights that will resonate across fields of community, ecosystem and landscape ecology.

Proposed Approach: In the coming phase of BES, we propose address our overarching hypothesis with continued long-term research in the three focal areas representing fundamental processes in urban ecosystems: the flows of materials, community assembly, and human choices that encompass the biophysical and social science core areas of urban LTER research (Fig 1). We will continue our long-term watershed and permanent plot studies, our measures of urban plant dynamics on 202 spatially extensive plots, and the social surveys that we have collected since 1998. We will also continue and enhance our long-term intensive interdisciplinary investigation of three focal watersheds of similar area that span exurban (Baisman Run), suburban (Dead Run 5), and urban (WS263) conditions. We further build on our long-term i-Tree based sampling with new extensive sampling campaigns (hereafter called PULSEs) to measure the spatial heterogeneity in ecological conditions across the urban landscape. We propose to conduct PULSEs during each LTER cycle to foster investigation of dynamic heterogeneity in both space and time (Fig 13).

Synthesis and integration will be driven by three integrative questions (Section 2.1.1) that encompass project components, drive diverse collection of multiple data in shared locations, and promote joint analysis of the resulting datasets. We will employ simulation and *hierarchical statistical modeling,* integrating mechanistic processes with data models to quantify interactions and feedbacks among the interacting spatial mosaics. These analyses will identify drivers of long-term changes in ecological processes and provide a basis for prediction of future conditions.

Figure 13. Sampling, mapping and quantitative investigation of interacting multiple spatial mosaics that influence long-term ecological change



1. Demographic landscape: PRIZM lifestyle categories by neighborhood (see Grove et al. 2015 for key)
2. Sampling plots ~200 stratified random sampling plot (i-Tree) mapped over vegetation cover
3A. American Robin population: Krieged distributions based on 132 points (Rega et al. 2015)
3B. Soil lead: Model predictions in urban soils. Red areas >400ppm (Schwartz et al. 2013)

Structure of proposed research: We have structured this proposed phase of BES by posing integrative questions to guide three focal research areas. Within each of these focal areas, discipline-specific research questions and activities will provide critical information necessary to answer the integrative questions. This nested structure allows us to address discipline-specific research questions in an integrative context that will produce a synthetic research program to address long-term questions in urban ecosystem ecology.

2.1.1. Integrated Research Questions Guiding Proposed Research

We pose three integrative questions that have emerged from our long-term data and theory of dynamic heterogeneity, and which focus integrated model development.

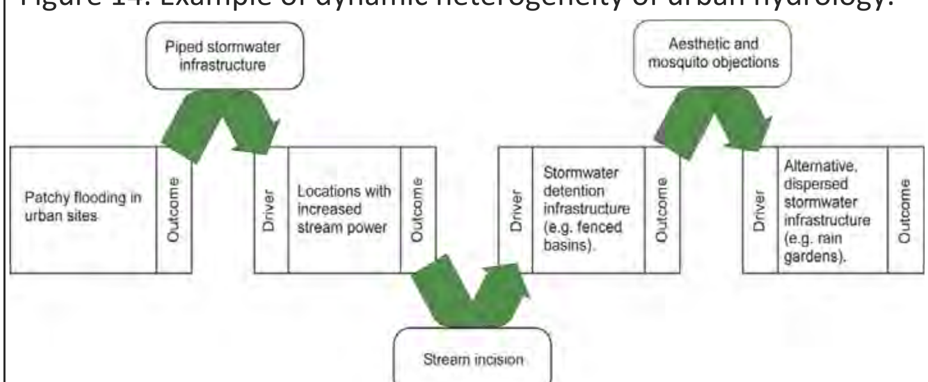
Q1: How does dynamic hydrological, biogeochemical and social heterogeneity influence watershed nutrient retention?

Q2: How does dynamic heterogeneity in biophysical and social processes across the urban landscape influence biotic community assembly and diversity?

Q3: How do the choices people make about where they live and how they use and manage their land interact with dynamic heterogeneous ecological conditions?

Below, we briefly justify each question, describe our research

Figure 14. Example of dynamic heterogeneity of urban hydrology.



approach, and present an integrated analytical approach. In Section 2.2, we provide more detailed methods, including specific hypotheses in each focal research area.

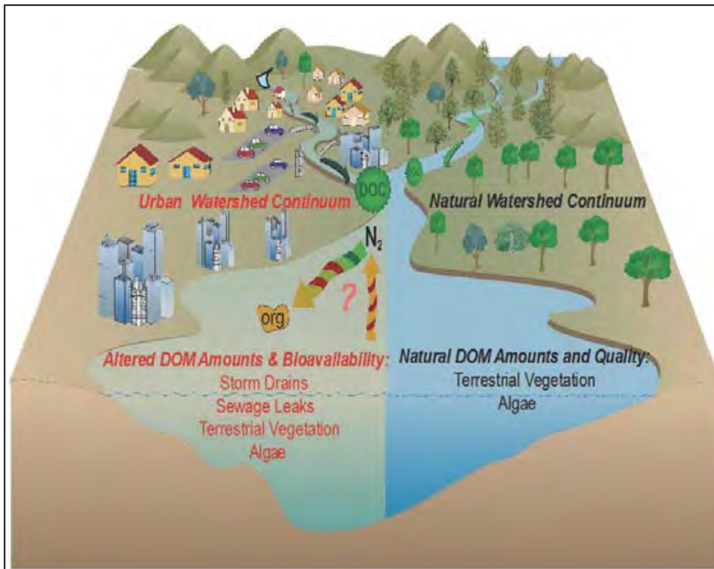


Figure 15. The Urban Watershed Continuum conceptual model showing alterations in the amounts and quality of organic carbon along the urbanizing watershed continuum compared to forested watersheds (Kaushal and Belt 2012).

2.1.2 Addressing Q1: How does dynamic hydrological, biogeochemical and social heterogeneity influence watershed nutrient retention? Long-term monitoring of watershed nutrient retention has emerged from BES research as a dynamic response variable that provides a link to other LTER sites (Likens 1992, Costanza et al. 2001, Williams et al. 2005). This research provides a strong platform for integration across disciplines. Answering this question requires continued long-term monitoring of water and nutrient fluxes from our long-term study, and integration with biogeochemical data on nutrient dynamics in soil and vegetation and social data on human choices and decisions at multiple levels. Watershed nutrient retention is also an excellent focal process for exploring heterogeneity as both a driver and outcome of ecological change. Our long-term research has shown how heterogeneity in hydrologic dynamics (e.g., flooding, nutrient export to Chesapeake Bay) was an outcome of urban land use change. This flooding then becomes the driver of the installation of multiple generations of stormwater infrastructure (e.g., large detention basins, rain gardens). The installation of stormwater infrastructure created a series of outcomes (mosquito disamenities, flooded basements, changes in property values) that acted as drivers of further changes in the heterogeneity of both natural and human hydrologic structure (Fig 14). We use a conceptual framework, the “urban watershed continuum" (Fig 15; Kaushal and Belt 2012; Walsh et al. 2005), that guides our research on the dynamic coupled human and biophysical heterogeneity that functions as a driver and outcome of watershed characteristics that influence watershed nutrient retention.

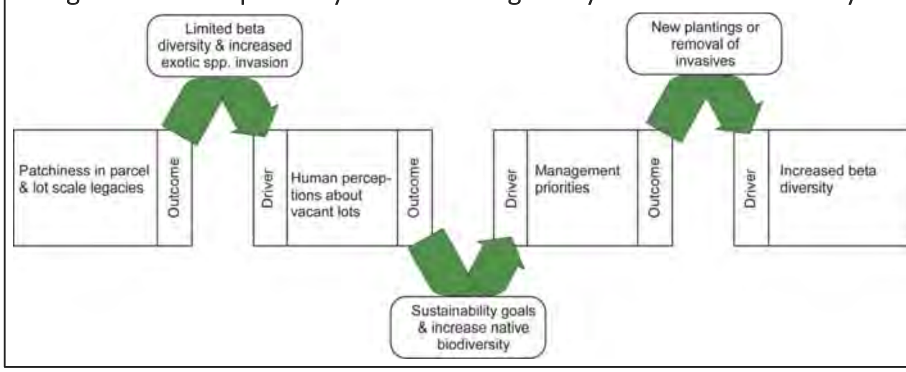
General Hypothesis: Our hypothesis is that the dynamic hydrologic and biogeochemical heterogeneity of urban watersheds, which includes natural and human components, drives the sources and sinks of water and nutrients in those watersheds (Fig 14, Fig 15). Over the long-term, these processes interact with climate variability to determine watershed nutrient retention. We further hypothesize that increasing the amount of green infrastructure, reducing sewage leaks, and reproducing patterns of natural vegetation and stream geomorphology along flowpaths will optimize watershed-scale retention and restoration goals. If the interventions prove to be insufficient, more aggressive measures may be needed.

Research Approach: At the beginning of BES, we established a network of urban, suburban, exurban, agricultural and forest reference watersheds in which we have tracked the flux of water and nutrients for over 18 years. The watershed studies are coupled to long-term study plots in urban and rural forests, urban lawns and riparian areas that are designed to examine mechanisms of nutrient dynamics. In addition, detailed studies provide further information about the role of nutrient uptake stream channels as a driver (or not) of watershed nutrient retention. We propose to continue work in these 10 watersheds and do more focused work in three watersheds as specific locales for integrated research: exurban (Baisman Run), suburban (Dead Run), and highly urban (WS263).

To better understand the complexity exposed by our long-term studies of urban streams and riparian areas, we must characterize the heterogeneity in stream/riparian ecosystem structure and function in the wider urban landscape (Cadenasso et al. 2007). Therefore, we will initiate a new long-term, spatially extensive PULSE sampling of broadly distributed stream and riparian sites. The stream/riparian PULSE will use 100 locations across the urban landscape, using a stratified random design to capture the variability in streams and riparian zones throughout the urban landscape. We will investigate the spatial variability and configuration of key ecological variables across these 100 sites and compare these to long-term records at the 10 BES stream and riparian sites. We will explore aspects of the dynamic heterogeneity influencing streams and riparian zones in the urban ecosystem by examining maximum, minimum, and variance of the data collected in the PULSE and develop spatial mosaics using PULSE data to identify hotspots of stream material processing. The spatial and temporal heterogeneity of watershed nutrient retention and stream/riparian structure and function can be evaluated in relation to layers of biotic and human heterogeneity. We will use simulation modeling and hierarchical statistical analyses to understand how dynamic hydrological, biogeochemical and social heterogeneity influence watershed nutrient retention and stream and ecosystem structure.

2.1.3 Addressing Q2. How does dynamic heterogeneity in biophysical and social processes across the urban landscape influence biotic community assembly and diversity? Exploring the distribution of organisms and biotic performance of species is crucial for characterizing community structure and for understanding the biotic contribution to ecosystem processes (Jax 2010, Wang and Loreau 2014). We posit that the layered patterns of heterogeneity in physical, biological and social processes in an urban landscape create a novel foundation for studying biological community assembly. In urban ecosystems, community assembly is dominated by management, with the relative importance of exotic and native species, spontaneous versus planted species, and selective pressures associated with urban stressors, including environmental pollution, heat island effects, etc., varying across space. Further, we recognize that urban biotic communities are highly dynamic over time as organisms interact and respond to changes in human activity and management as well as to changing biophysical constraints (Shochat et al. 2010, Nilon 2011, Hepinstall et al. 2008).

Figure 16. Example of dynamic heterogeneity of urban biodiversity



Three themes have emerged from previous BES biodiversity research: (1) urban biota are neither uniformly exotic nor exhibit low diversity, (2) biotic communities in urban landscapes assemble and change at relatively fine spatio-temporal scales, and (3) heterogeneous community composition is associated with heterogeneity in ecosystem function. Our long-term data illustrate the dynamic heterogeneity as an outcome and driver of biotic communities (Fig 16). For example, we have observed patchiness in land use legacies that are differentially colonized or invaded by plant species and communities. These patterns of plant diversity then influence human perceptions about vacant lots and alter the sustainability goals and management practices for these lots. This is in turn influences intentional removal or planting strategies. The combination of land use legacies, plant invasion, human perception and management lead to heterogeneous distributions of plant species in the urban landscape. Past BES research on the community dynamics of plants, soil invertebrates, birds, and mosquitoes have identified clear and predictable heterogeneity in these taxon-specific communities in the urban landscape. We propose to develop a quantitative and predictive understanding of patterns in local and inter-patch biodiversity for a suite of taxa as both outcome and driver of heterogeneity in biophysical and socially-derived properties of the urban landscape.

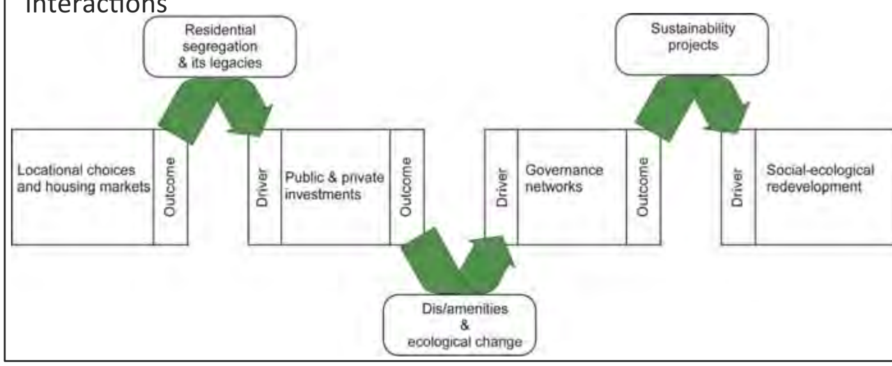
General Hypothesis: Local scale biological diversity is both a driver and an outcome of ecosystem function and how people exert their influence on the environment. More specifically, dynamic heterogeneity of environmental conditions and human actions have created a mosaic of ecological communities that changes at distinct spatial and temporal scales due to dispersal, adaptation, and human interventions.

Research Approach: We propose coordinated PULSEs to survey microbes, plants, soil invertebrates, mosquitoes, and birds at 200 spatially distributed locations, using a stratified random design to capture the diversity of habitats present in the urban landscape. Plots will be to facilitate experimental contrasts among urban, suburban and exurban locations, and vacant lots, and to ensure a sufficient density of plots in our focal watersheds: WS263, Dead Run 5, Baisman Run This work will build directly on our previous long-term tree and bird composition data, adding a suite of taxa that span size and life rate scales from microbes to trees. Multiple metrics of community assembly and diversity will be explored through data-model integration of long-term data streams with the terrestrial PULSE data.

We will use these data to investigate the spatial heterogeneity of biological communities across the urban landscape to investigate patterns of distribution, e.g. hot and cool spots of species diversity and patterns of community distribution. Mosaics will be used to explore the spatial scales of patches to evaluate both standard metrics of alpha (local) and beta (turnover) diversity across and between taxa, as well as to identify drivers explaining spatial heterogeneity in the proportion of exotic and invasive species. We will also compare spatial mosaics across the taxon-specific communities, e.g. is mosquito diversity associated with diversity of birds or plant communities? We will compare biotic mosaics to other aspects of the urban landscape that we have mapped to investigate which variables influence communities, i.e. are mosquito populations related to lifestyle classifications (e.g. Weiss 2000)? Repeated PULSEs will allow us to explore patterns of population spread and community dynamics over *space and time.*

We will use a Hierarchical Bayesian regression framework specifically incorporating the biotic data to identify the spatial scales at which beta and alpha diversity are maximized, while also comparing relative support for explanatory variables, including habitat condition (e.g., unmanaged versus planted) and resource availability (e.g., soil moisture, source populations, nutrients). The Hierarchical Bayesian framework is an effective tool for integrating diverse data sources to generate inference on processes as well as identifying sources of uncertainty (Clark and Gelfand 2006).

Figure 17. Example of dynamic heterogeneity affecting socio-ecological interactions



2.1.4 Addressing Q3: How do the choices people make about where they live and how they use and manage their land interact with dynamic heterogeneous ecological conditions? Since its inception, BES has focused on how the decisions people make at multiple scales influence ecological features of an urban region and how these ecological conditions in turn feed back to influence households, neighborhoods, municipalities, and governance networks. Ecological conditions can be perceived as amenities or disamenities that influence locational, land use or land management choices. It is important to recognize, however, that while some ecosystem structures and functions may influence individual locational and management choices directly, many other feedbacks involve higher levels such as governance networks, zoning, and regulations to protect habitats and ecosystem functions. An example of how heterogeneity plays out in the socio-ecological dynamics of an urban landscape is illustrated in Fig. 17. The diversity of locational choices and housing markets is influenced by legacies such as racial segregation. This drives heterogeneity in both public and private investments that in turn influence ecological changes. Heterogeneity in perceptions of amenities, disamenities and ecological condition influences heterogeneity in governance networks and management plans. The combination of these factors leads to a heterogeneous landscape of socio-ecological redevelopment across the urban landscape that is a result of these factors interacting over time.

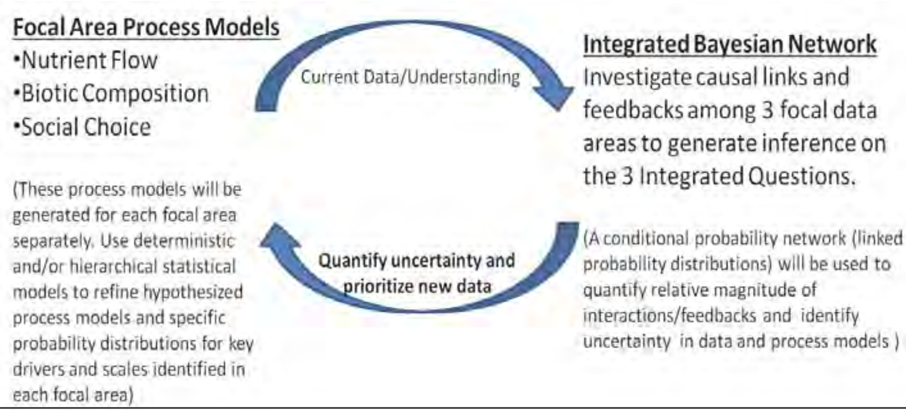
Our focus in the next phase of BES will be on spatially explicit human decision-making, and is based on propositions emerging from our previous work: 1) Households, firms, and public and civic organizations make locational and land management choices that have intended and unintended ecological consequences. 2) Locational and management choices are heterogeneous, which affects the spatial distribution of amenities and disamenities, along with the spatial configuration of urban ecological structures and functions. 3) Individuals and governance networks of public, private, and civic actors respond to and influence the spatial configuration of locational and land choices and, consequently, the spatial configuration of urban ecological structures and functions. Finally, 4) the spatially explicit changes in these ecological amenities and disamenities in turn affect individuals, governance networks, and locational and land choices.

General Hypothesis: We hypothesize that locational choices and housing markets are an outcome and driver of changes in dis/amenities and ecological structures and functions over the long term (Fig 17). We recognize that exogenous forces, such as access to economic opportunities and residential segregation and its legacies, produce unequal public and private investments that affect these choices. Changes in ecological structure and function include diminished biophysical processes associated with stream water quality and vulnerability to disturbances such as flooding, heat waves, wind events, and vector-borne diseases. We further hypothesize that these changes in ecological structure and function and their associated environmental hazards lead to changes in governance network structures and behaviors.

Research Approach: We propose an extensive/intensive data strategy that incorporates a mixed-methods (Maxwell 2016) approach with data specified in terms of location, time and scale in order to understand both patterns and mechanisms over the long term (Grove et al. 2013, 2015a). We have 1) conducted extensive, spatially explicit household telephone and organizational network surveys, 2) produced high-resolution land cover data (~1 m) and 3) assembled long-term data on the creation of subdivisions. We have also assembled datasets on 4) land and housing markets, and 5) on neighborhood socio-demographics. We will continue to collect these long-term data. In addition, we will coordinate with the Stream/Riparian and Community Assembly PULSEs to co-locate and collect intensive, qualitative data about our three focal urban, suburban, and exurban watersheds and from key organizations. These intensive data will enable us to better understand 1) specific motivations, choices and behaviors of households, communities, organizations, and firms; 2) sources and flows of information for policy, planning, and management among different types of actors; and 3) organizational behaviors of central and marginal members of governance networks, all with specific reference to the ecological conditions being studied in the PULSEs (see above).

2.1.5. From focal areas to integration: Using process models and Bayesian Networks for social-ecological prediction and model testing. BES has developed mechanistic understanding of critical drivers and scales of heterogeneity in the three focal areas of flux of materials, biotic community assembly, and locational and land choices, using long-term data and models to define and understand feedbacks and evolution of system states and processes. Ecohydrological models, for instance, can effectively evaluate the impact of different scenarios of human behavior, climate, and other exogenous processes on carbon and nutrient cycling, while land use economic models can evaluate impacts of environmental states and policy on new housing development trends. Interaction between these models is based on updating states and processes in one model that have impacts on processes of change in the other model (Fig 18). At present, we have a loose coupling with models running at different temporal and spatial scales. In the next phase of BES, we will specify interactions of the model domains using shared variables that address dynamic heterogeneity.

Figure 18. Iterative Data-Model Assimilation Approach



A critical challenge for BES, and ecology more generally, is to develop frameworks for coherently integrating social, ecological and physiological data at scales relevant to multiple, heterogeneous processes within a single model to explicitly evaluate interactions and identify emergent properties. For example, understanding biotic community assembly across neighborhoods is likely to require understanding spatial variability in the legacy and dispersal limitations on source populations, the human decisions and behaviors that further regulate species composition and the spatio-temporal variability in environmental filters that fundamentally limit plant growth. We propose a Bayesian Network (BN) approach for explicit evaluation of interactions and nonlinearities between social and biophysical processes. A Bayesian Network represents a high-dimensional system combining conditional, univariate probability distributions in a directed acyclic graph (DAG) (McCann, Marcot and Ellis 2006, Marcot et al. 2006). This tool is commonly used in medical diagnostics, risk and decision assessment and increasingly, in ecological studies (Maxwell et al. 2015, Rigosi et al. 2015, van Dam et al. 2013, Leigh et al. 2011). While other graphical modeling techniques may be explored, we focus on Bayesian Networks because they coherently handle missing data and because uncertainty is explicitly estimated in posterior probabilities. Likewise, the Bayesian probability framework allows for straightforward integration across diverse data sources and sub-models (Clark and Gelfand 2006), making it appropriate for investigating interactions and interdependent associations among biophysical, ecological and social processes. The BN is a graphical representation of directed connections (arcs) between states or variables of interest (nodes). Each ("child") node is defined by a joint probability distribution, given all nodes above it in the network ("parents"). Researchers define the graphical structure and use probability to represent current understanding of drivers and relationships between nodes. The BN is then used to learn parameter values and to generate probability estimates describing likely outcomes (forecasts) given changes in states or connectivity.

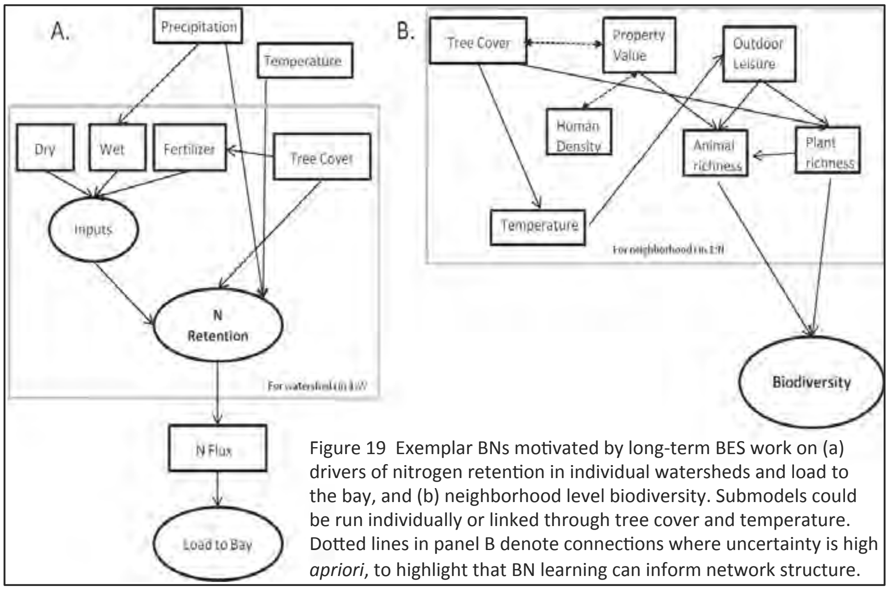


Figure 19 Exemplar BNs motivated by long-term BES work on (a) drivers of nitrogen retention in individual watersheds and load to the bay, and (b) neighborhood level biodiversity. Submodels could be run individually or linked through tree cover and temperature. Dotted lines in panel B denote connections where uncertainty is high *apriori*, to highlight that BN learning can inform network structure.

A dedicated synthesis postdoctoral fellow will be hired to work with BES co-PIs to address our Integrated Hypothesis, mentored by Rosi-Marshall and Co-PI LaDeau, who heads the Project Synthesis Team. The fellow will work the BES community to construct the best graphical structure given current understanding and long-term data resources, such as the example BN in Fig 19. While the fellow will lead the modeling effort described here, synthesis will be facilitated project-wide by devoting one quarterly all-hands meeting each year to the process.

To address each integrative question, the BN model will integrate current understanding of key processes across foci (Sections 2.1.1-4) to evaluate how well we understand the interactions. Synthesis between the mechanistic and probabilistic modeling approaches will be iterative. As each disciplinary model is improved, we will update the processes and connections in the BN model. Uncertainty identified in the BN approach will guide data collection and process model refinement. When the BN is validated to adequately represent current states, it can be used to generate probabilistic predictions under management and environmental change scenarios. The BN will build on the detailed analyses and synthesis in each research focus to investigate our general Questions 1-3 in a framework that allows for dynamic biophysical, ecological, and social processes to be linked over time. This approach complements more detailed mechanistic models applicable to each of the focal research areas.

In practice, we will follow guidelines describe in (Marcot 2012, Marcot et al. 2006) to construct and evaluate BNs, initially using the software Netica (Norsys Software Corporation). The BN (Fig 19) is an exemplar network addressing the integrative Q1, and describes the drivers of nitrogen retention in individual watersheds and subsequent influence on hydrologic export of nitrogen to the Chesapeake Bay. This particular BN defines probabilistic relationships between tree cover and N-retention and could easily be evaluated for different management scenarios affecting tree cover (Tree Baltimore http://www.treebaltimore.org/). While this diagram represents a static BN across multiple subwatersheds, Dynamic Bayesian Networks (e.g, state-space, kalman filter methods) can also propagate the network over time (Queen and Albers 2009, Royle and Kery 2007, Zhang et al. 2012). Likewise, the intial component model (Fig 19A) could be linked through tree canopy cover within the BN to a second sub-network investigating biotic composition (Fig 19B). This BN could then be used to predict changes in ntirogen retention and biological diversity under different tree management scenarios.

Section 2.2 Experimental Plan: Specific hypotheses and detailed methods

2.2.1 Focal Area 1: The Watershed Approach and the Flow of Materials

Research Team: Groffman, Rosi-Marshall, Band, Kaushal, Welty, Miller, Baker, Smith.

Our conceptual framework for research on the flows of materials is the "urban watershed continuum" (UWC; Kaushal and Belt 2012), which explicitly considers dynamic heterogeneity in time and space that is generated by geomorphic setting, the built environment (including grey and green infrastructure), and the hydrological and biogeochemical processes that influence watershed dynamics. In addition, it explicitly orients ecosystem heterogeneity as the configuration of hydrologic flowpaths. The UWC centers on the well-established observation that flowpaths that are predominantly subsurface in undeveloped conditions are replaced during urban development by surface flow paths and pipe networks and that hillslope flow lengths can be truncated by terrain resculpting and by drainage infrastructure such as storm sewers and curbs (Jones et al. 2014). This change increases transport rates while decreasing potential biogeochemical retention processes in urban areas relative to less human-dominated systems.

More specifically the UWC asserts that: 1) First order streams are largely replaced longitudinally and laterally by urban infrastructure such as storm drains, ditches, and pipes. 2) There is extensive longitudinal and lateral modification of organic carbon and nutrient retention in engineered headwaters. 3) There are longitudinal downstream pulses in material and energy exports that are amplified by interactions between land-use and hydrologic variability. 4) Leaky sanitary sewers and water supply pipes interact vertically with groundwater to influence stream solute transport. 5) The urban watershed continuum is a transformer and transporter of materials and energy based on hydrologic residence times. 6) Temporally, there is a predictable pattern of change in biogeochemical cycles and ecosystem functions as land use and urban infrastructure change over time (Kaushal et al. 2014b, 2015).

In this phase of BES, we will use the UWC framework and insights from our long-term data to address the integrative question, **Q1: How does dynamic hydrological, biogeochemical and social heterogeneity influence watershed nutrient retention?** To address this integrative question, we will test the overarching hypothesis that the dynamic hydrologic and biogeochemical heterogeneity of urban watersheds, which includes natural and human components of infrastructure, drive the sources and sinks of water and nutrients in a watershed. Hydrologic modeling, simulation models, and Bayesian network models focused on UWC variables will be combined to produce comprehensive assessments of integrative question Q1. We also pose a series more focal area specific hypotheses that we will address using our long-term research on focal watersheds and in our spatially extensive stream/riparian PULSE.

Specific hypotheses that we will address include:

- The stream flow regime of urban watersheds (runoff ratio and retention ratio) will be less flashy over the next 10 years due to green infrastructure interventions at multiple scales throughout urban and suburban watersheds. These interventions, which will be funded in part by a new stormwater utility fee in some parts of Baltimore metropolitan area, will range from interventions in headwater source areas (drain pipes, rain barrels, rain gardens that decrease transport rates and increase retention processes) to large scale interventions lower in the watershed (stormwater detention basins, stream restoration projects). This sequence of interventions will provide controls on the ratio of transport to retention rates along the hydrologic flowpaths, and reduce extreme high flow, low retention conditions. We will test the hypothesis about flashiness by continuing to monitor hydrology at our long-term watershed sites and develop mechanistic understanding of the interventions using simulation models and field measurements.

• The importance of sanitary sewer infrastructure as a nutrient source in urban and suburban watersheds will increase over the next 10 years as the surface sources of atmospheric deposition and fertilizer use decline. Atmospheric deposition of nitrogen is declining and will continue to decline due to the Clean Air Act. Fertilizer use will decline due to City and County laws restricting formulation and use of nitrogen and phosphorus fertilizers. We will test this hypothesis by continuing long-term monitoring of hydrology and nitrogen at our watershed sites, processing data from long-term study plots, and compiling estimates of nitrogen balances and retention. Partitioning of different sources will be quantified by measuring changes in export under different hydrologic conditions, i.e., different sources are exported at different rates of streamflow, and by stable isotope source-tracking.

• Sanitary sewer infrastructure creates contaminant sources that are patchy and vary in space and time along an urban to exurban gradient, from older, under-served urban neighborhoods (vacant housing, aging, leaking sanitary sewer infrastructure) to exurban areas (septic systems). These contaminants may influence the structure, evolution and processes in aquatic ecosystems that create feedbacks to nutrient cycling dynamics. The biogeochemical dynamics in these patches are not merely a result of the typical drivers of nutrients and carbon but may be influenced by past or current exposure to specific sewage stressors such as salt, labile dissolved organic matter, and pharmaceuticals and personal care products.

• There are "sweet spots" within the urban to exurban gradient where social and biophysical factors converge to create opportunities for ecological restoration to reduce nutrient delivery to receiving waters. These factors include high nutrient concentrations, a high proportion of nutrient load export at low to moderate flow conditions, and neighborhoods that are receptive to or can benefit from restoration activities. This hypothesis will be tested by combining long-term watershed hydrology and biogeochemistry data streams with our extensive telephone and intensive open-ended household surveys on ecological restoration.

• Ecological conditions of urban stream and riparian ecosystems are temporally and spatially variable. Moreover these conditions are more related to the configuration of land use of upstream landscape (i.e., catchment configuration) than the immediate conditions adjacent to the stream/riparian system. We will test this hypothesis by examining how our long-term study watersheds have changed along with extensive results from our stream/riparian PULSE.

Methods: Flows of Materials

Watershed. Watershed studies in BES have focused on the Gwynns Falls, which has headwaters in suburban Baltimore County, traverses older (1950s) suburban areas, enters Baltimore City, and drains into Baltimore Harbor (Figure 20; Doheny 1999). We established four longitudinal long-term sampling stations on this stream: (1) Glyndon, in the headwaters; (2) Gwynnbrook, approximately 25% downstream; (3) Villa Nova, at the mid-point of the watershed; and (4) Carroll Park, near the confluence with the harbor but above tidal reach. We also established an array of additional sampling stations to provide land-use contrasts in similar-sized watersheds including: (1) Pond Branch, a forested reference site; (2) Baisman Run, an exurban site with low-

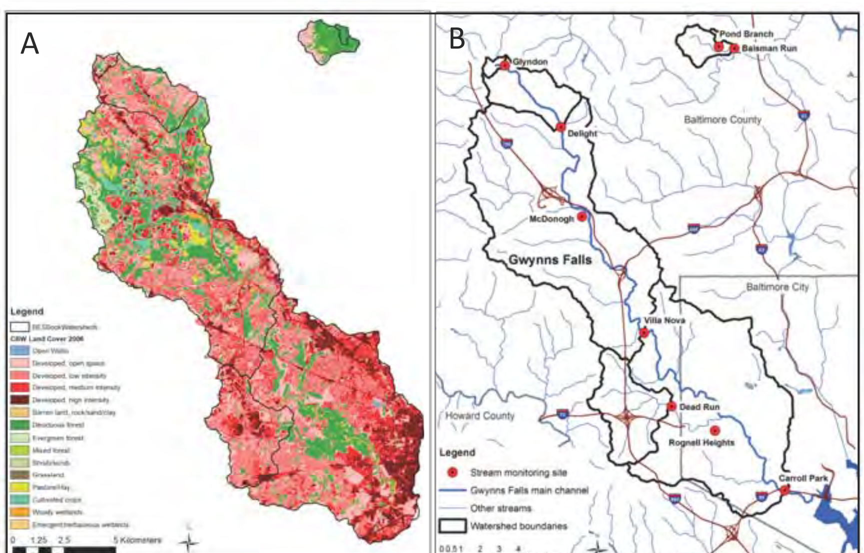


Figure 20. Land use (AP) and long-term sampling stations (B) in and near the Gwynns Falls watershed.

density residential development served by septic systems; (3) McDonogh, an agricultural watershed; and (4) a series of urban watersheds (Dead Run, Gwynns Run, Rognel Heights).

Continuous data on stream stage and discharge are collected by the USGS via subcontract from BES and/or collaborations with other agencies in the region. Data from most of the gages utilized by BES are available in near real time (http://waterdata.usgs.gov/usa/nwis/uv?01589352). Weekly manual sampling of stream water for water quality analyses began at most sites in Fall 1998. Automated samplers have been added at several sites to provide flow proportional sampling along with the manual sampling. Weekly analyses include nitrate, phosphate, total nitrogen, total phosphorus, chloride, sulfate, turbidity, temperature, dissolved oxygen, and pH. Cations, dissolved organic carbon and nitrogen, *E. coli* and contaminants such as metals and pharmaceuticals have been analyzed for selected samples. Starting in Jan 2016, we have continuous measures of dissolved oxygen and temperature at all stream sampling points to provide a new long-term record of stream metabolism, a useful indicator of ecosystem activity (Penino et al. 2014, Hall et al. 2015) and possibly a surrogate for instream nutrient uptake/demand (Hall and Tank 2003, Hall et al. 2013). Data are made publicly available through the BES and LTER data portals within one year of collection. We will measure carbon cycling, nitrogen cycling and stream bacterial community responses to exposure to a suite of urban chemical stressors (e.g. salt, nutrients, and pharmaceuticals and personal care productions) using *in situ* nutrient and contaminant exposure assays (Tank et al. 2006, Rosi-Marshall et al. 2013, Costello et al. 2015) in Years 1, 3, and 5.

BES maintains an LTER standard meteorological station and a network of rain gages distributed across the main study watersheds (Brazel et al. 2000, Savva et al. 2010). We are also providing partial support for the long-term high resolution radar rainfall data set for the Baltimore metropolitan area developed by Smith et al. (2012). This dataset includes rainfall fields at 15 min intervals and 1 km horizontal resolution for the entire 17,000 km^2 region and is characterized by striking spatial heterogeneities in both mean and extreme rainfall (Meierdiercks et al. 2010).

Long-term study plots. The BES network of long-term study plots currently includes 7 forest and 2 grass sites that have been sampled monthly since 1998 (forests) or 2001 (grass) 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. Continuous monitoring of soil temperature and moisture began in 2011. We also have four riparian sites where we have measured water table depth monthly since 2000 and trace gas fluxes monthly since 2012. The long-term study plots provide critical information for ongoing calculations of retention and loss of nitrogen and phosphorus in the key ecosystem types (upland forest, residential, riparian) in the study watersheds.

PULSEs to investigate the heterogeneity of stream and riparian ecosystems across the urban watershed continuum. We propose to institute a PULSE stream/riparian survey starting in year 1 (2017) that will provide spatially extensive data. This PULSE will provide broad spatial context for our long-term site research, provide data to refine our estimates of nitrogen sources and sinks within our study watersheds, and will allow us to characterize the spatial heterogeneity of ecological conditions in the urban landscape. The stream/riparian PULSE will be repeated at six-year intervals and will thus become part of our long-term data. One hundred points will be selected along the stream network in the Gwynns Falls, Baisman Run watersheds, and will also include points around the larger Baltimore metropolitan area. We will use a stratified random approach to select sites to ensure they represent a range of catchment size, land use and social dimensions (e.g. PRIZM lifestyle classifications; Grove et al. 2006b). This survey will produce a comprehensive assessment of stream and riparian heterogeneity, e.g. incision, distribution of habitats, etc. and provide an assessment of how well data collected at our intensive long-term stream sampling sites reflects the spatial heterogeneity of riparian and stream conditions throughout the metropolitan region. We will also sample ecosystem function measures and biofilm biodiversity (Section 2.2.2) to investigate relationships between stream and riparian structure and function.

We will sample all sites during baseflow conditions only, avoiding storms, during the summer low flow season from June-September. At each sampling point, we will conduct a stream and riparian assessment, using methods developed by the Maryland Biological Stream Survey, that includes measures of stream width and depth, the distribution of habitat types (pools, riffles, organic debris) and indicators of change, e.g., erosion. We will also make measurements of plant species composition, streamwater chemistry and microbial species composition (Section 2.2.2 Stream Microbial Communities) as well as measures of stream ecosystem function (primary production and ecosystem respiration) similar to measures made continuously at the 8 long-term stream sampling sites and sediment and riparian soil processes (e.g. microbial respiration, potential net N mineralization and nitrification, denitrification potential, microbial biomass C and N content). These data will build on our long-term dataset on riparian microbial biomass and activity, and will allow us to characterize functional heterogeneity and to investigate links between structure and function in our watersheds.

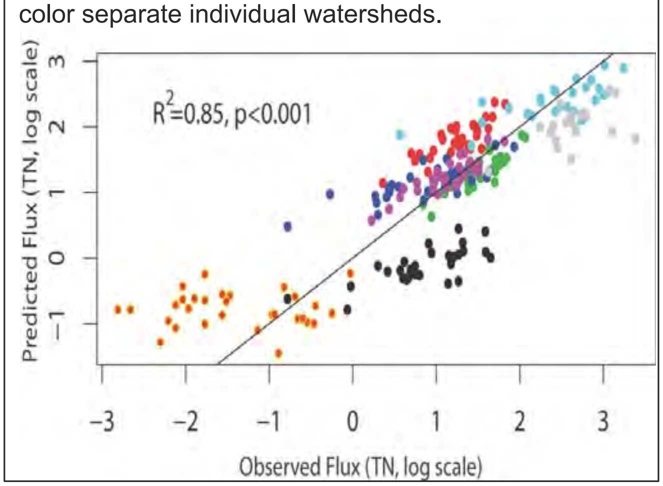
In year 3 (2019) we will collect soil biogeochemical and hydrologic data as part of the new i-Tree-based **Terrestrial PULSE** that will be a centerpiece of the Community Assembly and Biotic Potential research focus described below. Two hundred points will be selected randomly in the Gwynns Falls and Baisman Run watersheds. At each point, we will do biotic surveys (see methods below in the Community Assembly and Biotic Potential section) and make the suite of ecosystem function measurements described above. We will also collect more detailed data on impervious surface and green infrastructure features as input for the new i-Tree Hydro module that is designed for watershed scale analyses of vegetation and impervious cover effects on hydrology (Wang et al. 2008, Yang et al. 2011). i-Tree Hydro is a stand-alone application designed to simulate the effects of changes in tree and impervious cover characteristics within a defined watershed on stream flow and water quality (Yang and Endreny 2013, Stephan and Endreny 2016). i-Tree Hydro represents a statistical spatial distribution of runoff producing areas, relative to both upslope and downslope features that can potentially buffer water quantity and quality. It therefore fits conceptually between the statistically based BN models developed at the catchment scale, and the spatially explicit, mechanistic RHESSys model. Field observations are combined with high resolution topographic data to produce hydrologic assessments for each plot and to evaluate the effects of different plot features, e.g., impervious cover, green infrastructure features on hourly and total changes in stream flow and water quality (Wang et al. 2006). The i-Tree Hydro model can be used to determine how various best management practices affect water quality. In addition, by altering precipitation inputs to simulate storms of various intensities, the model can be used to determine how management practices can affect local flooding.

Data analysis: Flows of Materials

Our long-term records are now extensive enough to be used for novel multi-metric time-series and uncertainty analyses for BN modeling to test and refine mechanistic understanding and for development and testing of predictive simulation models (Mittman et al. 2012, Miles and Band, 2015, Schwartz and Smith 2014). We have begun to use new statistical approaches to synthesize and integrate our long-term watershed data. For example, a hierarchical Bayesian model was fit to the long-term data on annual watershed nitrogen export, with covariates for land cover and seasonal weather conditions. Comparison of observed and model predicted nitrogen fluxes (Fig 21) from across focal sub-watersheds demonstrates that while the predictor covariates are able to capture flux on average (R^2 = 0.85), there are important deficiencies in the model's ability to predict nitrogen export from some of the watersheds. This analysis highlights important sources of heterogeneity, in particular sewage infrastructure, that will be addressed in the next phase of our research.

We will continue to use probabilistic Bayesian models to integrate spatially explicit long-term data on annual watershed nitrogen export with process definitions that represent current understanding to identify uncertainties and refine understanding. We will expand these analyses to other variables (riparian water tables, soil:atmosphere gas fluxes), with covariates for variables such as forest cover, agricultural cover, total precipitation, mean temperature, an indicator for growing season, and time. Data from the watershed, riparian and biotic PULSEs will allow for quantifying the variability to include in models and will add a variety of mechanistic covariates. Combining these two data sets will allow us to investigate the spatial heterogeneity of biological communities across the urban landscape relative to the flow of materials. Locations of

Figure 21. Predicted versus observed total nitrogen flux from BES long-term study watersheds from 1998 – 2010. The solid line shows the 1:1 comparison and the color separate individual watersheds.



high versus low species richness, the proportions of exotic species, beta diversity, and community structure can be related to watershed structure and biogeochemical fluxes. The watershed and riparian PULSE data can also be related to the locational choice and governance network data sets (Section 2.2.3).

A focus of ecohydrological modeling has been RHESSys, a distributed ecohydrological model that operates at neighborhood to catchment scales with a spatial resolution of processes at the sub-parcel level (Tague and Band 2004). Balances of water, carbon and nitrogen are embedded within two-dimensional surface and subsurface hydrologic flow fields, such that upslope to downslope transport and subsidy of water and nutrients can be represented, the effects of riparian zones in variable source runoff generation and nitrogen processing, and redirection of drainage by infrastructure, such as sewers and curbs. RHESSys can accept management actions at the parcel level, and at scales representing aggregations of parcels or patches of increasing size, as temporal or state dependent events, and can simulate both terrestrial nutrient cycling and transport rates at the scale of patches including various hillslope flowpaths. Different urban forms and biotic assembly of the spatial arrangement of canopy cover, soils, impervious surface and drainage infrastructure (and temporal change in these patterns) can be explicitly incorporated and tested for impacts on stormwater and nutrient retention processes (Law et al. 2004, Mittman et al. 2012, Miles and Band 2015). Importantly, RHESSys can provide estimates of state and flux/transformation variables (e.g. soil moisture, nitrate concentrations, soil organic carbon) at scales commensurate to the distributed sampling planned. RHESSys is typically used within an uncertainty framework by allowing multiple realizations of key parameter values, and potential variation in process specification to both identify behavioral model forms (different models that can successfully predict system dynamics) and incorporate uncertainty in predictions. As discussed above, repeated iterations of model testing with new data can further improve model and parameter identifiability, including extending time series, and introduction of newly sampled variables. We have used RHESSys to evaluate changes in water, carbon and nutrient cycles associated with actual and simulated changes in land cover and infrastructure and in individual and institutional parcel scale land management choices associated with vegetation type (tree, shrubs, lawn), irrigation and fertilization in a set of our focal watersheds (Mittman et al, 2012; Miles and Band, 2015).

The stream and riparian survey along with NEXRAD radar data will enhance both the BN, i-Tree Hydro, and RHESSYs modeling to improve assessments of the drivers of heterogeneity in structure and function (and their interactions) across the landscape. Input from complementary research on groundwater heterogeneity (Ryan et al. 2010) also will help to refine these models.

2.2.2 Focal Area 2: Community Assembly and Differential Biotic Performance

Research Team: Swan, LaDeau, Pickett, Cadenasso, Rosi-Marshall, Szlavecz, Nilon, Nowak, Kelly.

The biological component of ecosystems is crucial to their metabolism and capacities to adjust to changing conditions. Therefore, one of our focal research areas seeks to quantify the assembly of biotic communities in heterogeneous urban space, and to understand their changes over time. We use the metacommunity concept (Liebold 2011) as a tool to test and apply the theory of dynamic heterogeneity. This concept embraces space explicitly in explaining biodiversity at local (α), across location (β), and regional (γ) scales. The environmental and social factors that regulate spatial variability in habitat quality across patches as well as organismal dispersal between patches are sources of heterogeneity. Furthermore, the heterogeneity in biotic community composition can feed back to generate spatially variable environmental conditions, which influence the types of decisions people make.

We hypothesize that species diversity in urban landscapes from parcel to neighborhood scales is maintained through a multiple suite of processes, including intentional and unintentional human-mediated dispersal, differential recruitment success, and possibly adaptation by species to novel ecological conditions in the urban landscape. The functional diversity of biological communities is maintained through subsequent species interactions. The form of the relationship between biodiversity at the taxonomic and functional scales and ecosystem function is mediated by numerous factors including environmental variables, human choices, and anthropogenic stressors at fine and neighborhood-level scales. We will continue long-term tree and bird datasets developed over the past 18 years to identify pattern, process, and function of biotic assembly and diversity across multiple taxa and add new PULSE efforts to expand the biotic scope and develop the dynamic heterogeneity context for our analyses.

Specific hypotheses that we will test include:

• Present day patterns of biological diversity have resulted from legacies of human choices and anthropogenic stressors that mediate metapopulation dynamics, interspecific variability in environmental constraints, and the nature of species interactions. As one moves across the rural to urban gradient, we expect that the influence of human disturbances on populations and communities will become increasingly severe *and the importance of biological interactions for community structure will decrease*. In effect, increasing disturbance will remove the effects of the local biological filters of competition and predation. Because many populations are limited by human disturbance they cannot reach abundances at which competitors and predators will play a significant role in eliminating species from the community. Such effects will be complicated by the human choices people make to plant/remove species and any collateral effects of such introductions. We predict that certain introduced species might proliferate in disturbed environments owing to compatible life-history strategies.

• Species richness from parcel to neighborhood scales is maintained through metacommunity processes, including intentional human-mediated dispersal. The functional diversity of biological communities is maintained through (subsequent) species interactions. In urban ecosystems, disturbance should lead to a decline in taxonomic diversity as disturbance-intolerant species are eliminated from the local community (Shochat et al. 2010). Theoretical and empirical work suggests that in highly disturbed communities, species assemblages should exhibit relatively low functional diversity, as biotic interactions that promote trait divergence (e.g., character displacement in competing assemblages) are relaxed in favor of species with similar traits to deal with the strong environmental filtering imposed by disturbance (e.g., Walker 1992). Maintenance of local diversity may be supported, in part, by the spontaneous and/or purposeful dispersal of species valued by humans.

• The form of the relationship between biodiversity at the phylogenetic, taxonomic, and functional scales and ecosystem function is mediated by human choices and anthropogenic stressors, with nonlinearities across fine, neighborhood-level scales. We hypothesize that fundamentally different relationships occur among phylogenetic, taxonomic and functional diversity in the urban and suburban habitats compared with rural analogs. These are constrained by two prevailing factors: (a) changes in dispersal imposed by fragmentation and/or movement by humans, and (b) high local environmental filtering as a result of abiotic stress (e.g., moisture availability, degraded soil or water quality). The result can be a maintenance of taxonomic diversity, but a reduction in both phylogenetic and functional diversities over time.

Methods: Community Assembly and Biotic Potential

Community composition and abundance of several focal taxa have been measured since 1998 as a core BES data set. We will continue the collection of these data and initiate a new series of PULSEs to investigate large-scale patterns in species distributions and long-term trends in community assembly and biotic performance. The sampling PULSEs are designed to be spatially congruent with data on biophysical drivers, built and social drivers of the ecological communities, and measures of ecosystem function throughout metropolitan Baltimore. The organisms we sample are important for understanding structure and function of urban ecosystems. Canopy trees and understory shrubs provide the structural framework of the urban forest, with its influence on other organisms, and on human effects such as heat island and neighborhood well-being (Troy et al. 2007). Herbaceous plants contribute to forest understory and are the dominants in many managed and abandoned parcels (Johnson and Swan 2014). Birds, insects, soil invertebrates, and stream biofilm organisms are key components of urban food webs. These taxa affect each others' population numbers and distributions, mediate organic matter decomposition, and control aquatic and terrestrial productivity (LaDeau et al. 2013, Nilon et al. 2011).

Urban forest canopy (i-Tree): The main platform for long-term biotic data collection in BES has been the i-Tree sampling and analysis tools that use standardized field data from 202 stratified randomly located permanent plots to quantify urban forest structure, species composition, tree health, and diameter distribution (Nowak et al. 2008). This sampling has now been conducted four times (1999, 2004, 2009, 2014). We propose to continue this effort with sampling in 2019. At these plots, we will continue to identify and measure every individual woody plant species to estimate individual tree growth, health and mortality, net primary production, species composition of the forest, and changes in species composition (Nowak et al 2008; Swan et al. *in review*). These repeated measures of the Baltimore forest canopy are part of a larger network to characterize the urban forest canopy in cities throughout the US. Baltimore is one of the few places where these measurements have been made repeatedly, allowing for comparison with other cities (Nowak et al 2013a, b) and over time.

Terrestrial PULSE: We propose to establish a new suite of 200 plots where we will collect data on species composition and abundance across multiple taxonomic groups, including trees (using i-Tree protocols), herbaceous plants, birds, insects, ground-dwelling invertebrates and soil microbial communities, to characterize biophysical drivers of diversity at multiple scales. This sampling regime will allow us to relate patterns of biodiversity to heterogeneity in local management regimes (or lack thereof) and to the long-term dynamics of the urban forest canopy. A subset of these plots (50 to 100, after receiving permission from parcel owners) will overlap with the existing i-Tree plots located within Baltimore City. The additional plots will span the entire Gwynns Falls watershed, which covers an urban to suburban gradient traversing Baltimore City and County as well as the exurban Baisman Run watershed. Plots will also be selected in a stratified random pattern to facilitate experimental contrasts among urban, suburban and exurban locations, vacant lots, and to ensure a sufficient density of plots in our focal watersheds: WS263, Dead Run 5, Baisman Run. Resident-occupied plots will be selected from respondents to the BES long-term telephone survey who indicate a willingness to participate in our study. We have used this approach to selecting urban parcels with success in a previous study of six cities across the U.S., where over 60% of respondents indicated a willingness to have measurements made in their yards (Polsky et al. 2014). We will sample these new plots in year 3 (2019) measuring the suite of variables described below. Data will be centrally collected, processed and distributed to biotic research team members. Synthesis and integration of the different data streams will be facilitated by the synthesis team and postdoc (Section 2.3). A similar approach for data collection and analysis was used elsewhere (Groffman et al. 2014).

Herbaceous Plants: Vegetation will be sampled following Johnson et al (2015) during the Terrestrial PULSE. Individuals will be sampled when at least 15 cm high to allow identification of species. Percent cover for each species will be visually estimated in stratified, randomly-placed 1 m^2 quadrats distributed along a transects parallel lengthwise through the center of the plot. A total of n=6, 1 m^2 quadrats will be placed randomly along a transect. Functional trait measurements will be recorded in the field for at least 25 individuals for each species: specific leaf area, height, number of flowers. Trait databases will be consulted for life form and ecological specialization (e.g., perennial/annual, legume).

Urban Bird Population Dynamics: For the last 9 years, we have used a subset of the i-Tree plots to investigate the bird community across Baltimore City and have correlated bird species composition with land cover variables, i-Tree plot variables, and census block group variables. Co-location of bird monitoring with these plots facilitates use of BES data on local environmental features and household- and neighborhood-scale management collected from the same sites. We will continue annual monitoring of the breeding bird communities using 82 sample points drawn from the i-Tree plots in Baltimore City and 50 sites drawn from more intensive i-Tree sampling that was done in WS263. Each bird census point will be surveyed (five-minute unlimited radius count surveys) three times between May and July between sunrise and 4 h post-sunrise. We will record species, distance from observer, and type of detection (visual, call or song) for each bird detected as well as wind speed and temperature (Nilon et al. 2011, Rega et al. 2015). We will also expand our monitoring efforts to newly established i-Tree plots in the Dead Run and Baisman's Run watersheds. 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. 2011). The presence of each community type is significantly correlated with local or lot-scale 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). Previously, we constructed a spatial Bayesian hierarchical model for bird detection data, i-Tree plot data, land cover data, and census block group data to predict American robin abundance (Wu et al. 2015). We will continue to use this approach for other species, and will integrate these data with social data (Section 2.2.3).

Insects: We have identified three protocols for rapid assessment of pollinator insects and blood-feeding insects commonly found in urban landscapes. A pollinator assessment tool was piloted in 2015 with the BES summer student program (Section 3). We will conduct surveys throughout the spring/summer seasons, as phenology changes across sampling dates during the Terrestrial PULSE. During these surveys, we will measure pollinator activity, tick presence, and resting insects associated with the vegetation and larger visible invertebrates using sweep nets. These methods were successful for collecting small invertebrates (Reed et al. 2010) and for mosquito collection by LaDeau in 2015.

Ground-dwelling invertebrate communities: We will sample soil macroinvertebrates using pitfall traps (65 mm diameter x 70 mm deep) deployed for two weeks as part of the terrestrial PULSE. Samples will be sorted to major orders or similar higher taxa and preserved in 80% ethanol. Isopods, ants, millipedes, and carabid beetles will be identified to species level. For nematodes and enchytraeids, approximately 50 g soil will be collected from the top 5 cm of each plot. Animals will be extracted in Baerman funnels. Nematodes will be identified to genus. Microarthropods will be extracted in Berlese funnels and sorted to functional groups.

Stream biofilm communities: We will collect samples as part of the stream/riparian PULSE to investigate aquatic microbial community diversity patterns. We have collected preliminary data that indicates that biofilm communities in the most urban streams are as diverse as those in the more rural streams. Our data indicate that microbial communities are differentially sensitive to urban stressors (Rosi-Marshall et al. 2013). We propose to use high throughput sequencing, e.g. Illumina, to examine the bacterial and algal community structure as we have done to date (e.g. Rosi-Marshall et al. 2013, Drury et al. 2013, Lee et al. *in review*).

Data analysis: Community Assembly and Biotic Potential

We have three primary objectives for analysis of biotic community data. First, we will identify the spatial structure of heterogeneity in community composition and diversity metrics. Second, we will discover the suite of variables that drive changes in community diversity across the landscape and over time. Finally, we will identify how heterogeneity in biodiversity influences ecosystem function. While there are multiple metrics of diversity, we will specifically evaluate local (alpha) and between-habitat (beta) diversity (Whittaker 1960) using species richness and functional/trait based diversity at parcel, neighborhood and watershed levels to identify key scales of turnover (beta diversity) and important drivers of spatial heterogeneity. The urban landscape is a mosaic of ecological habitat with heterogeneous quality, persistence, and accessibility. Biological diversity is determined through stochasticity and by deterministic processes defined by species traits (e.g., dispersal ability, growth rate), as well as by human intervention.

The spatially extensive PULSE will be analyzed for the spatial heterogeneity of biotic communities across the urban landscape. The spatial distributions of biota will be examined at the level of patches to evaluate alpha (local) diversity and beta (turnover) diversity across and between taxa. The relationships between alpha and beta diversity will be regressed against potential drivers of spatial heterogeneity, especially examining the exotic and/or invasive species components. We will also develop spatial mosaics of the biological taxa and compare them to each other, e.g. are mosquito populations related to birds or plant communities? The relationship of biotic structure to commonly recognized ecosystem services will be examined using the i-Tree model (Escobedo and Nowak 2009). i-Tree algorithms are combined with local hourly air pollution and meteorological data to calculate vegetation effects on ozone and particulate air pollution, climate modification and building energy use. We will also compare mosaics to socially-derived aspects of the urban landscape to investigate how communities and diversity are related to lifestyle features (Grove et al. 2014) or other socio-demographic characteristics (Troy et al. 2012). Over the long-term, the repeated spatially extensive biotic PULSEs will expose patterns of population spread over space and the resulting dynamics of biotic communities.

We will quantify species richness and functional diversity at parcel-to-watershed levels for each of the focal taxonomic groups. We will systematically evaluate the relative importance of deterministic and stochastic processes in generating and sustaining biological communities using long-term BES data and the new targeted biodiversity sampling PULSEs. Null distribution models will be generated for species observations within each taxon among sites, to be compared to observed frequencies using randomization procedures to understand the relative importance of stochastic and deterministic assembly processes across sites evaluated at different spatial scales (Chase et al. 2011). We will use hierarchical regression to examine how biological diversity is related to social structure and capacity within a neighborhood (e.g., property value, crime, perception of the environment, Section 2.2.3), as well as to evaluate patterns in invasive species presence and dominance across taxonomic groups. For example, we will use a spatially-explicit model informed by the long-term data streams and updated with each field PULSE to model state changes in biological diversity through time, using metrics and spatial scale as defined by analyses above. For example, species richness of birds and trees are both influenced by a suite of environmental and social predictor variables. We wish to understand where species coexistence allows for high biodiversity in each taxon and how this changes over time. This will require each taxon to have its own regression model. For example, we may hypothesize that for a given sample date and plot, tree species richness is a function of the previous state, impervious surface, neighborhood income, plot management, and weather variables. Each variable is potentially dynamic and all unknowns are estimated as posterior probability distributions in a Bayesian framework focusing on biota. This framework allows for shared causal structure across taxa, so the influence of socio-economic status can be evaluated simultaneously across taxonomic levels.

2.2.3 Focal Area 3: The Choices that People and Institutions Make

Research Team: Grove, Irwin, Ogden, Boone, Buckley, and Troy.

Locational choice theory provides an economics-based approach to explaining household and firm decisions (Tiebout 1956, Alonso 1964, Ottaviano and Thisse 2014). We recognize, however, that additional social theories are needed to examine the incentives and constraints that are exogenous at the individual household level and how these higher-level drivers change over time. These constraints are due to cumulative actions of individuals, but also to decisions by other actors -- communities, governments, NGOs, businesses -- and outcomes of higher-level processes such as social stratification (Troy et al. 2007, Lord and Norquist 2010), civic networks (Campbell 2014), and globalization (Robbins 2012, Ogden et al. 2013). Our general hypothesis posits that locational choices and housing markets are both an outcome and driver of changes in ecological structures and functions over the long term (Irwin and Bockstael 2002) and dis/amenities (von Doehren and Haase 2015). More specifically, we propose to investigate the following to increase our understanding of dynamic heterogeneity: 1) the tipping points and spatial effects of urban redevelopment on locational choices and housing markets; 2) the role of social inequities and its legacies on ecological conditions and concomitant feedbacks to human choices; 3) the ecological drivers of governance networks; and 4) the connections between governance networks and neighborhood norms and ecological conditions.

Specific hypotheses that we will test include:

• Urban redevelopment can improve ecological amenities and reduce environmental hazards, which in turn can generate positive spatial benefits for surrounding housing values and induce greater neighborhood housing demand of varying distance (spillover effects). Previous work using hedonic modeling has demonstrated the value of addressing ecological disamenities such as brownfields sites within an urban setting, leading to large increases in surrounding housing values. However, these and other studies rely on an assumption of perfectly functioning markets and costless moving by households. Older urban neighborhoods often have an excess supply of both housing and urban land due to the durability of structures, expense of land redevelopment, and costs of moving to households. An oversupply of deteriorating housing stock can generate negative neighborhood externalities—e.g., higher crime rates and deteriorating green space—that, in addition to other market frictions, dampen the housing market and induce cycles of urban decline that can last for decades. Under these conditions, the real estate market is inefficient and the value of environmental amenities is not fully revealed by the traditional hedonic approach. An example of limitations of the hedonic approach in Baltimore City is the Vacants to Values Program as a tool to spur revitalization in high-abandonment neighborhoods. This is an attempt to compensate for the failure of the traditional housing market in many neighborhoods, and is an important element to the development of the city's Green Network Master Plan.

We further hypothesize that the durability and depreciation of housing stock leads to tipping points in urban housing markets and the dynamics of urban redevelopment. Glaeser and Gyourko (2005) first noted the existence of these tipping points in the context of new home development: if the value of housing dips below construction costs, there is no incentive for developers to invest in new housing. The durability of the existing stock prevents supply from readily adjusting to the reduced demand and suppresses housing prices. In contrast, the market responds much more quickly to growing demand since adding new houses is not subject to the same durability constraint. We predict that the same dynamics underlie urban redevelopment and that this tipping point mediates the positive spatial effects of nearby ecological amenities and disamenities. Specifically, we hypothesize three cases: 1) Investments in local parks or other greening efforts may generate positive price benefits to nearby houses, but will not spur urban redevelopment when housing prices are well below the costs of redevelopment. 2) Such investments can generate sufficient spatial effects that spur redevelopment when housing prices are just below this cost threshold. 3) Greening projects that both generate positive ecological amenities and remove excess housing supply are the most effective at spurring redevelopment since they act on both the demand and supply sides in ways that bid up housing values. The City of Baltimore has begun a process of clearing many vacant homes and redeveloping or greening vacant lots through its Vacants to Values program. In addition to investigating these spillover hypotheses of heterogeneous, spatial effects of ecological dis/amenities, we will also examine how redevelopment in the urban core influences intra-metropolitan dynamics, including migration within and between the city and suburbs and land use changes across the city-suburban-exurban gradient.

• Residential segregation and its legacies constrain current and future locational and land choices of households and reinforce existing inequities, including the heterogeneous distribution of ecological amenities and disamenities. Neighborhoods in Baltimore have experienced long-term patterns and processes of residential segregation and inequities, producing differential investments in critical resources such as housing, transportation and amenities including parks and street trees, and disamenities such as polluting businesses, crime and vacant lands. We hypothesize that these long-term patterns create persistent legacies that constrain current and future locational and land choices in several ways. First, residents' long-term experience with disinvestment and absence of green amenities may influence their sense of place, and constrain their vision of a greener, more sustainable environment. Second, past experiences with disinvestment, failed government programs, and inability to maintain current green investments may cause residents to eschew new greening programs. Third, concerns over gentrification and displacement may lead residents to be reluctant to support greening and sustainability initiatives that may affect neighborhood desirability and property values and therefore may cause them to be displaced by gentrification. Further, certain "green investments" may in fact serve as disamenities in certain contexts in the absence of active stewardship and management. For instance, it has been found that in Baltimore that property values are negatively affected by proximity to parks when those parks are characterized by high crime, while in low crime areas the opposite is true.

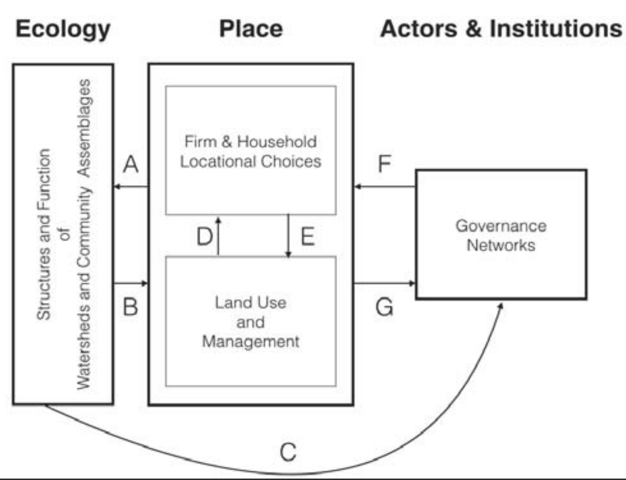
• Changes in ecological structure, function and environmental hazards can lead to changes in governance networks. Changes in ecological structure and function include diminished biophysical processes affecting watershed fluxes and community assembly. These changes in ecological structures and functions lead us to predict that governance networks will change through an increasing number of members in the network, a decrease in the density and centralization of the network, addition of governance levels from regional to parcel, and a bifurcation in the network with some actors focusing on conserving current conditions, while others seek to reverse decline and address environmental and economic justice. While ecological structures and functions may have a significant effect on governance networks, there is a great need to understand *which* ecological structures and functions are most important to those networks, how governance networks change over time, and whether governance networks are more likely to respond to gradual, punctuated, or anticipated changes in ecological structures and functions. For instance, Baltimore City and the surrounding counties are implementing Watershed Implementation Plans (WIPs), which are legally required by their municipal stormwater permits from the Maryland Department of the Environment and Federal Environmental Projection Agency. WIPs address a variety of total maximum daily loads (TMDLs) including nutrients, sediment, trash, and involve a variety of strategies and projects including stream restorations, sub-division retention ponds, and mitigation on individual, private residential parcels. These strategies involve a diverse set of actors, owners, and types of landuses that are increasingly incorporated into each municipality's overall sustainability initiatives.

• We hypothesize that sustainability projects on residential lands are more likely to be adopted for the private landscape of back yards than for the civic or public-facing landscape of front yards. In the cases where sustainability projects are adopted for the civic or public-facing landscape of front yards, those projects are more likely to conform to existing neighborhood aesthetics. Informal norms may affect fine scale, ecologically impactful land management. Both the quantity of vegetation and expenditures on landscaping have been found to be associated with a number of lifestyle related factors that suggest the importance of social groups beyond income and race. A given household's land management preferences are often affected by *informal* means such as concerns about real estate value and neighbor judgments. Neighborhood-level norms and land management choices can influence individual household behaviors, and may signal social cohesion and wealth, power, or prestige by indicating membership in a desirable social group. This phenomenon has been formalized in the Ecology of Prestige, which hypothesizes that "household patterns of consumption and expenditure on environmentally relevant goods and services are motivated by group identity and perceptions of social status associated with different lifestyles." However, the ecology of prestige may operate differently when the "public/private" spaces of individual parcels are evaluated. We predict that land management practices and the adoption of sustainability projects in residential areas will differ between the public landscape of residential front yards and the private landscape of back yards. Novel, unfamiliar, or "messy" land management practices and sustainability projects including rain gardens, bioswales, rain barrels, and wildlife habitat plantings are unlikely to conform with the expectations of the public landscape: neat, weed-free, and green. Instead, diverse, novel land management practices and sustainability projects are more likely to be found in the private landscape and associated with higher levels of ecological function and biodiversity.

Methods: Locational Choice and Land Management Decisions
To test our hypotheses, we will use our long term social surveys and publicly available data to quantify people- and place-based drivers of 1) public and private investments affecting locational choices, land use, and housing markets that influence and respond to ecological changes; 2) governance networks that modify and respond to those social and ecological drivers and outcomes; 3) governance networks and neighborhood norms and their influence on land choices among households, firms, communities, and organizations, and 4) the role of long-term social dynamics such as economic opportunities and racial segregation that may influence locational choices (Fig 22). Key to our efforts is the use of an extensive / intensive data strategy that incorporates a mixed-methods approaches (Maxwell 2016) with data specified in terms of location, time and scale (Grove et al. 2013, Connolly et al. 2015, Grove et al. 2015a). To date, we have conducted extensive, spatially explicit household telephone and organizational network surveys, produced high-resolution land cover data (~1 m), and assembled long-term data on the creation of subdivisions, on land and housing markets, and on neighborhood socio-demographics. We will continue to collect these long-term data and will supplement these data by adding intensive new data streams: 1) we will coordinate with PULSEs to co-locate and collect intensive household and neighborhood-level data and 2) examine long-term changes in key organizations from network surveys.

Household Telephone Survey examines locational and land management choices, including the direct assessment of environmental knowledge, values, and behaviors; how these influence ecosystem structure and function; *and* how changes in ecosystem structure and function may affect people's physical activity, social cohesion, neighborhood desirability and willingness to move over time (Vemuri et al. 2011, Holtan et al. 2014). The telephone survey is spatially explicit at the parcel and household level, facilitating integration with remotely-sensed, field, administrative, and census data (Grove et al. 2015a). The survey has a sample size of ~3,000 completed surveys and is stratified by population density, income, education, race, and lifestage (Vemuri et al. 2011). The survey sampling protocol can be intensified geographically for before-after-controlled-intervention assessments (BACI) (Hager et al. 2013). The survey asks whether participants would be interested in follow-up, intensive surveys, including open-ended interviews and ecological field surveys of their property. In the past, 60% of participants have agreed to follow-up surveys, facilitating highly successful extensive-intensive, nested data sampling of social and ecological data (Polsky et al. 2014, Groffman et al. 2016). We will use responses to this question to select households to participate in the field PULSEs. Components of the telephone survey are related to each of the sub-hypotheses. We will conduct the household telephone survey in 2017.

Figure 22. Links among ecology, place and actors and institutions.



Land cover data will continue to be produced using object-oriented classification techniques from high-resolution multi-spectral imagery (~1 m, National Aerial Imagery Program: NAIP) and LiDAR. These data permit the characterization of land cover and its spatial structure and configuration at multiple scales, including the parcel and sub-parcel scale over time (Zhou et al. 2006, Zhou and Troy 2008). These data are produced on a six-year cycle (2016, 2022) and are an essential component for quantifying the distribution of ecological dis/amenities for all our sub-hypotheses in general and to characterize differences in landcover structure in front and back yards in particular.

Locational choice and land use data on households, landowners, and firms over the long-term reveal the factors that influence the demand and supply of land and housing at neighborhood and regional scales, how these processes interact across the urban-suburban-exurban gradient and how they change over time (e.g., Gnagey and Irwin *in review*, Irwin et al. *in review*, Livy and Klaiber 2016, Newburn and Ferris 2015, Wrenn and Irwin 2015. Zhang et al*. in press*). These data include 1) parcel-level land use, including the creation of subdivisions; 2) individual housing and land transactions; and (3) homeowner characteristics, including income, race and marital status. We will add **Urban redevelopment data** including demolition permits, vacant land and homes, and other features at the neighborhood scale associated with housing markets: demographics, housing, community development, crime and safety, arts and culture, and ecological dis/amenities such as tree plantings, parks, and other open spaces. Crime data will also be analyzed to examine spatial trends, including perceived and actual public safety, given the importance of this factor in determining locational choices. These data will permit us to examine spatial effects (spillovers) and tipping points in urban redevelopment.

Governance Network survey includes all government agencies, non-governmental organizations, businesses, and community groups that affect how land and water are managed. The network survey collects data on organizational exchanges of information, funds, materials, staff, and the locations where organizations work. These data permit networks to be analyzed in terms of network membership (total and by sector), density, centrality, and nodal and marginal actors (Svendsen and Campbell 2008; Romolini 2012). Because the survey is spatially explicit, network data are integrated and analyzed in terms of placed-based social and ecological phenomenon. In 2011, 350 members were identified and surveyed in the network (Romolini 2012; Romolini et al. 2013). The extensive governance network survey will be repeated in 2018. We will add ***organizational histories*** to the governance network survey for both nodal and marginal organizations. These histories will be created based upon key informant surveys and archival data to understand which ecological structures and functions are most important to organizations and how the importance of different ecological structures and functions change over time. We will also collect information about how organizations change over time and how they respond to gradual, punctuated, or anticipated changes in ecological structures and functions (Ernstson et al. 2007, Connolly et al. 2013).

Neighborhood Ethnographies will be added to BES. The term “sense of place” describes the ways that geographic locations, such as neighborhoods, are made meaningful through social history and collective memory (e.g., Basso 1996). Ethnographies of place reveal the ways in which sense of place shapes environmental decision making by residents and policymakers, including sustainability planning (Newman and Jennings 2008). Work in political ecology is complementary, and demonstrates *how* choice is constrained by economic and political structures (Robbins 2012). Our research approach combines the analytics of place-based qualitative research with political ecology to examine the ways that place is produced and contested at multiple scales. The ethnographies will include intensive, open-ended household surveys to examine specific motivations, formal and informal norms, and behaviors of household locational and land choices. These surveys will be coupled with key informant interviews and archival data collection and analyses to create neighborhood ethnographies. The selection of neighborhoods will be coordinated with the long-term Watershed and Community Assembly field PULSEs. Households will be selected from the extensive household telephone survey (above). Neighborhood ethnographies will be created annually in the 3 focal watersheds. These data will be crucial for examining how residential segregation and informal and formal norms constrain current and future land choices.

Data analysis: Locational Choice and Land Management Decisions

A critical feature of BES is the integration and synthesis of disparate data to facilitate analysis of our theory of dynamic heterogeneity and to test our general and sub-hypotheses. Integration of social, economic, and ecological data occurs by linking datasets with “spatial hooks,” such as latitude/longitude or address, or with semantic terms (Grove et al. 2015a). In addition to location or semantic terms, these data can be further specified in terms of time and scale, which permits novel analyses. Examples of analyses include 1) spatial analysis: spatial pattern and configuration of housing, land cover and ecological dis/amenities, and of spillover and neighborhood effects (e.g., Carrion and Irwin 2010, Wrenn and Irwin 2012, Zhang et al. In press); 2) multi-level analyses: interacting phenomenon at household/parcel, neighborhood, and municipal/county levels (e.g., Livy 2015); 3) change analysis: such as rates of change, lags, and legacies, before-after-controlled-interventions associated with changes in policies, plans, and management, and responses to extreme events such as flooding and heatwaves (e.g., Wrenn and Irwin 2015, Irwin et al. *in review*); 4) network analysis: organizational exchanges of information, funds, materials, staff, and locations where organizations work; network membership (total and by sector), and network structure in terms of density, centrality, and nodal and marginal actors (Svendsen and Campbell 2008, Fisher et al. 2012, Romolini 2012); and 5) content analysis: qualitative data from archival records and household and organizational open-ended surveys.

It is important to note here that the combination of these analyses, made possible because of our emphasis on long-term, spatially-explicit, multi-scale data creates exciting opportunities to understand the complexity of urban social ecological systems (Cadenasso et al. 2006, and Grove et al. 2015b). Previously, our quantitative social modeling focused on household locational choice, ecological (dis)amenities, housing values, and land development and policy in suburban and exurban areas of the Baltimore region. We will continue to build on this work in the next phase of BES by extending our quantitative, empirically-based models of housing markets, locational choice, and land use change to examine the consequences of vacancies, environmental hazards and redevelopment in the city, and the extent to which these housing market dynamics are influenced by housing demand and supply in the suburban and exurban region of Baltimore. Specific analyses include hedonic pricing models to identify 1) the spillover effects of the City's "Vacants to Values" redevelopment program and Green Network master plan on housing values in targeted and adjacent neighborhoods of Baltimore City; 2) the influence of environmental hazards, including flooding, extreme weather events, and pollution exposure, and improved ecosystem services in urban areas, including cleanup of hazardous waste, remediation of brownfields and creation of green infrastructure, on housing values; and 3) the interdependencies of housing and land markets across urban, suburban and exurban counties of the Baltimore metro region. We will use locational choice modeling to examine how urban redevelopment and environmental risks influence the residential location choices of heterogeneous households. Finally, simulation modeling will be used to examine the potential effects of future policy scenarios, such as new green infrastructure and urban redevelopment projects in the City's Green Network Master Plan, on the locational choices of households within Baltimore City and across the urban, suburban and exurban Baltimore region.

Section 2.3 Moving from Focal Areas to Integration
Project-wide effort led by: LaDeau, Rosi-Marshall, Cadenasso, Baker, Band, Pickett, Irwin, Grove.

Our approach to integration across physical, biological, and social science research domains will be to bring together long-term data streams using the process-based simulation models and hierarchical statistical analysis, discussed above. These approaches will be applied to our long-term watershed, extensive plot and social survey data, as well as to data from our new extensive PULSEs. Integration will also be fostered by focusing on three small watersheds ranging from a dense urban watershed with an underserved population and significant numbers of vacant lots (WS263), a high socio-economic status, low density exurban watershed served by septic systems (Baisman Run), and an older, denser, sewered suburban watershed (DR5). To date, the RHESSys model operating at daily time steps has been developed for the DR5 and Baisman Run catchments (Mittman et al 2012; Miles and Band 2015).

We will continue to develop and integrate the distributed ecohydrological and land use-locational choice models as tools for project integration. In addition, synthesis in this phase of BES will be facilitated by a new project structure and new position for a "synthesis post doc" devoted 100% to synthesis activities. Our new project structure is centered on using core LTER funds to support centralized collection of long-term data streams (watersheds, intensive plots and surveys, extensive field PULSEs, social-demographic data) and targeted subawards to facilitate analysis of these data. Project integration and synthesis will be coordinated by our Project Synthesis Team (PST) headed by Co-PI LaDeau. This team will meet monthly and will work closely with our "synthesis postdoc", who will facilitate synthesis and integration in the project. The synthesis postdoc will be responsible for working with the PST and the Information Manager to collect, organize and distribute datasets that facilitate cross-disciplinary analysis. The PST will collate individual long-term data streams produced by the proposed extensive field PULSEs for hierarchical statistical analysis and simulation modeling. Development of this new synthesis approach will also be practically and conceptually facilitated by our participation in two Urban Sustainability Research Network projects, one focused on integrated water systems and the other focused on urban responses to extreme events. Both SRN projects fund a cadre of synthesis postdocs and graduate students and will be a resource of ideas and interactions for the BES LTER synthesis postdoc and PST.

Simulation modeling will include i-Tree modeling of urban forest structure (e.g., species composition, number of trees, tree density, tree health, etc.), the amount of pollution (ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter <10 μ) removed by the urban forest, urban forest volatile organic compound emissions, and the relative impact of tree species on net ozone and carbon monoxide formation. i-Tree also estimates the economic benefits of tree effects on air quality, total carbon stored and net carbon annually sequestered by the urban forest, building energy use and consequent effects on carbon dioxide emissions from power plants. Other parameters estimated by

i-Tree include yearly tree canopy rainfall interception summarized by tree species or land use, tree pollen allergenicity index, pest risk analyses based on host susceptibility, and pest/disease range and tree structural value. i-Tree Hydro modeling will simulate the effects of changes in tree and impervious cover characteristics within a defined watershed on stream flow and water quality. The spatial statistical approach of i-Tree Hydro, complements the mechanistic, spatially explicit approach of RHESSys, and catchment-scale analysis of annual nutrient flux provided by the BN methods. We will collect detailed field data at multiple scales to test and improve the scientific soundness of these models.

The PST will apply Bayesian hierarchical regression modeling to our long-term data (Section 2.1.5). Preliminary analysis of watershed nitrogen export using these techniques has discovered important sources of heterogeneity that we propose to address in the next phase of BES. We will apply these approaches to our long-term data on watershed hydrology and biogeochemistry, soil:atmosphere trace gas fluxes, riparian water tables and chemistry, soil temperature and moisture and soil solution chemistry, and social science variables (telephone survey). Moreover, we will use the new data streams produced by our extensive field PULSEs of streams, riparian zones, herbaceous vegetation, insects, mosquitoes, etc. to explore dynamic heterogeneity of numerous dimensions of the urban mosaic. We will also explore relationships among these dimensions to identify the significant drivers of long-term ecological change in an urban ecosystem.

In addition to the integrative modeling and statistical analyses, the PST will continue to contribute to the growth of urban ecological theory, as a tool to understand how Baltimore fits in the diverse dynamics of urban change throughout the United States (Pickett et al. 2011, Cadenasso et al. 2013). Theories of sustainability, resilience, and complexity are ripe for further exploration as synthesis tools for BES (Childers et al. 2014, Pickett et al. 2014). Theoretical frameworks will also be explored to improve the understanding of urbanization and urban heterogeneity in both developing and industrial countries (Cadenasso et al. 2006, McHale et al. 2015, Pickett and Zhou 2015).

Section 2.4 Related Research Our project structure is centered on using core LTER funds to support centralized collection of long-term data streams (watersheds, intensive plots and surveys, extensive field PULSEs, socio-demographic data) and targeted subawards to facilitate analysis of these data. This structure helps prioritize the LTER budgeting process and creates a powerful platform for related research efforts. The USDA Forest Service Urban Field station in Baltimore is fundamental to BES. It receives LTER funds to collect key long-term data (e.g., i-Tree, social science) and personnel, related research, and analysis of BES data are made available by the Forest Service collaboration. The long-term data platform established by BES has facilitated acquisition of other grants from NSF and other agencies including grants for an Urban Sustainability Research Coordination Network, Water Sustainability and Climate, Coastal Sustainability, two Urban Sustainability Research Network grants, Coupled Natural Human Systems, a Math Science Partnership, STEM +C, and Ecosystem Studies. A Macrosystems Biology project compares Baltimore with five other cities across the U.S., including Phoenix. In addition to these funded projects, BES also provides an “intellectual home” for many collaborators, graduate and undergraduate students. Our annual meeting, typically attended by over 100 participants, and our quarterly meetings focused on specific research themes are well attended by BES participants and collaborators. Thus BES is a vibrant community of scientists dedicated to fostering the research set forth in the proposal and far beyond.

Cross-Site Research: Our sibling urban LTER program in Phoenix (CAP) and BES have a long history of collaboration. The two projects jointly direct the Urban Sustainability Research Coordination Network.

Much of our cross-site work with CAP scientists has been organic and informal, though, and we propose to strengthen and formalize this connection. We propose to send a BES scientist and student to the CAP Annual Meeting every year and we will host a CAP student and scientist at our annual All Hands Meetings. Our Project Management Committee (PMC) will work with the CAP Leadership Team to choose a cross-site collaboration theme, e.g. bird biodiversity, or residential landscapes, and we will use that theme to decide which "ambassadors" to send to each other's meetings. While there, they will meet with the appropriate colleagues and begin work on cross-site comparative projects.

SECTION 3: EDUCATION AND OUTREACH ACTIVITES

BES will build on collaborations and partnerships with city and county public schools, NGO's, city, county, state and federal agencies, decision makers and citizens. BES education and engagement is spearheaded by a team of scientists, educators, and community organizers from the Parks & People Foundation, UMBC, the USDA Forest Service, and the Cary Institute. BES activities include:

Schoolyard LTER/Education Programs. BES schoolyard education supports place- and science-based teaching and learning about urban ecosystems using BES approaches and data in the schools. Our core programs will include: a) continued work with teachers through the Baltimore Partnership for Environmental Science Literacy, b) partnerships with high priority Baltimore City Public schools, and c) developing tools for enhancing data literacy in local education systems. Most of these efforts focus on the Baltimore City Schools, a majority minority school district.

Our work with teachers fills a need in Baltimore for professional teacher training in environmental science knowledge and instruction, bringing BES and related science into curriculum and instruction across all disciplines. We provide on-going support of a learning community of teachers, scientists, and science educators through year-long Teacher Institutes. We will continue these institutes to develop, refine, and disseminate resources for K-12 and undergraduate teaching. In close formal collaboration with the Office of Science in the Baltimore City Schools, we will develop modules that satisfy the Next Generation Science Standards for "three dimensional teaching," bringing together BES data, models, and science practices from BES. We will use BES models, data, and cross-cutting ideas as they apply to core science classes in biology, physics and chemistry, as well as environmental science electives.

BES has established partnerships, largely leveraged by non-NSF funds, with targeted Baltimore City schools. Close relationships with Green Street Academy, an environment-focused public middle and high school, and Francis Scott Key Elementary/Middle School will be continued, and other schools added as opportunities and funds become available. These partnerships allow us to work in-depth and over the long term with schools committed to infusing BES science across grades and curriculum, and link BES with a school district with 83% African-American students.

To enhance data literacy, we will expand our work in creating teacher- and student-friendly datasets based on BES. We will continue the Baltimore Data Jam competition, where middle and high school students analyze and interpret BES datasets and then use their creativity to convey their findings to a lay audience. The data sets, workshops, and in-school support we provide as part of the Data Jam facilitate teachers to engage students in analyzing, visualizing, and interpreting real data. The competition also gives students the chance to develop and express their creativity, and brings together the growing community of artists and scientists interested in this exciting interface.

High School and Undergraduate Research Programs. We will provide research experiences in urban ecosystem discovery for students to increase interest and likelihood of success in pursuing careers in ecology. Programs will include:

The BES Young Environmental Scientists (BES-YES) program, launched in the summer of 2015, will be a core activity in the next phase of BES. This program engages underrepresented urban youth in BES research and enrichment activities over 5 weeks in the summer. The program will be integrated into the Parks and People Foundation PPF's summer high school program and will recruit students broadly. Youth in BES-YES collect data in 3-5 protocols, helping develop long-term datasets of interest to BES scientists, while also pilot testing new protocols for potential inclusion in the long-term program. BES and Forest Service scientists and educators will provide science mentorship, and PPF will conduct youth development and group coordination.

We propose to offer a research experiences for undergraduates (REU) program for 2 students each summer. Each fall the Project Management Committee will solicit REU project proposals from BES scientists, encouraging projects that: 1) address core BES questions; 2) are coordinated across disciplines, e.g., one in social science and one in environmental science but on a common theme so that the students benefit from the transdisciplinary approach of BES to urban ecology; or 3) would involve cross-site research with CAP. Students will be housed and have offices with other students and researchers at UMBC or another local institution depending on the mentor, and have multiple avenues for interaction with other students, scientists, and educators. They will attend the BES Community Awareness and Safety Training, the June Quarterly Project Meeting, meetings in Baltimore associated with the two SRN projects BES is part of (UWIN and Urban Extremes), and, as appropriate, enrichment activities of the UWIN Undergraduate Research Program and the Cary Institute's REU program. These will include virtual workshops in research skills in an urban setting, career development and transdisciplinary science, and seminars in urban environmental science and sustainability. Nation-wide recruitment and selection of BES REU students will emphasize several facets of diversity as part of the BES diversity plan, including first-generation college students and students from Baltimore's urban neighborhoods, and those from groups underrepresented in STEM. Partnership with UMBC, well known for its success in STEM education (Hrabowski 2015), will facilitate our efforts.

Community Engagement: The two primary goals of BES engagement activities are to involve diverse types of groups -- government agencies, NGOs, community groups, and businesses -- working in a variety of environmental, social, economic, and health conditions to inform our long-term research and, at the same time, to inform decision making (Hager et al. 2013; Grove et al. 2015a; Grove et al. 2015b). Our inclusion process is accomplished through our collaborative networks with partners and stakeholders (Romolini 2013). Key BES engagement strategies include:

A culture of inclusion. BES will develop a diversity plan to outline methods for seeking, nurturing and recognizing diverse perspectives and talents within the BES research community of staff, researchers, and program participants. A yearly Community Awareness and Safety training program is required for new scientists, staff, and students to enhance cultural knowledge and sensitivity for local communities and to help researchers conducting fieldwork in Baltimore understand neighborhood dynamics. BES conducts several types of meetings—Quarterly and Annual Project meetings—to facilitate the involvement of interested parties.

Government agencies and NGOs. Since its inception, BES has maintained close relationships with NGOs such as the Parks & People Foundation and government agencies that assist in planning, implementation, interpretation and communication of BES research as a means of both advancing ecological knowledge and informing decisions. Interactions include consultations, meetings, webinars, research summaries, and joint projects with technical staff in Maryland Department of Natural Resources; the Baltimore County Department of Environmental Protection and Sustainability, and Baltimore City Departments of Recreation and Parks, Public Works, and the Office of Sustainability. BES scientists, educators and partners are involved with numerous levels of government and coalitions to connect researchers and data produced through BES to Baltimore initiatives and NGO work. Group discussions are held three times each year with the City's Office of Sustainability to explore timely issues and initiatives on sustainability and resilience from scientific and administrative perspectives. BES educators meet regularly with STEM leaders in the Baltimore City Public School Administration.

Communities and neighborhoods. In partnership with Parks & People, BES scientists develop engagement strategies for each project to involve Baltimore communities and neighborhoods. Examples of community involvement include citizen science programs in low-income neighborhoods, educator training programs, and service and community activities linked to research. This raises awareness of BES; fosters trust amongst researchers and residents in communities that may be wary of 'outside' involvement in neighborhoods; and promotes security of areas being studied because the community understands the purpose of the research.

Science communication and access to BES information. A committee of staff and partners focuses on communication and delivery to promote use of the collective expertise in BES as a resource. This is accomplished through public events and activities including the BES Annual Meeting and Open House, media relations, and activities that disseminate BES information in non-traditional ways, such as through BES artist-in-residence exhibits at Baltimore galleries.

Literature Cited

Alberti, M. 2008. Advances in urban ecology: integrating humans and ecological processes in urban ecosystems. Springer, New York.

Alonso, W. 1964. Location and land use: toward a general theory of land rent. Harvard University Press, Cambridge, MA.

Baltimore City (n.d.) http://www.baltimoresustainability.org/plans/sustainability-plan/

Baltimore County (n.d.) Baltimore County Department of Environmental Protection and Sustainability. 2015. Sustainability Overview. http://www.baltimorecountymd.gov/Agencies/environment/sustainability/

Basso, K. 1996. Wisdom Sits in Places: Landscape and Language Among the Western Apache. Albuquerque: University of New Mexico Press.

Battaglia, M.J., G.L. Buckley, M.F. Galvin, J.M. Grove. 2014. It's not easy going green: Obstacles to tree-planting programs in East Baltimore. Cities and the environment 7(2):Article 6.

Becker, B., P. T. Leisnham, and S. L. LaDeau. 2014. A Tale of Two City Blocks: Differences in Immature and Adult Mosquito Abundances between Socioeconomically Different Urban Blocks in Baltimore (Maryland, USA). International Journal of Environmental Research and Public Health 11:3256-3270.

Bettez, N. D., and P. M. Groffman. 2012. Denitrification potential in stormwater control structures and natural riparian zones in an urban landscape. Environmental Science & Technology 46:10909 - 10917.

Bettez, N. D., and P. M. Groffman. 2013. Nitrogen deposition in and near an urban ecosystem. Environmental Science & Technology 47:6047-6051.

Bettez, N. D., J. M. Duncan, P. M. Groffman, L. E. Band, J. O'Neil-Dunne, S. S. Kaushal, K. T. Belt, and N. Law. 2015. Climate variation overwhelms efforts to reduce nitrogen delivery to coastal waters. Ecosystems Submitted.

Bhaskar, A. S., and C. Welty. 2012. Water balances along an urban-to-rural gradient of metropolitan Baltimore, 2001–2009. Environmental & Engineering Geoscience, Vol. XVIII, No. 1, February 2012, pp. 37–50.

Bhaskar, A.S., and C. Welty. 2015. Analysis of subsurface storage and streamflow generation in urban watersheds. Water Resources Research, 51, doi:10.1002/2014WR015607.

Bodner, D. 2015. The effectiveness of resident-based mosquito control through changes in knowledge and behaviors along a socioeconomic gradient. Department of Environmental Science and Technology, University of Maryland.

Bohlen, P. J., S. Scheu, C. M. Hale, M. A. McLean, S. Migge, P. M. Groffman, and D. Parkinson. 2004. Non-native invasive earthworms as agents of change in northern temperate forests. Frontiers in Ecology and the Environment 2:427-435.

Boone, C. G., G. L. Buckley, J. M. Grove, and C. Sister. 2009. Parks and people: an environmental justice inquiry in Baltimore, Maryland. Annals of the Association of American Geographers 99:767-787.

Boone, C., M. Cadenasso, J. Grove, K. Schwarz, and G. Buckley. 2010. Landscape, vegetation characteristics, and group identity in an urban and suburban watershed: why the 60s matter. Urban Ecosystems 13:255-271.

Boone, C. G. 2013. Social dynamics and sustainable urban design. Pages 47–61 in S. T. A. Pickett, M. L. Cadenasso, and B. McGrath, editors. Resilience in ecology and urban design: linking theory and practice for sustainable cities. Springer, New York.

Bormann, F. H., and G. E. Likens. 1969. The watershed-ecosystem concept and studies of nutrient cycles. in G. M. van Dyne, editor. The ecosystem concept in natural resource management. Academic Press, New York.

Brady M, EG Irwin. 2011. Accounting for spatial effects in economic models of land use: Recent developments and challenges ahead. Environmental and Resource Economics. 48(3): 487-509.

Brazel, A., N. Selover, R. Vose, and G. Heisler. 2000. The tale of two climates - Baltimore and Phoenix urban LTER sites. Climate Research **15**:123-135.

Buckley, G. L., and C. G. Boone. 2010. To promote the material and moral welfare of the community: Neighborhood improvement associations in Baltimore, Maryland, 1900 - 1945. In: R. Rodger and

G. Massard-Guilbarud, editors. Environmental and Social Inequalities in the City since 1800 Berghahn Press, Munich.
Cadenasso, M. L., S. T. A. Pickett, and J. M. Grove. 2006. Integrative approaches to investigating human-natural systems: the Baltimore ecosystem study. Natures Sciences Societies 14:4–14.
Cadenasso, M. L., S. T. A. Pickett, and K. Schwarz. 2007. Spatial heterogeneity in urban ecosystems: reconceptualizing land cover and a framework for classification. Frontiers in Ecology and the Environment 5:80-88.
Cadenasso, M. L., S. T. A. Pickett, P. M. Groffman, L. E. Band, G. S. Brush, M. F. Galvin, J. M. Grove, G. Hagar, V. Marshall, B. McGrath, J. O'Neil-Dunne, B. Stack, and A. Troy. 2008. Exchanges across land-water-scape boundaries in urban systems: strategies for reducing nitrate pollution. Annual Review of Conservation and the Environment 1134:213-232.
Cadenasso, M.L., S.T.A. Pickett, B.P. McGrath, V. Marshall. 2013. Ecological heterogeneity in urban ecosystems: Reconceptualized land cover models as a bridge to urban design. 107-129. In:Pickett, S.T.A., M.L. Cadenasso, B.P. McGrath, eds. Resilience in urban ecology and design: Linking theory and practice for sustainable cities. Springer. New York.
Campbell, L. K. 2014. Constructing New York City's urban forest: the politics and governance of the MillionTreesNYC campaign. In: Sandberg, A. L., Bardekjian, A., and Butt, S., eds. Urban forests, trees and greenspace. A policy perspective. New York, NY: Routledge: 242-260. Chapter 16.
Caplan, B., Gunckel, K. L., Warnock, A., & Cano, A. (2013). Investigating water pathways in schoolyards. Green Teacher **98**(Winter):28-33.
Carrico, A. R., J. Fraser, and J. T. Bazuin. 2012. Green with envy: psychological and social predictors of lawn fertilizer application. Environment and Behavior. doi:10.1177/0013916511434637
Carrico, A. R., J. Fraser, and J. T. Bazuin. 2013. Green with envy: Psychological and social predictors of lawn fertilizer application. Environment and Behavior **45**:427-454.
Carrion-Flores, C., E.G. Irwin. 2010. Identifying spatial interactions effect in the presence of spatial error autocorrelation: an application to land use spillovers. 32(2):135-153. doi: 10.1016/j.reseneeco.2009.11.009.
Chang, C.-H., K. Szlavecz, T. Filley, J. Buyer, M. Bernard, and S. Pitz. 2015. Belowground competition among invading detritovores. To be submitted to Ecology.
Chase, J. M., N. J. B. Kraft, K. G. Smith, M. Vellend, and B. D. Inouye. 2011. Using null models to disentangle variation in community dissimilarity from variation in alpha-diversity. Ecosphere 2:UNSP 24.
Chen, Y., E.G. Irwin, C. Jayaprakash. 2011. Incorporating spatial complexity into economic models of land markets and land use change. 40(3):321-340. doi:
Childers, D. L., S. T. A. Pickett, J. M. Grove, L. Ogden, and A. Whitmer. 2014. Advancing urban sustainability theory and action: Challenges and opportunities. Landscape and Urban Planning 125:320–328.
Clark, J. and A. Gelfand. 2006. Hierarchical Modelling for the Environmental Sciences-- Statistical Methods and Applications. Oxford University Press, New York.
Connolly, J. J., E. S. Svendsen, D. R. Fisher, and L. K. Campbell. 2013. Organizing urban ecosystem services through environmental stewardship governance in New York City. Landscape and Urban Planning 109:76-84.
Connolly, J. J., E. S. Svendsen, D. R. Fisher, and L. K. Campbell. 2015. Mixed methods analysis of urban environmental stewardship networks. In: Ruth, Matthias, ed. Handbook of research methods and applications in environmental studies. Pages 102-121. Northampton, MA: Edward Elgar Publishing.
Covitt, B., C. Harris and A. Anderson. 2013. Evaluating Scientific Arguments with Slow Thinking. Science Scope **37**(3):44-52.
Costa, K. H., and P. M. Groffman. 2013. Factors regulating net methane flux by soils in urban forests and grasslands. Soil Science Society of America Journal 77:850-855.
Costanza, R. 2001. Visions, values, valuation and the need for an ecological economics. 51 (459-468. Costello, D. M., E. J. Rosi-Marshall, L. E. Shaw, M. R. Grace, and J. J. Kelly. 2015. A novel method for measuring the effects of chemical stressors on biofilm structure and function. Freshwater Biology. doi:10.1111/fwb.12641
Cui, Z., C. Welty, and R. M. Maxwell. 2014. Modeling nitrogen transport and transformation in aquifers using a particle-tracking approach. Computers and Geosciences 70:1-14.

doi:10.1016/j.cageo.2014.05.005
Doheny, E.J. 1999. Index of hydrologic characteristics and data resources for the Gwynns Falls watershed, Baltimore County and Baltimore City, Maryland.
Duan, S., K. Delaney-Newcomb, S. Kaushal, S. G. Findlay, and K. Belt. 2014. Potential effects of leaf litter on water quality in urban watersheds. Biogeochemistry 121:61-80.
Duan, S., S. S. Kaushal, P. M. Groffman, L. E. Band, and K. T. Belt. 2012. Phosphorus export across an urban to rural gradient in the Chesapeake Bay watershed. Journal of Geophysical Research Biogeosciences 117:G01025.
Drury, B., J. Scott, E. J. Rosi-Marshall, and J. J. Kelly. 2013. Triclosan exposure increases triclosan resistance and alters taxonomic composition of benthic bacterial communities. *Environmental Science and Technology* 47:8923-8930. dx.doi.org/10.1021/es401919k
Elmore, A. J., and S. S. Kaushal. 2008. Disappearing headwaters: patterns of stream burial due to urbanization. Frontiers in Ecology and the Environment 6:308-312.
Ernstson, H., S. Sörlin, and T. Elmqvist. 2007. Social movements and ecosystem services - the role of social network structure in protecting and managing urban green areas in Stockholm. Landscape and Urban Planning 13:46-55.
Escobedo, F. J., and D. J. Nowak. 2009. Spatial heterogeneity and air pollution removal by an urban forest. Landscape and Urban Planning 90:102-110.
Fisher, D. R., L. Campbell, and E. S. Svendsen. 2012. The organizational structure of urban environmental stewardship. Environmental Politics 21:26-48.
Fisher, S. G. 1992. Pattern, process and scale in freshwater systems: some unifying thoughts. Pages 575–591 In: Aquatic Ecology. Oxford University Press, London.
Fraser, J. C., J. T. Bazuin, L. E. Band, and J. M. Grove. 2013. Covenants, cohesion, and community: The effects of neighborhood governance on lawn fertilization. Landscape and Urban Planning 115:30-38.
Gift, D. M., P. M. Groffman, S. S. Kaushal, and P. M. Mayer. 2010. Denitrification potential, root biomass, and organic matter in degraded and restored urban riparian zones. Restoration Ecology 18:113-120.
Glaeser, E.L. and J. Gyourko. 2005. Urban Decline and Durable Housing. Journal of Political Economy, Volume 113: 345-375.
Gnagey, Matt and Elena G. Irwin. In Review “Does distance still matter? Evidence from a semi-parametric analysis of land prices.” Submitted to Regional Science and Urban Economics.
Groffman, P. M., N. J. Boulware, W. C. Zipperer, R. V. Pouyat, L. E. Band, and M. F. Colosimo. 2002. Soil nitrogen cycle processes in urban riparian zones. Environmental Science & Technology 36:4547-4552.
Groffman, P. M., D. J. Bain, L. E. Band, K. T. Belt, G. S. Brush, J. M. Grove, R. V. Pouyat, I. C. Yesilonis, and W. C. Zipperer. 2003. Down by the riverside: urban riparian ecology. Frontiers in Ecology and the Environment **1**:315-321.
Groffman, P. M., and R. V. Pouyat. 2009. Methane uptake in urban forests and lawns. Environmental Science & Technology 43:5229-5235.
Groffman, P. M., C. O. Williams, R. V. Pouyat, L. E. Band, and I. Yesilonis. 2009. Nitrate leaching and nitrous oxide flux in urban forests and grasslands. Journal of Environmental Quality 38:1848-1860.
Groffman, P. M., J. Cavender-Bares, N. D. Bettez, J. M. Grove, S. J. Hall, J. B. Heffernan, S. E. Hobbie, K. L. Larson, J. L. Morse, C. Neill, K. Nelson, J. O'Neil-Dunne, L. Ogden, D. E. Pataki, C. Polsky, R. R. Chowdhury, and M. K. Steele. 2014. Ecological homogenization of urban USA. Frontiers in Ecology and the Environment 12:74-81.
Groffman, P. M., N. L. Law, K. T. Belt, L. E. Band, and G. T. Fisher. 2004. Nitrogen fluxes and retention in urban watershed ecosystems. Ecosystems 7:393-403.
Groffman, P. M., J. M. Grove, C. Polsky, N. D. Bettez, J. L. Morse, J. Cavender-Bares, S. J. Hall, J. B. Heffernan, S. E. Hobbie, K. L. Larson, C. Neill, K. Nelson, L. A. Ogden, J. O'Neil-Dunne, D. E. Pataki, R. Roy Chowdhury, and D. H. Locke. 2016. Satisfaction, water and fertilizer use in the American residential macrosystem. Environmental Research Letters **In press**.
Grove, J. M. A. Troy, J. O'Neil-Dunne, S. Pickett and M. Cadenasso. 2006a. Characterization of households and its implications for urban ecosystems. Ecosystems 9:578-597.

Grove, J. M., D. Locke, and J. M. O'Neil-Dunne. 2014. An ecology of prestige in New York City: Examining the relationships among population density, socio-economic status, group identity, and residential canopy cover. Environmental Management 54:402-419.

Grove, J. M., M. L. Cadenasso, W. R. Burch, S. T. A. Pickett, K. Schwarz, J. O'Neil-Dunne, M. Wilson, A. Troy, and C. Boone. 2006b. Data and methods comparing social structure and vegetation structure of urban neighborhoods in Baltimore, Maryland. Society & Natural Resources 19:117-136.

Grove, J. M., R. R. Chowdhury, and D. L. Childers. 2015. Co-Design, Co-Production, and Dissemination of Social-Ecological Knowledge to Promote Sustainability and Resilience: Urban Experiences from the U.S. Long Term Ecological Research (LTER) Network. Global Land Project News 11:6-11.

Grove, J. M., S. T. A. Pickett, A. Whitmer, and M. L. Cadenasso. 2013. Building an urban LTSER: the case of the Baltimore Ecosystem Study and the D.C./B.C. ULTRA-Ex Project. Pages 369–408 in J. S. Singh, H. Haberl, M. Chertow, M. Mirtl, and M. Schmid, editors. Long term socio-ecological research: studies in society:nature interactions across spatial and temporal scales. Springer, New York.

Grove, M., M. L. Cadenasso, S. T. A. Pickett, G. Machlis, and W. R. Burch Jr. 2015. The Baltimore School of Urban Ecology. Yale University Press, New Haven.

Gunckel, K. L., Covitt, B. A., Salinas, I., & Anderson, C. W. 2012. A learning progression for water in socio-ecological systems. Journal of Research in Science Teaching*,* **49**:843-868.

Hager, Guy W, Kenneth T Belt, William Stack, Kimberly Burgess, J Morgan Grove, Bess Caplan, Mary Hardcastle, Desiree Shelley, Steward Ta Pickett, and Peter M Groffman. 2013. "Socioecological Revitalization of an Urban Watershed." *Frontiers in Ecology and the Environment* 11 (1).

Hall, R.O. and J.L. Tank. 2003. Ecosystem metabolism controls nitrogen uptake in streams in Grand Teton National Park, Wyoming. Limnology and Oceanography 48: 1120-1128.

Hall Jr., R. O., C. B. Yackulic, T. A. Kennedy, M. D. Yard, E. J. Rosi-Marshall, N. Voichick, and K. E. Behn. 2015. Turbidity, light, and hydropeaking control daily variation in primary production in the regulated Colorado River in Grand Canyon, Arizona. Limnology and Oceanography 60:512-526. doi:10.1002/lno.10031

Hall Jr., R. O., M. A. Baker, E. J. Rosi-Marshall, J. L. Tank, and J. D. Newbold. 2013. Solute specific scaling of inorganic nitrogen and phosphorus uptake in streams. Biogeosciences 10:6671-6693.

Harris, C., A.R. Berkowitz, J.H. Doherty and L.M. Hartley. 2013. Exploring biodiversity's big ideas in your school yard. Science Scope. **36**:20-27.

Harrison, M. D., A. J. Miller, P. M. Groffman, P. M. Mayer, and S. S. Kaushal. 2014. Hydrologic Controls on Nitrogen and Phosphorous Dynamics in Relict Oxbow Wetlands Adjacent to an Urban Restored Stream. Journal of the American Water Resources Association (JAWRA) 50:1365-1382.

Harrison, M. D., P. M. Groffman, P. M. Mayer, and S. S. Kaushal. 2012a. Microbial biomass and activity in geomorphic features in forested and urban restored and degraded streams. Ecological Engineering 38:1-10.

Harrison, M. D., P. M. Groffman, P. M. Mayer, and S. S. Kaushal. 2012b. Nitrate removal in two relict oxbow urban wetlands: a 15N mass balance approach. Biogeochemistry 111:647-660.

Harrison, M. D., P. M. Groffman, P. M. Mayer, S. S. Kaushal, and T. A. Newcomer. 2011. Denitrification in alluvial wetlands in an urban landscape. Journal of Environmental Quality 40:634-646.

Hepinstall, J. A., M. Alberti, and J. M. Marzluff. 2008. Predicting land cover change and avian community responses in rapidly urbanizing environments. Landscape Ecology 23:1257-1276.

Holtan, M. T., S. L. Dieterlen, and W. C. Sullivan. 2014. Social life under cover: tree canopy and social capital in Baltimore, Maryland. Environment and Behavior, January, 1-14. doi: 10.1177/0013916513518064

Hrabowski, F.A. 2015. Holding fast to dreams: Empowering youth from the Civil Rights Crusade to STEM Achievement. Beacon Press.

Huang, G., W. Zhou, and M. L. Cadenasso. 2011. Is everyone hot in the city? Spatial pattern of land surface temperatures, land cover and neighborhood socioeconomic characteristics in Baltimore, MD. Journal of Environmental Management 92:1753-1759.

Irwin, E. G., and N. E. Bockstael. 2002. Interacting agents, spatial externalities and the evolution of residential land use patterns. Journal of Economic Geography 2:31-54.

Irwin, E.G., C. Jayaprakash, D.K. Munroe. 2009a. Towards a comprehensive model of urban spatial dynamics. 24(9):1223–1236. doi: 10.1007/s10980-009-9353-9.
Irwin, E.G., K.P. Bell, N.E. Bockstael, D.A. Newburn, M.D. Partridge, J. Wu. 2009b. The economics of urban-rural space. 1(1):435-462. doi: 10.1146/annurev.resource.050708.144253.
Irwin, E.G. 2010. New directions for urban economic models of land use change: incorporating spatial dynamics and heterogeneity. 50(1):65-91. doi: 10.1111/j.1467-9787.2009.00655.x.
Irwin, E.G., D. Wrenn. 2012. Developing spatial economic models of land change for policy simulation. 8(41-44.
Irwin, NB HA Klaiber, EG Irwin. *in review*. The Potential for Co-Benefits from Stormwater Management for Suburban Households.
Jax, K. 2010. Ecosystem functioning. Cambridge, New York.
Jin, H., & Anderson, C. W. 2012. A learning progression for energy in socio-ecological systems. Journal of Research in Science Teaching*,* **49**:1149-1180.
Jenerette, G. D., J. Wu, N. B. Grimm, and D. Hope. 2006. Points, patches, and regions: scaling soil biogeochemical patterns in an urbanized arid ecosystem. Global Change Biology 12:1532–1544.
Johnson, A. L., and C. M. Swan. 2014. Drivers of vegetation species diversity and composition in urban ecosystems. In: R. A. McCleery, M. N. Peterson, and C. E. Moorman, editors. Urban Wildlife Science: Theory and Practice. Springer, New York.
Johnson, A.L., E. Tauzer, C.M. Swan. 2015. Human legacies differentially organize functional and phylogenetic diversity of urban herbaceous plant communities at multiple spatial scales. Applied Vegetation Science 18:513-527.
Jones, D.K., M.E. Baker, A.J. Miller, S.T. Jarnagin, D.M. Hogan. 2014. Tracking geomorphic signatures of watershed suburbanization with multi-temporal LIDAR. Geomorphology 219:42-52.
Kaushal, S. S., and K. T. Belt. 2012. The urban watershed continuum: Evolving spatial and temporal dimensions. Urban Ecosystems 15:409-435.
Kaushal, S. S., P. M. Groffman, L. E. Band, C. A. Shields, R. P. Morgan, M. A. Palmer, K. T. Belt, C. M. Swan, S. E. G. Findlay, and G. T. Fisher. 2008a. Interaction between urbanization and climate variability amplifies watershed nitrate export in Maryland. Environmental Science & Technology 42:5872-5878.
Kaushal, S. S., P. M. Groffman, L. E. Band, E. M. Elliott, C. A. Shields, and C. Kendall. 2011. Tracking nonpoint source nitrogen pollution in human-impacted watersheds. Environmental Science & Technology 45:8225-8232.
Kaushal, S. S., P. M. Groffman, P. M. Mayer, E. Striz, and A. J. Gold. 2008b. Effects of stream restoration on denitrification in an urbanizing watershed. Ecological Applications 18:789-804.
Kaushal, S., K. Delaney-Newcomb, S. G. Findlay, T. Newcomer, S. Duan, M. Pennino, G. Sivirichi, A. Sides-Raley, M. Walbridge, and K. Belt. 2014a. Longitudinal patterns in carbon and nitrogen fluxes and stream metabolism along an urban watershed continuum. Biogeochemistry doi: 10.1007/s10533-014-9979-9.
Kaushal, S.S., W.H. McDowell, W.M. Wollheim. 2014b. Tracking evolution of urban biogeochemical cycles: past, present, and future. 121(1):1-21. doi: 10.1007/s10533-014-0014-y.
Kaushal, S.S., W.H. McDowell, W.M. Wollheim, T.A. Newcomer-Johnson, P.M. Mayer, K.T. Belt and M.J. Pennino. 2015. Urban evolution: the role of water. Water 7: 4063-4087.
Klocker, C., S. Kaushal, P. Groffman, P. Mayer, and R. Morgan. 2009. Nitrogen uptake and denitrification in restored and unrestored streams in urban Maryland, USA. Aquatic Sciences 71:411-424.
LaDeau, S. L., P. T. Leisnham, D. Biehler, and D. Bodner. 2013. Higher Mosquito Production in Low-Income Neighborhoods of Baltimore and Washington, DC: Understanding Ecological Drivers and Mosquito-Borne Disease Risk in Temperate Cities. International Journal of Environmental Research and Public Health 10:1505-1526.
Law, L. N., E. L. Band, and J. M. Grove. 2004. Nitrogen input from residential lawn care practices in suburban watersheds in Baltimore County, MD. Journal of Environmental Planning and Management 47:737-755.
Lee, S., Paspalof, A. Snow, D.l; Richmond, E. Rosi-Marshall, E.; Kelly, J. In Review. Occurrence and potential biological effects of amphetamine in stream ecosystems. Submitted to Environmental Science and Technology.

Leibold, M. A. 2011. The metacommunity concept and its theoretical underpinnings. Pages 163-183 In: S. M. Scheiner and M. R. Willig, editors. The Theory of Ecology. University of Chicago Press, Chicago.

Leigh, C., B. Stewart-Koster, F. Sheldon, and M. A. Burford. 2011. Understanding multiple ecological responses to anthropogenic disturbance: rivers and potential flow regime change. Ecological Applications **22**:250-263.

Lerman, S. B., K. H. Nislow, D. J. Nowak, S. DeStefano, D. I. King, and D. T. Jones-Farrand. 2014. Using urban forest assessment tools to model bird habitat potential. Landscape and Urban Planning 122:29-40.

Likens, G. E. 1992. The Ecosystem Approach: Its Use and Abuse. The Ecology Institute. Oldendork-Luhe, Germany.

Lindner, G.A. and A.J. Miller, 2012. Numerical modeling of stage-discharge relationships in urban streams. Journal of Hydrologic Engineering 17: 590-596.

Livy, M.R. 2015. Assessing the Impact of Environmental Amenities on Residential Location Choice. PhD. Dissertation. The Ohio State University.

Livy, M and Klaiber, HA. 2016 Maintaining Public Goods: Household Valuation of New and Renovated Local Parks. Land Economics 92(1): 96-116.

Locke, D. H., and J. M. Grove. 2014. Doing the hard work where it's easiest? Examining the relationships between urban greening programs and social and ecological characteristics. Pages 1-20 In: Applied Spatial Analysis.

Lord, C., and K. Norquist. 2010. Cities as emergent systems: race as a rule in organized complexity. Environmental Law 40:551-597.

McGuire, K.J., Torgersen, C.E., Likens, G.E., Buso, D.C., Lowe, W.H., Bailey, S.W. 2014. Network analysis reveals multiscale controls on streamwater chemistry. Proceedings of the National Academy of Sciences, 111(19):7030-7035, doi: 10.1073/pnas.1404820111.Marcot 2012

Marcot, B. G., J. D. Steventon, G. D. Sutherland, and R. K. McCann. 2006. Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere **36**:3063-3074.

McCann RK, Marcot BG, Ellis R (2006) Bayesian belief networks: applications in ecology and natural resource management. Can J For Res-Rev Can Rech For 36:3053–3062. doi: 10.1139/X06-238

Martinez, N. G., N. D. Bettez, and P. M. Groffman. 2014. Sources of variation in home lawn soil nitrogen dynamics Journal of Environmental Quality 43:2146-2151.

Maxwell PS, Pitt KA, Olds AD, et al (2015) Identifying habitats at risk: simple models can reveal complex ecosystem dynamics. Ecol Appl 25:573–587. doi: 10.1890/14-0395.1

Maxwell, J. A. 2016. Expanding the History and Range of Mixed Methods Research. Journal of Mixed Methods Research 10:12-27.

Mayer, P. M., P. M. Groffman, E. A. Striz, and S. S. Kaushal. 2010. Nitrogen dynamics at the groundwater-surface water interface of a degraded urban stream. Journal of Environmental Quality 39:810-823.

McDonnell, M. J., and A. Hahs. 2009. Comparative ecology of cities and towns: past, present and future. Pages 71–89 in M. J. McDonnell, A. Hahs, and J. Breuste, editors. Ecology of cities and towns: a comparative approach. Cambridge University Press, New York.

McGrath, B. P., editor. 2013. Urban design ecologies. John Wiley and Sons, Ltd, Hoboken.

McGrath, B. and S.T.A. Pickett. 2011. The Metacity: A conceptual framework for integrating ecology and urban design. Special Issue: Challenges in City Design: Realize the Value of Cities. Website: http://www.mdpi.com/si/challenges/city_design/ Guest Editor: Prof. Dr. Kongjian Yu. Challenges 2011, 2, 55-72 doi:10.3390/challe2040055

McHale, M.R., S.T.A. Pickett, O. Barbosa, D.N. Bunn, M.L. Cadenasso, D.L. Childers, M. Gartin, G.R. Hess, D.M. Iwaniec, T. McPhearson, M.N. Peterson, A.K. Poole, L. Rivers III, S.T. Shutters, W. Zhou. 2015. The New Global Urban Realm: Complex, Connected, Diffuse, and Diverse Social-Ecological Systems. 7(5):5211-5240. doi: 10.3390/su7055211.Meierdiecks et al. 2010

Meierdiercks, K. L., J. A. Smith, M. L. Baeck, and A. J. Miller. 2010. Heterogeneity of hydrologic response in urban watersheds. Journal of the American Water Resources Association **46**:1221-1237.

Miles, B., and L. E. Band. 2015. Green infrastructure stormwater management at the watershed scale: urban variable source area and watershed capacitance. Hydrological Processes. doi: 10.1002/hyp.10448.

Mittman, T., L. E. Band, T. Hwang, and M. L. Smith. 2012. Distributed hydrologic modeling in the suburban landscape: assessing parameter transferability from gauged reference catchments. Journal of the American Water Resources Association 48:546-557.

Newburn, D. and J. Ferris. 2015. “The effect of downzoning for managing residential development and density.” *Land Economics*, in press.

Newcomer Johnson, T., S. Kaushal, P. Mayer, and M. Grese. 2014. Effects of stormwater management and stream restoration on watershed nitrogen retention. Biogeochemistry 121:81-106.

Newcomer, T. A., S. S. Kaushal, P. M. Mayer, A. R. Shields, E. A. Canuel, P. M. Groffman, and A. J. Gold. 2012. Influence of natural and novel organic carbon sources on denitrification in forest, degraded urban, and restored streams. Ecological Monographs 82:449-466.

Newman, P., and I. Jennings. 2008. Cities as Sustainable Ecosystems: Principles and Practices. Washington, D.C.: Island Press.

Niemelä, J., J. Kotze, and V. Yli-Pelkonen. 2009. Comparative urban ecology: challenges and possibilities. Pages 9–24 in M. J. McDonnell, A. Hahs, and J. Breuste, editors. Ecology of cities and towns: a comparative approach. Cambridge University Press, New York.

Nilon, C. H. 2011. Urban biodiversity and the importance of management and conservation. Landscape and Ecological Engineering 7:45-52.

Nilon, C. H., P. S. Warren, and J. Wolf. 2011. Baltimore Birdscape Study: Identifying habitat and land-cover variables for an urban bird-monitoring project. Urban Habitats http://www.urbanhabitats.org/v06n01/baltimore_full.html

Nilon, C.H., A.R. Berkowitz, K.S. Hollweg. 2003. Introduction: ecosystem understanding is a key to understanding cities. 1-15.In:Berkowitz, A.R., C.H. Nilon, K.S. Hollweg, eds. Understanding urban ecosystems: a new frontier for science and education. Springer-Verlag. New York.

Nowak, D. J., D. E. Crane, J. C. Stevens, R. E. Hoehn, J. T. Walton, and J. Bond. 2008. A ground-based method of assessing urban forest structure and ecosystem services. Arboriculture and Urban Forestry 34:347-358.

Nowak, D. J., E. J. Greenfield, R. E. Hoehn, and E. Lapoint. 2013a. Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental Pollution 178:229-236.

Nowak, D. J., S. Hirabayashi, A. Bodine, and R. Hoehn. 2013b Modeled PM2.5 removal by trees in ten US cities and associated health effects. Environmental Pollution 178:395-402.

Ogden, L., N. Heynen, U. Oslender, P. West, K.-A. Kassam, and P. Robbins. 2013. Global Assemblages, Resilience, and Earth Stewardship in the Anthropocene. Frontiers in Ecology and the Environment 7:341-347.

Ottaviano, G. and J.F. Thisse. Agglomeration and economic geography. 2014. In: Handbook of Regional and Urban Economics, vol. 4, ed. V. Henderson and J.-F. Thisse. Amsterdam: North-Holland.

Pennino, M. J., S. S. Kaushal, J. J. Beaulieu, and P. M. Mayer. 2014. Impacts of headwater stream burial on nitrogen and carbon transformation: implications for watershed export. Biogeochemistry (In press).

Pickett, S. T. A., and M. L. Cadenasso. 2009. Altered resources, disturbance, and heterogeneity: a framework for comparing urban and non-urban soils. Urban Ecosystems 12:23–44.

Pickett, S.T.A., J.M. Grove. 2009. Urban ecosystems: what would Tansley do? 12(1):1-8. doi: 10.1007/s11252-008-0079-2.

Pickett, S. T. A., B. McGrath, M. L. Cadenasso, and A. J. Felson. 2014. Ecological resilience and resilient cities. Building Research and Information 42:143-157.

Pickett, S. T. A., C. G. Boone, B. P. McGrath, M. L. Cadenasso, D. L. Childers, L. A. Ogden, M. McHale, and J. M. Grove. 2013. Ecological science and transformation to the sustainable city. Cities 32:S10-S20.

Pickett, S. T. A., M. L. Cadenasso, J. M. Grove, C. G. Boone, P. M. Groffman, E. Irwin, S. S. Kaushal, V. Marshall, B. P. McGrath, C. H. Nilon, R. V. Pouyat, K. Szlavecz, A. Troy, and P. Warren. 2011. Urban ecological systems: scientific foundations and a decade of progress. Journal of Environmental Management 92:331-362.

Pickett, S.T.A., M.L. Cadenasso, Emma J. Rosi-Marshall, Kenneth T. Belt, Peter M. Groffman, J. Morgan Grove, Elena G. Irwin, Sujay S. Kaushal, Shannon L. LaDeau, Charles H. Nilon, Christopher M. Swan, Paige S. Warren. Dynamic Heterogeneity: A Framework to Promote Integration and Hypothesis Generation in Urban Systems. Urban Ecosystems, submitted.

Pickett, S.T.A., W. Zhou. 2015. Global urbanization as a shifting context for applying ecological science toward the sustainable city. 1(1):1:art5–art5. doi: 10.1890/EHS14-0014.1.
Polsky, C., J. M. Grove, C. Knudson, P. M. Groffman, N. D. Bettez, J. Cavender-Bares, S. J. Hall, J. B. Heffernan, S. E. Hobbie, K. Larson, J. L. Morse, C. Neill, K. C. Nelson, L. A. Ogden, J. O'Neil-Dunne, D. E. Pataki, R. R. Chowdhury, and M. K. Steele. 2014. Assessing the homogenization of urban land management with an application to US residential lawn care. Proceedings of the National Academy of Sciences 111:4432-4437.
Pouyat, R. V., K. Szlavecz, I. D. Yesilonis, P. M. Groffman, and K. Schwarz. 2010. Chemical, physical and biological characteristics of urban soils. Pages 119-152 in J. Aitkenhead-Peterson and A. Volder, editors. Urban Ecosystem Ecology. Agronomy Monograph 55. American Society of Agronomy, Madison, WI.
Queen, C. M. and C. J. Albers. 2009. Intervention and Causality: Forecasting Traffic Flows Using a Dynamic Bayesian Network. Journal of the American Statistical Association **104**:669-681.
Raciti, S. R., A. J. Burgin, P. M. Groffman, D. N. Lewis, and T. J. Fahey. 2011a. Denitrification in suburban lawn soils. Journal of Environmental Quality 40:1392-1940.
Raciti, S. R., P. M. Groffman, and T. J. Fahey. 2008. Nitrogen retention in urban lawns and forests. Ecological Applications 18:1615-1626.
Raciti, S. R., P. M. Groffman, J. C. Jenkins, R. V. Pouyat, and T. J. Fahey. 2011b. Nitrate production and availability in residential soils. Ecological Applications 21:2357-2366.
Raciti, S. R., P. M. Groffman, J. C. Jenkins, R. V. Pouyat, T. J. Fahey, M. L. Cadenasso, and S. T. A. Pickett. 2011c. Accumulation of carbon and nitrogen in residential soils with different land use histories. Ecosystems 14:287-297.
Ramamurthy, P., E. Bou-Zeid, J.A. Smith, Z. Wang, M.L. Baeck, N. Saliendra, J. Hom, C. Welty. 2014. Influence of sub-facet heterogeneity and material properties on the urban surface energy budget. 53(2114-2128. doi: 10.1175/JAMC-D-13-0286.1.
Reed, J. T., L. C. Adams, and C. A. Abel. 2010. Comparison of Three Insect Sampling Methods in Sweetpotato Foliage in Mississippi. Journal of Entomological Science **45**:111-128.
Rega, C. C., C. H. Nilon, and P. S. Warren. 2015. Avian abundance patterns in relation to the distribution of small urban greenspaces. Journal of Urban Planning and Development (In press).
Rigosi, A., P. Hanson, D. P. Hamilton, M. Hipsey, J. A. Rusak, J. Bois, K. Sparber, I. Chorus, A. J. Watkinson, B. Q. Qin, B. Kim, and J. D. Brookes. 2015. Determining the probability of cyanobacterial blooms: the application of Bayesian networks in multiple lake systems. Ecological Applications **25**:186-199.
Robbins, P. 2012. Political Ecology: A Critical Introduction, 2nd ed. Wiley & Sone, Malden MA.
Romolini, M. 2012. Governance of 21st Century Sustainable Cities: Examining Stewardship Networks in Baltimore & Seattle. Doctoral Dissertation. University of Vermont.
Romolini, M., J. M. Grove, and D. H. Locke. 2013. Assessing and comparing relationships between urban environmental stewardship networks and land cover in Baltimore and Seattle. Landscape and Urban Planning 120:190-207.
Rosi-Marshall, E. J. and T. V. Royer. 2012. Pharmaceutical compounds and ecosystem function: An emerging research challenge for aquatic ecologists. Ecosystems. doi:10.1007/s10021-012-9553-z
Rosi-Marshall, E. J., and J. J. Kelly. 2015. Antibiotic Stewardship Should Consider Environmental Fate of Antibiotics. Environmental Science and Technology 49:5257-5258.
Rosi-Marshall, E. J., D. Snow, S. L. Bartelt-Hunt, A. Paspalof, and J. L. Tank. 2015. A review of ecological effects and environmental fate of illicit drugs in aquatic ecosystems. Journal of Hazardous Materials 282:18-25.
Rosi-Marshall, E. J., D. W. Kincaid, H. A. Bechtold, T. V. Royer, M. Rojas, and J. J. Kelly. 2013. Pharmaceuticals suppress algal growth and microbial respiration and alter bacterial communities in stream biofilms. Ecological Applications 23:583-593.
Royle, J. A. and M. Kery. 2007. A Bayesian state-space formulation of dynamic occupancy models. Ecology **88**:1813-1823.
Ryan, R. J., C. Welty, and P. C. Larson. 2010. Variation in surface water-groundwater exchange with land use in an urban stream. Journal of Hydrology **392**:1-11.

Savva, Y., K. Szlavecz, R. V. Pouyat, P. M. Groffman, and G. Heisler. 2010. Effects of land use and vegetation cover on soil temperature in an urban ecosystem. Soil Science Society of America Journal **74**:469-480

Scheiner, S. M., and M. R. Willig. 2011. A general theory of ecology`. Pages 3–18 in S. M. Scheiner and M. R. Willig, editors. The theory of ecology. University of Chicago Press, Chicago.

Schwartz, S. S., and B. Smith. 2014. Slowflow fingerprints of urban hydrology. Journal of Hydrology 515:116-128.

Schwarz, K., K. C. Weathers, S. T. A. Pickett, R. G. Lathrop, Jr., R. V. Pouyat, and M. L. Cadenasso. 2013. A comparison of three empirically based, spatially explicit predictive models of residential soil Pb concentrations in Baltimore, Maryland, USA: understanding the variability within cities. Environmental Geochemistry and Health 35:495-510.

Schwarz, K., S. T. A. Pickett, R. G. Lathrop, K. C. Weathers, R. V. Pouyat, and M. L. Cadenasso. 2012. The effects of the urban built environment on the spatial distribution of lead in residential soils. Environmental Pollution 163:32-39.

Shane, D. G. 2005. Recombinant urbanism: conceptual modeling in architecture. John Wiley & Sons, Hoboken.

Shochat, E., S. B. Lerman, J. M. Anderies, P. S. Warren, S. H. Faeth, and C. H. Nilon. 2010. Invasion, competition, and biodiversity loss in urban ecosystems. BioScience 60:199-208.

Sivirichi, G. M., S. S. Kaushal, P. M. Mayer, C. Welty, K. T. Belt, T. A. Newcomer, K. D. Newcomb, and M. M. Grese. 2011. Longitudinal variability in streamwater chemistry and carbon and nitrogen fluxes in restored and degraded urban stream networks. Journal of Environmental Monitoring 13:288-303.

Smith, M. L., W. Zhou, M. L. Cadenasso, J. M. Grove, and L. E. Band. 2010. Evaluation of the National Land Cover Database for hydrologic applications in urban and suburban Baltimore, MD. Journal of the American Water Resources Association 46:429-442.

Smith, R.M., S.S. Kaushal, M.J. Pennino. 2012. Longitudinal patterns in carbon and nutrient export from urban watersheds with contrasting headwater management.

Smith, B.K., J.A. Smith, M.L. Baeck, G. Villarini, D.B. Wright. 2013. Spectrum of storm event hydrologic response in urban watersheds. 49(2649-2663. doi: 10.1002/wrcr.20223.

Smith, B.K., J.A. Smith, M.L. Baeck, A.J. Miller. 2015. Exploring storage and runoff generation processes for urban flooding through a physically based watershed model. 51(1552-1569. doi: 10.1002/2014WR016085.

Stephan, E.A. and T.A. Endreny, 2016. Weighting Nitrogen and Phosphorus Pixel Pollutant Loads to Represent Runoff and Buffering Likelihoods. Journal of the American Water Resources Association (JAWRA) 1-14. DOI: 10.1111/1752-1688.12390

Svendsen, E. S., and L. K. Campbell. 2008. Urban ecological stewardship: understanding the structure, function and network of community-based urban land management. Cities and the Environment 1:1-32.

Swan, C. M., A. L. Johnson, and D. Nowak. Differential organization of phylogenetic, taxonomic and functional diversity in an urban woody plant metacommunity. Applied Vegetation Science (In Review).

Swan, C. M., S. T. A. Pickett, K. Szlavecz, P. Warren, and K. T. Willey. 2011. Biodiversity and community composition in urban ecosystems: coupled human, spatial, and metacommunity processes. Pages 179-186 In: J. Niemelä, J. H. Breuste, G. Guntenspergen, N. E. McIntyre, T. Elmqvist, and P. James, editors. Urban Ecology: Patterns, Processes, and Applications. Oxford University Press, New York.

Szlavecz, K., P. Warren, and S. T. A. Pickett. 2011. Biodiversity in the urban landscape. Pages 75-101 In: R. P. Cincotta and L. J. Gorenflo, editors. Human Population: Its Influences on Biological Diversity, Ecological Studies 214. Springer-Verlag, Berlin Heidelberg.

Tague, C. L., and L. E. Band. 2004. RHESSys: Regional Hydro-Ecologic Simulation System - An object oriented approach to spatially distributed modeling of carbon, water and nutrient cycling. Earth Interactions 8:Paper 19.

Tank, J. L., M. J. Bernot, and E. J. Rosi-Marshall. 2006. Nitrogen limitation and uptake. Pages 213-238 In: F. R. Hauer and G. A. Lamberti (Eds.). Methods in Stream Ecology. Academic Press.

Tanner, C. J., F. R. Adler, N. B. Grimm, P. M. Groffman, S. A. Levin, J. Munshi-South, D. E. Pataki, M. Pavao-Zuckerman, and W. G. Wilson. 2014. Urban ecology: advancing science and society. Frontiers in Ecology and Environment 12:574–581.

Tiebout, C. M. 1956. A Pure Theory of Local Expenditures. The Journal of Political Economy 64:416-24.

Towe, Charles and Klaiber, H. Allen and Wrenn, Douglas H., Not My Problem: Growth Spillovers from Uncoordinated Land Use Policy (September 8, 2015). Available at SSRN: http://ssrn.com/abstract=2657751 or http://dx.doi.org/10.2139/ssrn.2657751

Tree Baltimore (n.d.) http://www.treebaltimore.org/

Troy, A. R., J. M. Grove, J. P. M. O'Neil-Dunne, M. L. Cadensaso, and S. T. A. Pickett. 2007. Predicting Opportunities for Greening and Patterns of Vegetation on Private Urban Lands. Environmental Management 40:394-412.

Troy, A., A. Nunnery, and J. M. Grove. 2016. The relationship between residential yard management and neighborhood crime: an analysis from Baltimore City and County. Landscape and Urban Planning 147:78-87.

Troy, A., J. M. Grove, and J. O'Neil-Dunne. 2012. The relationship between tree canopy and crime rates across an urban-rural gradient in the greater Baltimore region. Landscape and Urban Planning 106:262-270.

Turner, M. G., and F. S. Chapin III. 2005. Causes and consequences of spatial heterogeneity in ecosystem function. Pages 9–30 In: G. M. Lovett, C. G. Jones, M. G. Turner, and K. C. Weathers, editors. Ecosystem function in heterogeneous landscapes. Springer, New York.

Vemuri, A. W., J. M. Grove, M. A. Wilson, and W. R. J. Burch. 2011. A tale of two scales: evaluating the relationship among life satisfaction, social capital, income, and the natural environment at individual and neighborhood levels in metropolitan Baltimore. Environment and Behavior 43:1-25.

van Dam, A. A., J. Kipkemboi, M. M. Rahman, and G. M. Gettel. 2013. Linking Hydrology, Ecosystem Function, and Livelihood Outcomes in African Papyrus Wetlands Using a Bayesian Network Model. Wetlands **33**:381-397.

von Doehren, P., and D. Haase. 2015. Ecosystem disservices research: A review of the state of the art with a focus on cities. Ecological Indicators 52:490-497.

Walker B. H. 1992. Biodiversity and Ecological Redundancy**.** *Conservation Biology* 6: 18-23.

Walsh, C.J., A.H. Roy, J.W. Feminella, P.E. Cottingham, P.M. Groffman, I.R.P. Morgan. 2005. The urban stream syndrome: current knowledge and the search for a cure. 24(3):706-723.

Wang, J., T. A. Endreny, and J. M. Hassett. 2006. Power function decay of hydraulic conductivity for a TOPMODEL-based infiltration routine. Hydrological Processes **20**:3825-3834.

Wang, J., T. A. Endreny, and D. J. Nowak. 2008. Mechanistic simulation of tree effects in an urban water balance model. Journal of the American Water Resources Association **44**:75-85.

Wang, S., and M. Loreau. 2014. Ecosystem stability in space: alpha, beta and gamma variability. Ecology Letters 17:891-901.

Waters, E. R., J. L. Morse, N. D. Bettez, and P. M. Groffman. 2014. Differential carbon and nitrogen controls of denitrification in riparian zones and streams along an urban to exurban gradient. Journal of Environmental Quality 43:955-963.

Weathers, K. C., P. M. Groffman, E. Van Dolah, E. S. Bernhardt, N. B. Griffm, K. McMahon, J. P. Schimel, M. Paolisso, R. Maranger, S. Baer, K. Brauman, and E. Hincklye. 2016. Frontiers in ecosystem ecology from a community perspective: The future is boundless and bright. Ecosystems *in press*.

Weiss, M. J. 2000. The clustered world: how we live, what we buy, and what it all means about who we are. Little, Brown and Company, New York.

Whittaker, R. 1960. Vegetation of the Siskiyou mountains, Oregon and California. Ecological Monographs 30:279-338.

Wiens, J. 2000. Ecological heterogeneity: an ontogeny of concepts and approaches. In: M. J. Hutchins and A. J. A. Stewart, editors. The ecological consequences of environmental heterogeneity. Blackwell, Malden, MA.

Williams, M., C. Hopkinson, E. Rastetter, J. Vallino, and L. Claessens. 2005. Relationships of land use and stream solute concentrations in the Ipswich River basin, northeastern Massachusetts. Water, Air, and Soil Pollution **161** 55-74.

Wrenn, Douglas H. and Elena G. Irwin. 2012. "How Do Land Use Policies Influence Fragmentation? An Econometric Model of Land Development with Spatial Simulation" *Environmental Economics*. 3:82-96.

Wrenn, D.H., A.G. Sam. 2014. Geographically and temporally weighted likelihood regression: Exploring the spatiotemporal determinants of land use change. 44(1):60-74. doi: 10.1016/j.regsciurbeco.2013.10.005.
Wrenn, Douglas and Elena G. Irwin. 2015. Time Is Money: An Empirical Examination of the Effects of Regulatory Delay on Residential Subdivision Development. *Regional Science and Urban Economics* 51: 25-36.
Wu, J. G., and O. L. Loucks. 1995. From balance of nature to hierarchical patch dynamics: A paradigm shift in ecology. Quarterly Review of Biology 70:439–466.
Wu, G., S. H. Holan, C. H. Nilon, and C. K. Wikle. 2015. Bayesian binomial mixture models for estimating abundance in ecological monitoring studies. Annals of Applied Statistics (In press).
Yang, Y., T. A. Endreny, and D. J. Nowak. 2011. iTree-Hydro: Snow hydrology update for the urban forest hydrology model. Journal of the American Water Resources Association **47**:1211-1218**.**
Yang, Y., and T. A. Endreny. 2013. Watershed hydrograph model based on surface flow diffusion. Water Resources Research **49**:507-516.
Zhang, Y. Z., Y. H. Qu, J. D. Wang, S. L. Liang, and Y. Liu. 2012. Estimating leaf area index from MODIS and surface meteorological data using a dynamic Bayesian network. Remote Sensing of Environment **127**:30-43.
Zhang, C., J. Wu, N. B. Grimm, M. McHale, and A. Buyantuyev. 2013. A hierarchical patch mosaic ecosystem model for urban landscapes: Model development and evaluation. Ecological Modelling 250:81-100.
Zhang, Wendong, Douglas Wrenn, Elena G. Irwin. In Press. Spatial Heterogeneity, Accessibility, and Zoning: An Empirical Investigation of Leapfrog Development. *Journal of Economic Geography*.
Zhou, W., Troy, A., & Grove, J. M. (2006). Measuring Urban Parcel Lawn Greenness by Using an Object-oriented Classification Approach. *Proc. of Int. Geosci. Remote Sens. Symp.(IGARSS06), Denver, CO, USA*.
Zhou, W., A. Troy. 2008. An object-oriented approach for analyzing and characterizing urban landscape at the parcel level. 29(1):742-752
Zhou, W., G. Huang, A. Troy, and M. L. Cadenasso. 2009a. Object-based land cover classification of shaded areas in high spatial resolution imagery of urban areas: a comparison study. Remote Sensing of Environment 113:1769-1777.
Zhou, W. Q., A. Troy, J. M. Grove, and J. C. Jenkins. 2009b. Can money buy green? Demographic and socioeconomic predictors of lawn care expenditures and lawn greenness in urban residential areas. Society & Natural Resources 22:744-760.
Zhou, W., and M. L. Cadenasso. 2012. Effects of patch characteristics and within patch heterogeneity on the accuracy of urban land cover estimates from visual interpretation. Landscape Ecology 27:1291-1305.
Zhou, W., G. Huang, and M. L. Cadenasso. 2011a. Does spatial configuration matter? Understanding the effects of land cover pattern on land surface temperature in urban landscapes. Landscape and Urban Planning 102:54-63.
Zhou, W., G. Huang, S. Pickett, and M. Cadenasso. 2011b. 90 years of forest cover change in an urbanizing watershed: spatial and temporal dynamics. Landscape Ecology 26:645-659.
Zhou, W., K. Schwarz, and M. L. Cadenasso. 2010. Mapping urban landscape heterogeneity: agreement between visual interpretation and digital classification approaches. Landscape Ecology 25:53-67.
Zhou, W., M. L. Cadenasso, K. Schwarz, and S. T. A. Pickett. 2014. Quantifying spatial heterogeneity in urban landscapes: integrating visual interpretation and object-based classification. Remote Sensing 6:3369-3386.

Facilities, Equipment, and Other Resources of the Baltimore Ecosystem Study Long-Term Ecological Research Program

The Baltimore Ecosystem Study LTER is a collaborative effort among many widely distributed individuals and institutions (detailed below). BES is headquartered at the Cary Institute of Ecosystem Studies (CIES) and 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, terrestrial monitoring sites and PULSE campaigns will be collected and processed at the UMBC laboratories and then sent on to CIES for further 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. CUERE houses a data analysis and visualization laboratory and a Spatial Analysis Laboratory (see below).

Cary Institute of Ecoystem Studies (CIES)
(Drs. Emma Rosi-Marshall, Steward Pickett, Shannon LaDeau, and Alan Berkowitz)

Property: The Cary Institute of Ecosystem Studies is located at the 820 hectare (2,024 acre) Mary Flagler Cary Arboretum in the mid-Hudson Valley. The 3,066 square meter (33,000 square feet) Plant Science Building and the 1,254 square meter (13,500 square foot) Gene E. Likens Laboratory house state-of-the-art analytical facilities for organic and inorganic chemical analyses. A 10,600-volume scientific reference library in the Plant Science Building receives 175 journals and provides access to Web of Science, JSTOR and many online journals; a computer lab is located in the library for use by library patrons, students and visitors. Adjacent to the Plant Science Building is a 151-seat auditorium. Other buildings house cold storage facilities, a lath house and storage buildings, carpentry and mechanical shops. Dormitory facilities are available to house visitors and students while in residence.

Laboratory: Analytical facilities at the 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, 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 Spectrophotometer 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, a FastPrep24 sample homogenizer, a freeze dryer, drying ovens, a rotary evaporator, laminar flow hood; incubators, ultra-low freezer, walk-in cold room, muffle furnace, soil processing equipment, sonicator, temperature baths, turbidimeter, platform shakers, electronic balances (including microbalances), pH meters, electrical conductivity meters and a PowderSafe 700 series ductless balance enclosure. 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.

Additional instrumentation includes: a Dionex UltiMate 3000 HPLC system with controller, photodiode array detector, UV-VIS detector, fluorescence detector, auto-sampler and Chromelean 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, a Unisense microsensor multimeter, a Lachat QuickChem 8000 FIA Ion Analyzer, a Milestone Ethos EZ microwave digestion system and a Lancer automatic labware washer.

In addition to the central Cary Institute Analytical Laboratory, PIs' individual laboratories include a Shimadzu GC-14 with electron capture and thermal conductivity detectors and a Lachat QuickChem 8000 FIA Ion Analyzer with channels for nitrate, phosphate, total N and total P analysis. A Membrane Inlet Mass Spectrometer for measuring isotopes of dissolved gases. Dr. Rosi-Marshall's laboratory is equipped with equipment needed for field measurements of stream ecosystem processes such as multimeter sensors (n=23), pumps for nutrient injections, and a Suitcase Flow Injection analyzer capable of running water chemistry (at the mg/L concentration) in remote field locations. Rosi-Marshall's laboratory is also equipped with numerous field sampling equipment such as a 4WD truck, a field-based laboratory trailer for accessing study sites and for sustaining extensive field campaigns. LaDeau's laboratory is fully equipped to study mosquito populations including microscopes, collecting equipment and adult mosquito traps.

Additional in-kind services: The Cary Institute will also make available additional administrative and technical support to Rosi-Marshall. The Cary Institute will also make available a new vehicle for BES use in Baltimore.

University of Maryland Baltimore County
(Dr. Claire Welty)

The field headquarters of the Baltimore Ecosystem Study LTER is housed in the Technology Research Center (TRC) at UMBC, hosted by the Center for Urban Environmental Research and Education (CUERE, http://cuere.umbc.edu, C. Welty, Director).

Spatial Analysis Laboratory: CUERE houses a Spatial Analysis Laboratory that includes 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 for image analysis, TerraScan™ for LIDAR point classification and analysis and Definiens Analyst image analysis software that incorporates object oriented classification techniques.

Data Analysis and Visualization Laboratory: CUERE's data analysis and visualization laboratory is equipped with 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.

Major Equipment: CUERE owns a SET 510 Total Station, several weather stations, two Sontek Flowtracker acoustic Doppler velocimeters, an eddy covariance station, and a Picarro 2120-i liquid water isotope analyzer, and a high-precision Trimble GPS (Trimble GoeXH Handheld, 3.5G edition) and antenna. Satlantic nitrate (SUNA) sensors and YSI EXO2 oxygen, turbidity, conductivity and temperature sensors are deployed at 6 stream gage stations cooperatively operated by UMBC/USGS. UMBC's Environmental Engineering program houses a GC-MS, ICP-MS, IC-MS, IC, and spectrophotometer.

Computer: The UMBC High Performance Computing Facility (HPCF, http://hpcf.umbc.edu) is a community-based, interdisciplinary core facility for scientific computing and research on parallel algorithms. System administration is provided by UMBC's Division of Information Technology, and users have access to consulting support provided by a dedicated full-time GRA. The current machine in HPCF is the 324-node distributed-memory cluster Maya, released in summer 2014. The facility is open to UMBC researchers at no charge.

Other Resources: Four CUERE staff members provide administrative, computer, and software support to faculty, graduate students and other researchers affiliated with CUERE. These staff members (Business Manager, Accounting Associate, Assistant Director, Environmental Data Manager) are supported through indirect return on grants.

USGS
(Dr. Edward Doheny)

The USGS MD-DE-DC Water Science Center (http://md.water.usgs.gov) is located in UMBC's Research Park at the edge of campus, in a custom building designed for this purpose in 2007. This USGS office employs 80 water science professionals and support staff who maintain surface water and groundwater observational networks across Maryland, Delaware, and the District of Columbia. USGS facilities include a fleet of field vans, sample processing and chemical analytical laboratories, GIS facilities, data management facilities, an equipment warehouse, and office and meeting space. USGS maintains stream gages and publishes streamflow data for the BES LTER.

CUNY Advanced Science Research Center
(Dr. Peter Groffman)

The CUNY Advanced Science Research Center (ASRC) is part of a $1 billion multidisciplinary facility providing approximately 227,000 square feet of assignable area for flexible research labs, lab support spaces, shared specialty core facilities and offices. The building was designed to accommodate a range of research initiatives through a strategy of providing a modular utility "infrastructure" such that laboratory space can be modified to support specific research requirements. The five story ASRC building boasts three state-of-the-art spectroscopy suites, an imaging suite, cleanroom, surface science suite, visualization center and a vivarium, in addition to specific laboratories that support research in each of the focus areas; nanoscience, photonics, structural biology, neuroscience and environmental science. The furnished laboratory spaces are therefore able to support chemistry, biology, physics, materials, engineering, environmental, and computational research activities. The building and laboratory spaces were architecturally designed to allow for free movement and integration between disciplines to promote collaborations that facilitate true cross-disciplinary research.

Dr. Groffman manages the Advanced Laboratory for Chemical and Isotope Signatures (ALCIS) which is under development at the City University of New York Advanced Science Research Center. The mission of ALCIS is to support the characterization of the molecular, elemental, and isotopic signatures of materials in modern and paleo-earth systems, with a focus on understanding how human activities modify natural earth processes. Equipment in ALCIS will include mass spectrometers capable of analysis of light stable isotopes and radiogenic isotopes/heavy isotopes in trace gases, solids and liquid samples. The lab will also include gas chromatographs and flow injection analyzers necessary for analysis of soil carbon and nitrogen cycling processes essential to the soil fertility analysis proposed here.
Groffman also manages a nitrogen biogeochemistry laboratory at the Cary Institute of Ecosystem Studies located in Millbrook, NY that will be used for the measurements of microbial biomass and activity in this proposal. This facility includes a Shimadzu GC-14 with electron capture and thermal conductivity detectors and a Lachat QuickChem 8000 FIA Ion Analyzer with channels for nitrate, phosphate, total N and total P analysis. A soil core gas flow incubation system for measuring denitrification, with two Shimadzu GC-8 gas chromatographs (one with an electron capture and one with a thermal conductivity detector) is also resident in Groffman's lab at the Cary Institute. An NSF Field Station and Marine Lab (FSML) grant awarded in 2015 is funding acquisition of a membrane inlet mass spectrometer as well as improved gas chromatorgraphs and soil core incubation system components.

University of North Carolina at Chapel Hill
(Dr. Lawrence Band)

The proposed work will be performed at the Institute for the Environment at the University of North Carolina at Chapel Hill (UNCCH) and in the LTER field site. The facilities and equipment available for the project are listed here:

Offices: In Chapel Hill, IE faculty, research associates, and administrative and information technology support staff are located in Whitehead Building (on the UNC main campus) and in Europa Center. Office space at these locations can also be provided to affiliated, funded researchers and their graduate students and/or postdoctoral research associates. The Europa Center location currently houses about 35 IE faculty and research associates; about 10 administrative staff; about 10 graduate research associates and postdoctoral research associates; and several undergraduate interns and work-study students. The Whitehead Building, Third Floor, currently houses 3 faculty, 2 staff, 3 postdoctoral research associates and about 10 graduate research associates. The administrative staff at IE is highly experienced in administering the following: extramurally funded projects; research communications; projects conducted at remote locations (see "Field Sites/Stations" below); training programs; and research seminars, symposia and similar events. The offices in the Europa Center and in the Whitehead Building offer both wireless and wired internet, and full IT support.

Conference Rooms: IE has a 15-person conference room in the Europa Center that may be scheduled for use by affiliated researchers; it includes a projector, conference table, conference telephone and wired and wireless internet. This building also has a training room with full audio and videoconferencing capability, wireless internet and 18 training stations with wired internet on the UNC fiber optic system connecting to supercomputing resources in UNC's Information Technology Services (ITS) Manning Building. The training room also features a podium with full connectivity for the trainers/instructors leading sessions in the room. The Whitehead Building has three available conference/recitation rooms, as well as a student gathering room that may be used for informal research team meetings and similar events.

PI Band has a jointly operated lab for analysis of sediment, soil and water samples. Field equipment include two Satlantic Suna systems, Sontek Acoustic Doppler stream velocity meters, survey equipment and GPS, soil sampling instruments, waders, and other field hydrology and geomorphology equipment.

Computational Facilities:UNC Chapel Hill's Information Technology Services (**ITS**) provides excellent user support in model simulations and data analysis on different platforms. Please see more details at: http://its.unc.edu/research/its-research-computing/computing-resources/. Relevant ITS computing resources for this project, which are available on a first-come first-serve basis to the entire UNC-CH community are:

a) ***Kure (nearly 1000 computing cores)***

- Compute nodes: 122 blade servers, each with 8-cores 2.80 GHz Intel processors, and 48 GB memory for a total of 976 processing cores, two similar 8 core blades with 96 GB memory, and three more blades with 192 GB memory and 24 total cores.
- Operating System: RHEL 5.6 (Tikanga)
- Shared Filesystem: 40 TB IBM GPFS, 85 TB NetApp NFS, 15 TB "/netscr" storage
- Interconnect: Infiniband 4x QDR

b) KillDevil (over 9500 computing cores)

- Compute nodes:
  - 119 Dell C6100 servers or 476 compute nodes, each with 12-core, 2.93 GHz Intel processors, and 48 GB memory for a total of 5712 processing cores at 2:1 ratio IB interconnect
  - 17 Dell C6100 servers or 68 compute nodes, each with 12-core, 2.93 GHz Intel processors, 12M L3 cache (Model X5670), and 96 GB memory for a total of 816 processing cores at 2:1 ratio IB interconnect.

- 17 Dell C6220 servers or 68 compute nodes, each with 16-core, 2.6.0 Ghz Intel processors, 20M L3 cache (Model E5-2670), and 64GB memory for a total of 1088 processing cores at 2:1 ratio IB interconnect
  - 32 Dell C6100 servers or 128 compute nodes, each with 12-core, 2.93 GHz Intel processors, and 48 GB memory for a total of 1536 processing cores at FBB (full blocking factor) or 1:1 ratio IB interconnect.
- Large Memory Compute nodes:
  - 2 Dell R910 servers or 2 compute nodes, each with 32-core, 2.00 Ghz Intel processors, with 1 TB memory for a total of 64 processing cores.
- GPU Compute nodes:
  - 8 Dell C6100 servers or 32 compute nodes, each with 12-core, 2.67 GHz Intel processors, and 48 GB memory for a total of 384 processing cores.
  - 4 Dell C410X servers, each with 16 Nvidia M2070 GPUs for a total of 64 GPU units.
- Operating System: RHEL 5.6 (Tikanga)
- Shared Filesystems:
  - 50 TB "/lustre/scr" Lustre File System intended for large files (>1MB)
  - 85 TB "/nas02" NetApp NFS for home directories, depts space, and apps
  - > 500 TB /nas NetAPP file system for dedicated project space
  - 150 TB "/netscr" storage intended for smaller files (<1MB)
- Interconnect: Infiniband 4x QDR (see compute nodes above)

c) ***SAM-FS Mass Storage System:*** Automated tape-based backup system with scalable capacity of upto a Petabyte. Currently holds data upto several hundreds of Terabytes, providing near real-time access to data from compute servers.

Within the Institute for the Environment, PI Band maintains 6 high capacity iMac systems with over 10 TB storage, advanced spatial analysis and image processing software, and site licenses for common analytical software (e.g. Matlab, Arc-GIS) as well as open source analytical and GIS systems.

University of California, Davis
(Dr. Mary Cadenasso)

Cadenasso Landscape and Urban Ecology (CLUE) Lab (Plant Sciences Building 1211, 1240, 1314, and Robbins Hall 291). The CLUE lab consists of 4 spaces: 1. Cadenasso's analytical laboratory is 64 m^2 and houses extensive work surfaces, storage cabinets, and a full sized fume hood with a maintained acid bath. The lab is equipped with a Nanopure® water system, spectrometer, an analytical balance, electronic top loading scale and sample scales, a dissecting microscope, drying ovens (plants and soil), microwave digester, pH and conductance meters, Kleco 8 canister ball mills, desiccator cabinet, refrigerator and freezer. 2. Additional space of approximately the same size as the analytical lab is used for dirtier work such as the processing of plant and soil samples. This room contains benchtops for sorting and sieving, storage, nanopure® system, drying ovens, and desks and computers for up to 6 graduate students. Field equipment includes items needed for plant, soil and water sampling and collection such as measuring and dbh tapes, pole/hand pruners, clinometers, hand lenses, plant presses, densiometers, leaf area meters, LICOR 6400 (photosynthesis), soil bulk density samplers, augers and corers, a plant canopy analyzer, tree corers, GPS units, TDR probes, soil compaction tester, flow meter, and ISCO water samplers. 3 and 4. The GIS office and Cadenasso's office are each approximately 15 m^2 each and contain desk and storage space and are supplied with computers and external data storage compatible with data needs.

Conference rooms and library privileges: The PES building, where Cadenasso's lab is located contains several conference rooms of various sizes available for sign out and fully equipped with internet and teleconferencing capabilities. These rooms are adequate to accommodate the cohort of visiting graduate students. Cadenasso will ensure that the students will have wireless access to the internet from any location on campus and will be able to VPN into the UC Davis library. The library maintains a full complement of literature search databases and journals available electronically for pdf download.

US Forest Service Baltimore Field Station
(Dr. Morgan Grove)

The Forest Service's Baltimore Field Station includes an office, storage, and parking. The storage is off-site, two miles from the UMBC campus. Field equipment and samples are stored at this off-site facility. The main office is located on the UMBC campus and has ten offices for permanent and visiting scientists. It has four "bullpen" units, including desk and storage, for visiting scientists and students. There is one collaborative work space (6 persons) and one conference room (15 persons), which include videoconferencing equipment. All permanent staff and visitors have access to the internet, printers, and scanners. There are no restrictions on parking. The Field Station office has a field storage room for field equipment that is used frequently. and a library for published materials, principally books, about Baltimore and its history.

University of Maryland College Park
(Dr. Sujay Kaushal)

The Department of Geology and Earth System Science Interdisciplinary Center at the University of Maryland, College Park contains analytical facilities for research in geochemistry, hydrology, biogeochemistry, stable isotope geochemistry, trace metal geochemistry, geographic information systems and spatial analysis**.** Research support is comprehensive and state-of-the-art, offering for instance, ample refrigerator and freezer space for the storage and preservation of water samples for routine chemistry and geochemical characterization, stable isotopic analyses, trace metal analyses, and analyses of other perishable materials. Dr. Kaushal and the technician have access to ample office space. They also have numerous computers at University of Maryland, College Park including a high-end, dual-processor desktop and a notebook computer for travel, each capable of performing all of the data analyses. Computers at University of Maryland, College Park have access to the Internet and are linked together in a local network. University of Maryland, College Park Motor Transportation Services manages a fleet of field vehicles, including cars and trucks that are available for research projects that can be signed out and charged to research grants on a per-day basis.

University of Missouri
(Dr. Charles Nilon)

Institutional Resources
All multi-user facilities at MU are available to the project participants on a fee for use basis. These facilities include the following:

- DNA Core Facility – a state of the art research facility providing services to over 200 investigators on all four campus of the University of Missouri system, outside academic institutions and commercial enterprises. Our research facility provides services in: Sanger Sequencing; Fragment Analysis; Illumina (Next Gen) Sequencing; Illumina Library Construction; Affymetrix Arrays.
- Molecular Cytology Core – serves as a resource center for light and fluorescent microscopy, immunocytochemistry and in situ hybridization. The Core has microtomes, cryostats, cryo-ultramicrotomes and a variety of microscopes.
- Informatics Research Core Facility – provides consulting services, software development, and analysis and visualization of high-throughput data, especially next-generation sequence data.
- Sears/LSC Plant Growth Facility – greenhouse space and growth chambers available for use by the PI.

Shared Computing Resources at MU:
High Performance Computing

- SGI Altix 3700 Bx2, 64 1.5GHz Itanium2 processors, 128 GB RAM , 4TB SGI InfiniteStorage RAID, SuSE Linux Enterprise Server 9, with SGI ProPack 4
- Dell 1850 Dual Core Cluster, 128 node, dual core, dual processor cluster, 512 2.8GHz Intel Xeon EM64T processor cores, 640 GB RAM (64 nodes 6GB, 64 nodes 4GB), 8TB SGI InfiniteStorage RAID, 10 Gb/sec Topspin InfiniBand interconnect network, Platform Rocks Linux 4.0 (based on Red Hat)

- Sun/TimeLogic, DeCypher G4 FPGA, 8 DeCypher G4 engines (2 shown), installed in 4 Sun V240 servers, perform fast genomic searches/comparisons
- Teragrid infrastructure include more than 2 petaflops of computing capability and more than 50 petabytes of online and archival data storage, with rapid access and retrieval over high-performance networks

Network
- RNET – 1 Gbit capacity
- Missouri TigerNet 10/100 Mbit capacity
- Wireless access to TigerNet

School of Natural Resources (Nilon) The School of Natural Resources is located in the Anheuser-Busch Natural Resources Building, which was dedicated in September 1998. The building is a 99,000 square foot facility on the MU campus, devoted exclusively to addressing natural resource issues in Missouri, the nation and the world. The School of Natural Resources studies interactions and management of the natural environment, including agroforestry; water quality; conservation biology; watershed management; landscape management; recreational tourism; global climate change; forest management; and fisheries and wildlife management.

Parks & People Foundation
(Ms. Elisabeth Millspaugh Schroeder)

Land: Parks & People Foundation has a 9 acre campus in West Baltimore. The property is a part of Druid Hill Park which is owned by Baltimore City Department of Recreation & Parks. Parks & People Foundation long-term lease for its campus with Baltimore City Department of Recreation & Parks. Over 50 years remain on the lease.
The urban park space is located in the densely urban Greater Mondawmin area of Baltimore City. The campus is largely green space with one pervious parking lot and another parking lot surrounded by stormwater facilities. Several dozen trees are on the campus. Having just moved into the space in mid-2015, the landscaping plan is not yet complete. Preliminary ideas to enhance the space include areas for demonstration projects for monitoring, an active recreational area, a nature plays pace and small gardens.

Buildings: Currently three buildings are located on the campus. Two or original to the property – the Stone House and the Carriage House The Stone House was built in 1872 and designed by George Frederick, the same architect who designed Baltimore's City Hall. A small carriage house on the site also dates to 1872. Originally the home of Druid Hill Park's Superintendent and later the Superintendent of the Baltimore Zoo, much of the interior of the house was destroyed by two fires. Parks & People has rehabilitated the Superintendent's House and stabilized the neighboring Carriage House in keeping with their historical character and in accordance with the Secretary of Interiors' Standards for the Treatment of Historic Properties and LEED protocol. The Stone House serves as meeting and event space that can host approximately 70 individuals. It has a several AV features, a small kitchen, and private restrooms. It has an outdoor patio space and a covered porch. The space is used frequently by local partners and community organizations. The nearby Carriage House is used for storage.

The larger Sally & Butch Michel Center is a central place for people to discover, experience and develop a better understanding of the region's natural and recreational resources including what they can do to play a positive role in the community. It houses Parks & People's administrative offices and provide space for programs and meetings as well as a small library. It boasts and ecology center for educational programming that opens to a green roof that functions as a deck. It has two sets of restrooms, one for staff that provides showers and lockers. It has a kitchen for staff use and a small trash and recycling area. It tire site be designed to the highest level of green building, LEED Platinum. The project will seek LEED Platinum certification upon completion and will demonstrate environmentally responsible features including geothermal energy.

In 2016, a small modular building will be added to the Parks & People Foundation campus. The space will be used for adult and youth crews. It will contain office and meeting space, and restrooms. For more information, please visit - http://www.parksandpeople.org/support/capital-campaign/.

Equipment: Parks & People Foundation has seven trucks and several trailers for project implementation. It has a large hand tool inventory for use by its crews and volunteers in greening projects. In addition to its stationary work stations, it has laptops and portable projectors for use during community engagement and outreach as well as commonly used tabling supplies such as folding canopies and tables. It has to large smart screen televisions for educational programs and presentations.

Princeton University
(Dr. James Smith)

Laboratory: No laboratory space is required.

Clinical: No clinical test will be performed.

Animal: No animals will be involved.

Computer: PI Smith has adequate desktop computing equipment.

Office: PI and research staff have offices at Princeton University.

Other: none

Johns Hopkins University
(Dr. Katalin Szlavecz)

The soil laboratory at the Dept. of Earth and Planetary Sciences, JHU is available for sampling, preparation and processing of the soil and soil fauna samples. The laboratory is equipped with Nikon dissecting and compound microscopes, a modified Tullgren extractor, two large Percival incubators, drying oven, furnace, Wiley mill, electronic balances, source of deionized water, and flow hood. For construction of any special equipment JHU operates a mechanical and carpentry shop available for JHU employees. The laboratory also has a permit for importing soil from anywhere in the world. The Department of Earth and Planetary Sciences has a 14 passenger van available for field work. Computer facilities for regular tasks are available at the Dept. of Earth and Planetary Sciences. If needed, a large distributed database facility is at the dept. of Physics and Astronomy, JHU. This facility consists of 50 servers and it is built on Microsoft SQL Server. The front end is a 3-way fault tolerant web cluster that is running several websites with over 16 million web hits/month. The cluster is supporting various e-Science applications from the entire University and is willing to provide free hosting for the whole JHU copy of the database and service portal.

SECTION 5: INFORMATION MANAGEMENT

Highlights: 1) BES has signature long-term data sets posted online, including 18 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 Network Data Portal. 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 maintained by the Cary Institute of Ecoystem Studies (Druva InSync) that senses and backs up changed files automatically. The target drives are configured as RAID and that array in turn, backs up to on offsite RAID array. Since BES data has Demographic and Socioeconomic components, sensitive personal data such as addresses and incomes are collected. However, 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. The BES servers are now completely virtualized using VMWare.

The BES Information system is well documented in case of personnel turnover. Program code contains comments describing any difficult passages to aid in future revisions. 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. It also serves to inform the collaborators and the public of BES news and activities. Increasingly, BES is using website management tools, especially Google Sites, so that researchers can add and edit their own website content rather than having it done via the Information Manager.

Publications database: 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 1300 items. The database is presented with an online interface which is searchable and filterable. The database is updated continually. It also can output the data in a standard exchange format to share with larger collections. To facilitate interactions with Baltimore environmental managers and practitioners, who are generally not able to access traditional academic library resources, we have compiled a BES Zotero database including pdfs of our publications. This resource is widely used and appreciated.

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

Access: All data and metadata are made available online. BES has some 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 some users the files are too large to be retrieved online. The BES server has available online 32 gigabytes of spatial data in 4,913 files (see http://beslter.org/geodatabase_SAL). To make these data readily available, scientists are can send a portable drive which is remitted with the requested geodatabase.

Discovery: BES datasets are assigned keywords that are defined in the LTER controlled vocabulary. There is a search mechanism on the BES website and the LTER Network Data Portal.

Tracking: Datasets accessed via the BES website are tracked by means of a form which is 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 14450 requests. To date, 4180 of those requestors filled in their affiliation and reason for downloading the data form.

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

Mechanism: PIs 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 other systems to connect to the EML files so that they can be retrieved via the links to the datasets. BES metadata meet and exceed 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. Datasets are introduced to the LTER PASTA system by uploading the metadata records to the LTER Network Data Portal. The portal, in turn, accesses the metadata record. It collects and stores the metadata information and retrieves the data file using the link in the metadata. In response to a comment from a Mid-Term review panel, this code has been made available to the rest of the LTER network for use at: https://github.com/jonathanmwalsh/metadatabase

Certain data are collected via an online database which allows PIs in disparate locations to work on the same data together. These include the BES Bird Survey and the Stream Chemistry and Long-Term Biogeochemical Study Plot (under development) 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. Development of these databases was facilitated by Information Management supplement funding provided by NSF.

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 yearly, and is a member of the BES Project Management Committee and Steering Committee.

What mechanisms are in place to get PIs to contribute their data? Obligations to produce and share specific datasets are included in subcontracts that fund PI participation in BES. Reminders to submit data are made regularly, especially at the annual meeting, during preparation of the BES project annual report and when subcontracts are annually renewed.

How quickly are data made available to other researchers? Most datasets become available to BES PIs 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 have 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 gage data are available on a continual basis using a web interface to the recorder. Several datasets are single collections and not updated.

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, and the Network Communication Committee. In addition, the BES Information Manager has taken an active role in designing the new Network Information Management Organization (NIMO). BES participates fully with the LTER Information Management Committee in information management system design. All program code, ideas, and techniques are freely shared with LTER Network members.

We list BES data sets currently deposited into the LTER Network Information System in a Supplementary Document.

Postdoctoral Mentoring Plan

Postdoctoral Researchers funded by BES: We propose to provide partial funding for two postdoctoral researchers at the Cary Institute and at University of North Carolina. These two postdocs will be a part of their home institution communities with individual activities (specified below) and will be a part of the larger BES community with common activities as part of BES LTER. The proposed research spans traditional research domains from terrestrial to aquatic ecosystems, hydrology, and social science. Therefore, post-doctoral fellows involved in BES will interact with collaborators from numerous disciplines outside of their doctoral research discipline.

Cary Institute of Ecosystem Studies. The BES synthesis postdoc will be based at Cary and will be mentored by Lead-PI Rosi-Marshall with direct collaboration with CoPI LaDeau. The Cary Institute provides a collegial and productive environment for postdoctoral researchers. New postdocs are encouraged to give either a formal academic or less formal lunchtime seminar within the first three months of arrival. Postdocs are encouraged to attend monthly Scientific Staff meetings, to serve on Institutional committees, as interested, and they actively participate in our weekly seminar program by inviting speakers (at Institute expense). Postdocs also participate in Institutional programs on Responsible Conduct in Research, which include online training modules, discussion groups and seminars. Postdocs are also encouraged to co-mentor undergraduate students through the Cary Institute's site REU program, which allows development of mentoring skills as well as exploration of new research directions.

University of North Carolina. UNC Postdoc will be mentored by CoPI Band. The post-doctoral fellow at UNC will contribute to a one semester seminar aimed at undergraduates and graduate students on integrated modeling. With faculty guidance, the post-doctoral fellows will develop pedagogical practices necessary to integrate research into teaching. Postdocs are encouraged to co-mentor undergraduate students, which allows development of mentoring skills.

BES Activities and Expectations. In addition to becoming part of their respective institutions, the postdocs will become a key part of the BES research community, with an emphasis on providing the postdocs with collegial interactions and opportunities for leadership and independent initiative. Special effort is made to define expectations for the positions in detailed appointment letters. Specific tasks that need to be accomplished are listed, but the position is structured so that the postdocs have the opportunity to design aspects of the research themselves and to publish it as principal author. Postdocs are provided travel funds to present papers at conferences, including all BES meetings and the periodic LTER All-Hands Meetings.

Research Guidance for Synthesis Postdocs: BES Project Synthesis Team will work closely with postdocs to provide a mentoring network to effectively accomplish synthesis. A major goal of research guidance in this project is to develop skills in working with interdisciplinary skills, including the ability to both lead efforts and to provide support roles as appropriate through this project.

Networking: BES will enable the post-doctoral fellow to meet with a broad cross-section of investigators at the face-to-face project meetings (monthly synthesis meetings, quarterly BES meetings), expanding their professional network. Networking within the project, within the broader urban community, and with the broader scientific community will also support further professional development for post-doctoral fellows.

Professional Development: The collaborators will give the post-doctoral fellow extensive experience working with diverse audiences and stakeholder groups in workshop and public settings. Collaborators will provide the post-doctoral fellow with advice and constructive criticism on application materials, presentations, interviews, negotiations, etc., as the fellows move forward in their career. Finally post-doctoral fellows will be encouraged to participate in writing related collaborative proposals and the manuscripts resulting from this work.

PROJECT MANAGEMENT PLAN

Institutional Arrangements. The Baltimore Ecosystem Study LTER is administered by the Cary Institute of Ecosystem Studies, with subcontracts for research, education, and community engagement. The Cary Institute makes available administrative and technical support for BES and a field vehicle for use in Baltimore. The University of Maryland, Baltimore County (UMBC), through its Center for Urban Environmental Research and Education (CUERE), provides an intellectual and logistic home for BES in Baltimore. Through a Memorandum of Understanding UMBC/CUERE maintains wet and dry laboratories, geographic information system (GIS) facilities, equipment storage, field staging, and office space for technicians, education staff and PI's at the Technology Research Center building. The USDA Forest Service, Northern Research Station has maintained an Urban Field Station on the campus of UMBC since 1997. Eight (8) staff members are involved in BES related ecological research on soils, hydrology, aquatic and terrestrial species, and vegetation; anthropological and sociological research on households, communities, organizations, and governance networks; and BES related education, diversity, and science engagement activities. The Forest Service manages a subcontract to support social science research and the long-term i-Tree sampling. US Geological Survey is also located on the UMBC campus and maintains the stream gaging stations through a subcontract. Subcontractors include: City University of New York for long-term watershed and terrestrial plot studies; Parks & People Foundation (PPF) for community engagement, outreach, non-formal education, and training; Johns Hopkins University for soil biodiversity research; the University of Missouri for bird studies; the University of North Carolina for hydrologic modeling; Ohio University and Arizona State University for social science and historical geography; the University of Vermont for social science, GIS for social science databases, land cover, and spatial analysis; Ohio State University, Pennsylvania State University, and University of Maryland, College Park for land economics; Dartmouth College for household and neighborhood ethnographies; the University of California, Davis for land cover and research synthesis; the University of Maryland for stream biogeochemistry; Princeton University for high-resolution radar rainfall data; and UMBC for groundwater, stream geomorphology, social science, biodiversity, and land use research. Cary Institute research includes stream chemistry and stream/riparian ecology, land change, soil microbial ecology, vegetation, infectious disease ecology, modeling and synthesis, and education. Training of graduate students has been conducted through the universities above plus long-term collaboration with 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. 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. The Education Coordinator, Ms. Bess Caplan, is funded partially by the BES grant and leveraged support. She is stationed at UMBC 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. Ms. Valerie Rupp, Director of Community Greening and Great Parks at PPF, devotes a portion of her time to BES to facilitate interactions with communities, government agencies, and community groups for research, education, and engagement. She provides a conduit to community-oriented programs, to the local expertise of PPF, and with Cary Institute Information Officer Lori Quillen, to the press. CUERE makes GIS services available to BES through Mr. Joshua Cole's (Environmental Data Manager) time. CUERE provides incidental office logistic support. CUERE personnel report to Dr. Claire Welty. The Project Facilitator and Information Manager report to the Project Director. The Education Coordinator reports to BES Co-PI Dr. Alan Berkowitz, and Ms. Rupp reports to Co-PI Lisa Schroeder, President and CEO of PPF.

The project is characterized by racial and gender diversity. Of 28 BES Leaders (Table 4-1), two are African American and 25% are women. We currently have 29 active graduate students affiliated with BES. This group includes 4 students from underrepresented groups and 16 women. In addition, the much larger community of BES participants who attend our quarterly meetings, participate in research, and contribute to our intellectual presence in Baltimore augments our diversity. We will increase the diversity of BES at all levels by interacting with faculty from minority-serving institutions, facilitating REU participation from these schools, and interacting with the SEEDS (http://www.esa.org/seeds/) diversification program conducted by the Ecological Society of America. UMBC hosts a SEEDS Chapter. The USDA Forest Service has 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 Project 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.

The project supports an Arts and Science Integration Committee that includes local artists and scientists. The purpose of the committee is to promote novel artistic understanding of science and the use of science to inform art. The committee administers our Artist-in-Residence Program. Since 2013, an artist has been selected competitively for a one-year stipend to work with BES scientists on projects of the artist's choosing. We propose to continue this practice on a bi-annual basis. The Arts and Science Integration Committee also works at a network level, communicating with similar initiatives at other LTER and Forest Service sites.

Administration. BES is administered by a Project Management Committee, which meets monthly (Table 4-1). 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, is a member of the PMC. Once a year, we convene a Steering Committee, including all Co-PIs, post-docs, the graduate students, and staff. 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, Education and Engagement and the BES Bulletin Editorial Board.

Research decisions are shaped by discussions at quarterly project meetings that 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 community members attend these meetings. In the future, one Quarterly meeting each year will be devoted to project synthesis.

Fiscal Procedures. The Project Director (Lead PI) is responsible 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 the four quarterly meetings in Baltimore, and the BES News 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 among BES, local communities and government agencies.

Transition in Leadership. In the next phase of BES, we will have a new Lead PI (Project Director), Dr. Emma Rosi-Marshall. This transition has been ongoing since the mid-term review of BES III. Dr. Rosi-Marshall has been working closely with current Director Dr. Pickett. The two currently act as co-directors to make a smooth transition to the proposed phase of this project. Rosi-Marshall and Pickett led the activities for this proposal development and have been co-leading meetings since 2013. Pickett will remain actively involved in BES as a Co-PI to further enable a smooth leadership transition. Leadership continuity is also provided by Peter Groffman who has, and will continue to serve as Deputy Director. Groffman oversees project budgets, the on-site long-term data collection efforts, assists with oversight of Information Management and subcontract management.

Table 4-1. BES Participants and their roles for the proposed next phase of BES LTER.

Participant Name	**Institution**	**Management Role**	**Project Activity**
Rosi-Marshall, Emma	Cary Institute	Project Director, PMC	Streams, Synthesis
Baker, Matt	UMBC		Landscape, Synthesis
Band, Lawrence E	U North Carolina		Hydrological modeling
Berkowitz, Alan R	Cary Institute	PMC, Education Leader	Education
Boone, Christopher G	Arizona State U		Social sciences
Buckley, Geoffrey L	Ohio University		Historical geography
Cadenasso, Mary L	UC Davis	PMC	Landscape ecology
Doheny, Edward J	USGS	PMC	USGS Liason, Stream gaging
Groffman, Peter M	CUNY	PMC, Budget Admin.	Ecosystem ecology
Grove, J Morgan	Forest Service	PMC, Soc. Sci. Leader	Social sciences
Irwin, Elena G	Ohio State U		Social sciences, modeling
Kaushal, Sujay S	UMCES		Ecosystem ecology, streams
Kelly, John J.	Loyola University		Stream microbial biodiversity
LaDeau, Shannon L	Cary Institute		Disease ecology, Modeling
Miller, Andrew J	UMBC		Geomorphology, streams
Nilon, Charles H	U Missouri		Biodiversity
Nowak, David J	Forest Service		Vegetation, modeling
Ogden, Laura	Dartmouth		Anthropology
O'Neil-Dunne, Jarlath	U Vermont		Spatial data & analysis
Pickett, Steward T A	Cary Institute	PMC	Landscape; Synthesis
Schroeder, Lisa	Parks & People		Community relations, soc. scis.
Smith, Jim	Princeton		Rainfall modeling
Swan, Christopher	UMBC	PMC	Biodiversity
Szlavecz, Katalin	Johns Hopkins		Biodiversity
Troy, Austin R	U Vermont		Social sciences, spatial analys.
Walsh, Jonathan M	Cary Institute	PMC, Information Mgr.	Information management
Rupp, Valerie	Parks & People	PMC	Community relations, soc. scis.
Welty, Claire	UMBC	PMC	Hydrology, UMBC laiason

PMC = Project Management Committee

BES Datasets Available via LTER PASTA

BES ID	PASTA ID	Title and Description
Section 1 - Core data sets		
Category - Biodiversity		
BES_1000	knb-lter-bes.1000.12	Urban Forest Effects Model (UFORE) to calculate forest structure and function from sample ground data. Four part The UFORE model calculates forest structure and function from sample ground data.. Within the City of Baltimore, 195 permanent 1/10 circular plots were established based on a stratified random sample among land uses in 1999. These plots were re-measured in 2004 and 2009
Category - Dem/Soc		
BES_0482	knb-lter-bes.482.12	BES Household Telephone Survey, 1999 BES Household Telephone Survey, 1999, written components - Abstract, methods, documentation, data dictionary, questionnaire.
BES_0483	knb-lter-bes.483.12	BES Household Telephone Survey, 2000 BES Household Telephone Survey, 2000, written components - Abstract, methods, documentation, data dictionary, questionnaire.
BES_0041	knb-lter-bes.41.58	BES Household Telephone Survey, 2003, Environmental Behaviors BES Household Telephone Survey, 2003, GIS Components - Environmental Behaviors - Notice: The file is large and is part of a larger geodatabase. The entire geodatabase is also available on physical media by contacting BES
BES_0048	knb-lter-bes.48.58	BES Household Telephone Survey, 2003, Environmental Improvements BES Household Telephone Survey, 2003, GIS Components - Environmental Improvements
BES_0049	knb-lter-bes.49.58	BES Household Telephone Survey, 2003, Environmental Problems BES Household Telephone Survey, 2003, GIS Components - Environmental Problems

BES ID	PASTA ID	Title and Description
BES_0001	knb-lter-bes.1.58	BES Household Telephone Survey, 2003, Environmental Satisfaction
		BES Household Telephone Survey, 2003, GIS Components - Environmental Satisfaction
BES_0484	knb-lter-bes.484.12	BES Household Telephone Survey, 2006
		BES Household Telephone Survey, 2006, written components - Abstract, methods, documentation, data dictionary, questionnaire.
BES_0335	knb-lter-bes.335.58	Geocoded Baltimore City Telephone Survey 2006
		GIS Files Component of the Baltimore City Telephone Survey 2006 - Notice: The file size is large and is part of a larger geodatabase. The entire geodatabase is also available on physical media by contacting BES Directly.
BES_0336	knb-lter-bes.336.58	Geocoded Baltimore County Telephone Survey 2006
		GIS Files Component of the Baltimore County Telephone Survey 2006 - Notice: The file size is large and is part of a larger geodatabase. The entire geodatabase is also available on physical media by contacting BES Directly.

Category - Soil

BES_0417	knb-lter-bes.417.12	Soil moisture in long-term study plots
		These plots will provide long-term data on vegetation, soil and hydrologic processes in the key ecosystem types within the urban ecosystem. The current network of study plots includes eight forest plots, chosen to represent the range of forest conditions in the area, and four grass plots. These plots are complemented by a network of 200 less intensive study plots located across the Baltimore metropolitan area.
BES_0428	knb-lter-bes.428.24	Soil solution chemistry data from long-term study plots
BES_0585	knb-lter-bes.585.34	Soil: atmosphere fluxes of carbon dioxide, nitrous oxide and methane
BES_0432	knb-lter-bes.432.32	Soil: Temperature Data - Hillsdale 1 - Water Year 2000-
		Soil temperature is measured with HOBO H8 Pro Series Temp/External Temp data loggers from Onset Computer Corporation. One logger was installed in each plot to a depth of 10 cm.

BES ID	PASTA ID	Title and Description
BES_0490	knb-lter-bes.490.32	Soil: Temperature Data - Hillsdale 1 - Water year 2000-2011 - Complete Spreadsheet With Graphs and Background Information, Field Notes.
BES_0487	knb-lter-bes.487.32	Soil: Temperature Data - Hillsdale 2 - Water year 2000-2004
BES_0491	knb-lter-bes.491.32	Soil: Temperature Data - Hillsdale 2 - Water year 2000-2004 - Complete Spreadsheet With Graphs and Background Information, Field Notes.
BES_0492	knb-lter-bes.492.32	Soil: Temperature Data - Leakin 1 - Water year 2000-2011 - Complete Spreadsheet With Graphs and Background Information, Field Notes.
BES_0433	knb-lter-bes.433.32	Soil: Temperature Data - Leakin 1- Water year 2000-2011
BES_0493	knb-lter-bes.493.32	Soil: Temperature Data - Leakin 2 - Water year 2000-2011 - Complete Spreadsheet With Graphs and Background Information, Field Notes.
BES_0434	knb-lter-bes.434.32	Soil: Temperature Data - Leakin 2- Water year 2000-2011
BES_0436	knb-lter-bes.436.32	Soil: Temperature Data - McDonogh 1 - Water year 2000-
BES_0494	knb-lter-bes.494.32	Soil: Temperature Data - McDonogh 1 - Water year 2000-2007 - Complete Spreadsheet With Graphs and Background Information, Field Notes.
BES_0437	knb-lter-bes.437.32	Soil: Temperature Data - McDonogh 2 - Water year 2000-
BES_0495	knb-lter-bes.495.32	Soil: Temperature Data - McDonogh 2 - Water year 2000-2007 - Complete Spreadsheet With Graphs and Background Information, Field Notes.
BES_0438	knb-lter-bes.438.32	Soil: Temperature Data - Oregon Ridge Middle 1 - Water year 2000-2010

BES ID	PASTA ID	Title and Description
BES_0496	knb-lter-bes.496.32	Soil: Temperature Data - Oregon Ridge Middle 1 - Water year 2000-2010 - Complete Spreadsheet With Graphs and Background Information, Field Notes.
BES_0497	knb-lter-bes.497.32	Soil: Temperature Data - Oregon Ridge Middle 2 - - Water year 2000-2009 - Complete Spreadsheet With Graphs and Background Information, Field Notes.
BES_0439	knb-lter-bes.439.32	Soil: Temperature Data - Oregon Ridge Middle 2 - Water year 2000-2009
BES_0440	knb-lter-bes.440.32	Soil: Temperature Data - Oregon Ridge Upper 1 - water year 2000 - 2010
BES_0441	knb-lter-bes.441.32	Soil: Temperature Data - Oregon Ridge Upper 2 - water year 2000 - 2011
BES_0499	knb-lter-bes.499.32	Soil: Temperature Data - Oregon Ridge Upper 2 - Water year 2000-2011 - Complete Spreadsheet With Graphs and Background Information, Field Notes.
BES_0442	knb-lter-bes.442.32	Soil: Temperature Data - UMBC 1 - water year 2003 - 2011
BES_0500	knb-lter-bes.500.32	Soil: Temperature Data - UMBC 1 - Water year 2003 - 2011 - Complete Spreadsheet With Graphs and Background Information, Field Notes.
BES_0443	knb-lter-bes.443.32	Soil: Temperature Data - UMBC 2 - Water year 2003 - 2011
BES_0501	knb-lter-bes.501.32	Soil: Temperature Data - UMBC 2 - Water year 2003 - 2011 - Complete Spreadsheet With Graphs and Background Information, Field Notes.

BES ID	PASTA ID	Title and Description

Category - Stream

BES ID	PASTA ID	Title and Description
BES_0455	knb-lter-bes.455.32	Long-Term Monitoring of Riparian Water Table Depth and Groundwater Chemistry Long-term monitoring of riparian water tables and groundwater chemistry began in 2000 along four first or second order steams in and around the Gwynns Falls watershed in Baltimore City and County, MD. One site (Oregon) is in the completely forested Pond Branch catchment that serves as a "reference" study area for the
BES_0910	knb-lter-bes.910.44	Stream chemistry and stream flow overview, methods, and procedures Stream chemistry and stream flow overview, methods, and procedures: This is a document describing the methods and practices of stream chemistry data from collection, to storage, quality control, analysis, and curation. The document is in Rich Text format (RTF).
BES_2010	knb-lter-bes.2010.45	Stream chemistry for core sites in Gwynns Falls: concentration of Cl, NO3, PO4, total N and P, SO4, dissolved oxygen, E. coli, plus temperature, pH, clarity and Baltimore Ecosystem Study stream chemistry for core sites: a CSV File of stream chemistry values; parameters: Date, Site, Cl (mg/L), NO3 (mg N/L), TN (mg N/L), TP (ugP/L), PO4 (ug P/L), SO4 (mg/L), time, stage, temperature, dissolved oxygen, pH, clarity, turbidity (NTU), Ecoli
BES_0700	knb-lter-bes.700.45	Stream chemistry for core sites in Gwynns Falls: concentration of Cl, NO3, PO4, total N and P, SO4, dissolved oxygen, E. coli, plus temperature, pH, clarity and Baltimore Ecosystem Study stream chemistry for core sites: a CSV File of stream chemistry values; parameters: Date, Site, Cl (mg/L), NO3 (mg N/L), TN (mg N/L), TP (ugP/L), PO4 (ug P/L), SO4 (mg/L), time, stage, temperature, dissolved oxygen, pH, clarity, turbidity (NTU), Ecoli
BES_0900	knb-lter-bes.900.44	Stream chemistry for Cub Hill sites: concentration of Cl, NO3, PO4, total N and P, SO4, dissolved oxygen, E. coli, plus temperature, pH, clarity and turbidity Stream chemistry for Cub Hill sites. Cub Hill is the location of the BES flux tower. This is a CSV File of stream chemistry values; parameters: Date, Site, Cl (mg/L), NO3 (mg N/L), Total Nitrogen (TN) (mg N/L), Total Phosphorus (TP) (ugP/L), Phosphate (PO4) (ug P/L), and Sulfate (SO4)

BES ID	PASTA ID	Title and Description
BES_0800	knb-lter-bes.800.43	Stream chemistry for upper tributaries of Gwynns Falls watershed: concentration of Cl, NO3, PO4, total N and P, SO4, dissolved oxygen, E. coli, plus temperature, pH, clarity and turbidity Baltimore Ecosystem Study stream chemistry for upper tributaries of Gwynns Falls watershed: a CSV File of stream chemistry values; parameters: Date, Site, Cl (mg/L), NO3 (mg N/L), Total Nitrogen (TN) (mg N/L), Total Phosphorus (TP) (ugP/L), Phosphate (PO4) (ug P/L), and Sulfate (SO4)
BES_0950	knb-lter-bes.950.42	Stream chemistry for Watershed 263 sites. This is a CSV File of stream chemistry values; parameters: Date, Site, Cl (mg/L), NO3 (mg N/L), Total Nitrogen (TN) (mg N/L), Total Phosphorus (TP) (ugP/L), Phosphate (PO4) (ug P/L), and Sulfate (SO4) (mg/L). Stream chemistry for Watershed 263 sites. This is a CSV File of stream chemistry values; parameters: Date, Site, Cl (mg/L), NO3 (mg N/L), Total Nitrogen (TN) (mg N/L), Total Phosphorus (TP) (ugP/L), Phosphate (PO4) (ug P/L), and Sulfate (SO4) (mg/L).
BES_2070	knb-lter-bes.2070.14	Stream metabolism data for core sites in Gwynns Falls: high temporal frequency (5-10min resolution) measurements of dissolved oxygen, photosynthetically active radiation, temperature, discharge and depth. Baltimore Ecosystem Study stream metabolism data for core sites in Gwynns Falls: high temporal frequency (5-10min resolution) measurements of dissolved oxygen, photosynthetically active radiation, temperature, discharge and depth.
BES_1100	knb-lter-bes.1100.11	Synoptic water chemistry and discharge data for the Glyndon and Baismans Run sampling sites - 2001 - 2002 Stream water quality and discharge data collected by Steven Kenworthy using flow velocity measurment method. These data are for the Glyndon and Baisman's Run

Section 2 - Peripheral data sets

Category - Biodiversity

BES ID	PASTA ID	Title and Description
BES_1300	knb-lter-bes.1300.11	BES bird survey for Watershed 263, winter, 2012, survey data. This dataset pairs with a file of same name containing a summary of the survey. This is a survey of urban birds in locations within Watershed 263. Survey was taken in winter, 2012. This file accompanies one of same name labeled survey summary.

BES ID	PASTA ID	Title and Description
BES_1310	knb-lter-bes.1310.11	BES bird survey for Watershed 263, winter, 2012, survey summary. This dataset pairs with a file of same name containing the data (counts) for the survey. Summary of the data file BES_1300
BES_1320	knb-lter-bes.1320.11	BES bird survey habitat features. This is a collection of the habitat features for the BES bird sampling points. Features include number of houses, proximity to trees, shrubs, grass, annuals, and other vegetation and physical features. This is a collection of the habitat features for the BES bird sampling points. Features include number of houses, proximity to trees, shrubs, grass, annuals, and other vegetation and physical features.
BES_0543	knb-lter-bes.543.11	Biodiversity - Fauna - Bird Survey - Table 1 of 4 - Birds This is the species information table for the BES bird survey project.
BES_0544	knb-lter-bes.544.12	Biodiversity - Fauna - Bird Survey - Table 2 of 4 - Taxalist This is the taxonomy table for the BES Bird Survey project
BES_0545	knb-lter-bes.545.12	Biodiversity - Fauna - Bird Survey - Table 3 of 4 - Sites This is the table of the sites along the transects for the BES Bird Survey project.
BES_0546	knb-lter-bes.546.12	Biodiversity - Fauna - Bird Survey - Table 4 of 4 - Surveys This is the table containing the counts and survey information for the BES Bird Survey project.
BES_0547	knb-lter-bes.547.12	Biodiversity - Fauna - Soil Fauna - Cub Hill Forest This is a recording of the density of biomass by type along two transects
BES_0548	knb-lter-bes.548.12	Biodiversity - Fauna - Soil Fauna - Earthworm Localities This is a file of 26 observed earthworm species at 29 locations corresponding with many of the stream and soil
BES_0549	knb-lter-bes.549.12	Biodiversity - Fauna - Soil Fauna - Relative frequency of soil arthropod groups at Cub Hill Groups include Springtails, Spiders, Millipedes, Pillbugs, Beetles, Crickets, ants and their relative distribution in Grass, Mulch, Concrete, Shrub, Leaf Litter, Flower Bed, Ground Cover, Bare Soil, Wood and Forest

BES ID	PASTA ID	Title and Description
BES_0550	knb-lter-bes.550.12	Biodiversity - Fauna - Soil Fauna - Relative frequency of terrestrial isopod species in urban and rural forests Relative frequency of terrestrial isopod species in urban and rural forests including T. rathkei, C. convexus, H. riparius, P. muscorum Data were collected between Sep 1999 and April 2000. Ten pitfall traps were placed around each permanent forest plot and emptied monthly. Animals were later identified in the
BES_0551	knb-lter-bes.551.12	Biodiversity - Fauna - Soil Fauna - Species List Arthropod and isopod species list.
BES_2040	knb-lter-bes.2040.15	Data for L.R. Johnson and S.N. Handel - Restoration treatments in urban park forests drive long-term changes in vegetation trajectories - Ecological Applications doi:10.1890/14-2063.1 Urban Park Forests under Restoration: Ground layer species cover, woody understory stem counts by species, and tree DBH by species, Ground layer species cover, woody understory stem counts by species, and tree DBH by species.
BES_2030	knb-lter-bes.2030.11	Immature mosquito abundances in container habitat, 2013. These data represent relative weekly abundances of container-breeding mosquitoes at sites located across the BES long-term stream sampling sites and Watershed 263.
BES_0406	knb-lter-bes.406.11	Permanent Plot Vegetation Sampling, 2003 Ground Cover In 1998, 7 plots were surveyed into 3 forests in the study region of the Baltimore Ecosystem Study (BES): Oregon Ridge Park (4 plots), Hillsdale Park (1 plot), and Leakin Park (2 plots). In 2003, the same seven plots were re-surveyed and one in Hillsdale Park was added, for a total of eight
BES_0411	knb-lter-bes.411.11	Permanent Plot Vegetation Sampling, 2003 Height Data
BES_0412	knb-lter-bes.412.11	Permanent Plot Vegetation Sampling, 2003 Sapling Data
BES_0413	knb-lter-bes.413.11	Permanent Plot Vegetation Sampling, 2003 Seedling Data
BES_0414	knb-lter-bes.414.11	Permanent Plot Vegetation Sampling, 2003 Shrub and Vine Data
BES_0416	knb-lter-bes.416.11	Permanent Plot Vegetation Sampling, 2003 Species List

BES ID	PASTA ID	Title and Description
BES_0415	knb-lter-bes.415.11	Permanent Plot Vegetation Sampling, 2003 Tree Data
BES_3000	knb-lter-bes.3000.10	Riparian vegetation data - 1 of 11 - 1999 and 2004 trees Comparisons of vegetation between the rural/suburban (upper) and urban (lower) sections of the watershed show distinct patterns across an urban to rural gradient. In the lower, more urban section of the watershed, wetland tree species are either absent or occur as small stems while upland species are abundant, in mixed sizes. A comparison of the number of wetland and upland species in the mostly urbanized Gwynns Falls riparian zone with non-urbanized Piedmont floodplains throughout Maryland shows approximately twice as many upland species in the urban floodplain than in non-urbanized floodplains. The majority of shrubs in riparian zones through the Gwynns Falls are upland species. For herbaceous species, frequencies of upland and wetland species are about equal in the upper and middle regions of the watershed, but upland species are more common in the more urban lower floodplains by a factor of greater than two.
BES_3090	knb-lter-bes.3090.10	Riparian vegetation data - 10 of 11 - elevations_at_locations_across_transects
BES_3100	knb-lter-bes.3100.10	Riparian vegetation data - 11 of 11 - species_lists
BES_3010	knb-lter-bes.3010.10	Riparian vegetation data - 2 of 11 - 1999_plot_and_2004_transect_locations
BES_3020	knb-lter-bes.3020.10	Riparian vegetation data - 3 of 11 -
BES_3030	knb-lter-bes.3030.10	Riparian vegetation data - 4 of 11 - 1999_riparian_SHRUB_DATA
BES_3040	knb-lter-bes.3040.10	Riparian vegetation data - 5 of 11 -
BES_3050	knb-lter-bes.3050.10	Riparian vegetation data - 6 of 11 - 1999_TRANSECT_DESCRIPTIONS
BES_3060	knb-lter-bes.3060.10	Riparian vegetation data - 7 of 11 -

BES ID	PASTA ID	Title and Description
BES_3070	knb-lter-bes.3070.10	Riparian vegetation data - 8 of 11 - 2004_riparian_herb_data
BES_3080	knb-lter-bes.3080.10	Riparian vegetation data - 9 of 11 -
BES_0524	knb-lter-bes.524.12	Vegetation - Permanent Plots - Ground Vegetation Recorded observation of vegetation in the BES permanent
BES_0520	knb-lter-bes.520.12	Vegetation - Permanent Plots - Saplings
BES_0521	knb-lter-bes.521.12	Vegetation - Permanent Plots - Seedlings
BES_0523	knb-lter-bes.523.12	Vegetation - Permanent Plots - Shrubs and Vines
BES_0519	knb-lter-bes.519.12	Vegetation - Permanent Plots - Trees
BES_0522	knb-lter-bes.522.10	Vegetation - Permanent Plots - Woody Vegetation Height

Category - Dem/Soc

BES ID	PASTA ID	Title and Description
BES_0473	knb-lter-bes.473.11	Digital Elevation Model - 30 Meter Digital Elevation Model of Gwynns Falls Watershed 30 Meter Digital Elevation Model of Gwynns Falls Watershed ESRI Arc GIS file e00 format, zipped
BES_3120	knb-lter-bes.3120.15	Geodatabase for the Baltimore Ecosystem Study Spatial Comprehensive Geodatabase for the Baltimore Ecosystem Study Spatial Data - An ESRI file geodatabase. This collection consists of considerably large files. It can also be provided on physical media upon request.
BES_0075	knb-lter-bes.75.58	Long Term Sampling Grid, 100 Meters, Baltimore MSA Long Term Sampling Grid, 100 Meters, Baltimore MSA - - Notice: The file size is large and is part of a larger geodatabase. The entire geodatabase is also available on physical media by contacting BES Directly.
BES_0076	knb-lter-bes.76.58	Long Term Sampling Grid, 300 Meters, Baltimore MSA Long Term Sampling Grid, 300 Meters, Baltimore MSA - - Notice: The file size is large and is part of a larger geodatabase. The entire geodatabase is also available on physical media by contacting BES Directly.

BES ID	PASTA ID	Title and Description
BES_0403	knb-lter-bes.403.12	Policy Inventory for Baltimore Maryland USA This dataset was created to compile all the federal, state, county (in Baltimore Metropolitan Statistical Area), and municipal (Baltimore City) laws and policies governing the management of critical resources. Also see BES_2000.
BES_2000	knb-lter-bes.2000.12	Stewardship Mapping And Assessment Project (STEW-MAP) Data were collected for the Baltimore Stewardship Mapping & Assessment Project (Stewmap), using an inventory and survey methodology developed by USDA Forest Service scientists and modified for use in Baltimore, Chicago, and Seattle. Also see BES_0403.

Category - Hydrology

BES_0486	knb-lter-bes.486.11	Land Cover, Baltimore City Arc GIS file of land cover features for Baltimore City. Dbf format, compressed to zip.
BES_0485	knb-lter-bes.485.11	Land Cover, Baltimore County

Category - Meteorology

BES_0391	knb-lter-bes.391.10	Meteorology - Reference Station - Early project Data Early project data from the Baltimore Ecosystem Study (BES) reference meteorological station.
BES_3110	knb-lter-bes.3110.10	Precipitation - near-real time Precipitation - near-real time data (one minute rate) collected via unheated tipping buckets. Precipitation data have been collected at eight sites in the Gwynns Falls watershed (western Baltimore County, MD) since June 2009 by the Center for Urban Environmental Research and Education at University of Maryland, Baltimore County (http://www.umbc.edu/cuere). Each site consists of two unheated rainfall tipping buckets. The data are telemetered in near-real time to a central receiving station

BES ID	PASTA ID	Title and Description
Category - Soil		
BES_2020	knb-lter-bes.2020.12	Denitrification potential in riparian zones and streams Denitrification potential and a series of ancillary variables (inorganic nitrogen concentrations, moisture content, organic matter content, microbial biomass carbon and nitrogen content, potential net nitrogen mineralization and nitrification, microbial respiration, root biomass) has been measured in riparian zone soils and stream geomorphic features by a series of undergraduate and graduate student researchers as part of the Baltimore Ecosystem Study since
BES_0463	knb-lter-bes.463.12	Revitalizing Baltimore Program - GIS Shapefile - Soil Studies - GIS - Northeast GFW wetlands This wetlands coverage has been clipped with the Gwynns Falls watershed boundary.
BES_0464	knb-lter-bes.464.12	Revitalizing Baltimore Program - GIS Shapefile - Soil Studies - GIS - Northwest GFW wetlands
BES_0461	knb-lter-bes.461.12	Revitalizing Baltimore Program - GIS Shapefile - Soil Studies - GIS - Southeast GFW wetlands in Baltimore City
BES_0460	knb-lter-bes.460.12	Revitalizing Baltimore Program - GIS Shapefile - Soil Studies - GIS - Southeast GFW wetlands in Baltimore
BES_0462	knb-lter-bes.462.12	Revitalizing Baltimore Program - GIS Shapefile - Soil Studies - GIS - Southwest GFW wetlands
Category - Stream		
BES_0467	knb-lter-bes.467.11	Revitalizing Baltimore Program - GIS Shapefile - Stream and Watershed Studies - GIS - Boundary - GFW subwatershed boundaries
BES_0466	knb-lter-bes.466.11	Revitalizing Baltimore Program - GIS Shapefile - Stream and Watershed Studies - GIS - Boundary - Masking coverage to isolate the GFW from surroundings

BES ID	PASTA ID	Title and Description
BES_0468	knb-lter-bes.468.11	Revitalizing Baltimore Program - GIS Shapefile - Stream and Watershed Studies - GIS - Boundary - Patapsco watershed boundary (GFW is a subshed of the Patapsco)
BES_0469	knb-lter-bes.469.11	Revitalizing Baltimore Program - GIS Shapefile - Stream and Watershed Studies - GIS - Gwynns Falls Watershed
BES_0470	knb-lter-bes.470.11	Revitalizing Baltimore Program - GIS Shapefile - Stream and Watershed Studies - GIS - Patapsco Watershed Streams
BES_0471	knb-lter-bes.471.11	Revitalizing Baltimore Program - GIS Shapefile - Stream and Watershed Studies - GIS - SE city Gwynns Falls watershed wetlands for Baltimore city
BES_0472	knb-lter-bes.472.11	Revitalizing Baltimore Program - GIS Shapefile - Stream and Watershed Studies - GIS - SE county Gwynns Falls watershed wetlands for Baltimore county
BES_0465	knb-lter-bes.465.11	Revitalizing Baltimore Program - GIS Shapefile - Studies - GIS - Boundary - Gwynns Falls Watershed (GFW) Boundary
BES_0476	knb-lter-bes.476.12	Revitalizing Baltimore Program - GIS Shapefile - Surface Characteristics - Gwynns Falls Watershed forested land polygons - GIS
BES_0609	knb-lter-bes.609.13	Stable Isotopic Composition of Nitrates and POM in BES Streams Stable isotopic analyses were carried out on stream samples collected bi-weekly from June 2005 through December 2005 as part of the routine Baltimore LTER sampling.
BES_2080	knb-lter-bes.2080.16	Stream biofilm bacterial community composition Analysis of stream biofilm diversity in the Gwynns Falls and Oregon Ridge watersheds and relationship to urban land use and influence of wastewater effluent (e.g., pharmaceuticals, salt, nutrients).
BES_1740	knb-lter-bes.1740.12	Stream Temperature - (DRKR) Water year 2007-2008 A total of 22 sites contain sensors (HOBO Pro v2 Water Temperature Data Logger - U22-001) that take an instantaneous temperature reading every 2 minutes.
BES_1860	knb-lter-bes.1860.12	Stream Temperature - (PDML) Water year 2007-2008

BES ID	PASTA ID	Title and Description
BES_1920	knb-lter-bes.1920.12	Stream Temperature - (SCLB) Water year 2007-2008
BES_1410	knb-lter-bes.1410.11	Stream Temperature - Baisman Run (BARN) Water year 2004-2005
BES_0589	knb-lter-bes.589.12	Stream Temperature - Baisman Run (BARN) Water year 2006-2007
BES_1700	knb-lter-bes.1700.12	Stream Temperature - Baismans Run (BARN) Water year 2007-2008
BES_1400	knb-lter-bes.1400.12	Stream Temperature - Baltimore Street (BALT) Water year 2004-2005
BES_1420	knb-lter-bes.1420.11	Stream Temperature - Beech Hill (BHMD) Water year 2004-2005
BES_1710	knb-lter-bes.1710.12	Stream Temperature - Beech Hill (BHMD) Water year 2007-2008
BES_1430	knb-lter-bes.1430.11	Stream Temperature - Cinder Pipe (CNDP) Water year 2004-2005
BES_1720	knb-lter-bes.1720.12	Stream Temperature - Cinder Pipe (CNDP) Water year 2007-2008
BES_1440	knb-lter-bes.1440.11	Stream Temperature - Cinder Road (CNDR) Water year 2004-2005
BES_1730	knb-lter-bes.1730.12	Stream Temperature - Cinder Road (CNDR) Water year 2007-2008
BES_0597	knb-lter-bes.597.12	Stream Temperature - Dead Run (DRKR) Water year 2006-2007
BES_0590	knb-lter-bes.590.12	Stream Temperature - Gwynns Falls at Carroll Park (GFCP) Water year 2006-2007

BES ID	PASTA ID	Title and Description
BES_1750	knb-lter-bes.1750.12	Stream Temperature - Gwynns Falls at Carroll Park (GFCP) Water year 2007-2008
BES_1450	knb-lter-bes.1450.11	Stream Temperature - Gwynns Falls at Carroll Park (GFCP) Water year 2004-2005
BES_1470	knb-lter-bes.1470.11	Stream Temperature - Gwynns Falls at Glyndon (GFGL) Water year 2004-2005
BES_0592	knb-lter-bes.592.12	Stream Temperature - Gwynns Falls at Glyndon (GFGL) Water year 2006-2007
BES_1460	knb-lter-bes.1460.11	Stream Temperature - Gwynns Falls at Gwynnbrook (GFGB) Water year 2004-2005
BES_0591	knb-lter-bes.591.12	Stream Temperature - Gwynns Falls at Gwynnbrook (GFGB) Water year 2006-2007
BES_1760	knb-lter-bes.1760.12	Stream Temperature - Gwynns Falls at Gwynnbrook (GFGB) Water year 2007-2008
BES_1480	knb-lter-bes.1480.11	Stream Temperature - Gwynns Falls at Villa Nova (GFVN) Water year 2004-2005
BES_0593	knb-lter-bes.593.12	Stream Temperature - Gwynns Falls at Villa Nova (GFVN) Water year 2006-2007
BES_1770	knb-lter-bes.1770.12	Stream Temperature - Gwynns Falls at Villa Nova (GFVN) Water year 2007-2008
BES_1490	knb-lter-bes.1490.11	Stream Temperature - Hickory Lot (HYLT) Water year 2004-2005
BES_1780	knb-lter-bes.1780.12	Stream Temperature - Hickory Lot (HYLT) Water year 2007-2008

BES ID	PASTA ID	Title and Description
BES_1790	knb-lter-bes.1790.12	Stream Temperature - Jennifer Branch at Harford Hills (JBHH) Water year 2007-2008
BES_1500	knb-lter-bes.1500.11	Stream Temperature - Jennifer Branch at Harford Hills (JBHH) Water year 2004-2005
BES_1510	knb-lter-bes.1510.11	Stream Temperature - Jennifer Branch at Northwind (JBNW) Water year 2004-2005
BES_1800	knb-lter-bes.1800.12	Stream Temperature - Jennifer Branch at Northwind (JBNW) Water year 2007-2008
BES_1520	knb-lter-bes.1520.11	Stream Temperature - Jennifer Branch at Ontario (JBON) Water year 2004-2005
BES_1810	knb-lter-bes.1810.12	Stream Temperature - Jennifer Branch at Ontario (JBON) Water year 2007-2008
BES_1530	knb-lter-bes.1530.11	Stream Temperature - Jennifer Branch at Ontario Headwaters (JBONHW) Water year 2004-2005
BES_1820	knb-lter-bes.1820.12	Stream Temperature - Jennifer Branch at Ontario Headwaters (JBONHW) Water year 2007-2008
BES_1540	knb-lter-bes.1540.11	Stream Temperature - Lanvale (LANV) Water year 2004-
BES_1550	knb-lter-bes.1550.11	Stream Temperature - McDonogh (MCDN) Water year 2004-2005
BES_1830	knb-lter-bes.1830.12	Stream Temperature - McDonogh (MCDN) Water year 2007-2008
BES_1560	knb-lter-bes.1560.11	Stream Temperature - Metfield (MDCH) Water year 2004-
BES_1840	knb-lter-bes.1840.12	Stream Temperature - Metfield (MDCH) Water year 2007-

BES ID	PASTA ID	Title and Description
BES_1570	knb-lter-bes.1570.11	Stream Temperature - Overlook Park (OKPK) Water year 2004-2005
BES_1850	knb-lter-bes.1850.12	Stream Temperature - Overlook Park (OKPK) Water year 2007-2008
BES_1590	knb-lter-bes.1590.11	Stream Temperature - Parkland (PKLD) Water year 2004-
BES_1880	knb-lter-bes.1880.12	Stream Temperature - Parkland (PKLD) Water year 2007-
BES_1580	knb-lter-bes.1580.11	Stream Temperature - Placid Woods (PDWD) Water year 2004-2005
BES_1870	knb-lter-bes.1870.12	Stream Temperature - Placid Woods (PDWD) Water year 2007-2008
BES_0595	knb-lter-bes.595.12	Stream Temperature - Pond Branch (POBR) Water year 2006-2007
BES_1890	knb-lter-bes.1890.12	Stream Temperature - Pond Branch (POBR) Water year 2007-2008
BES_0594	knb-lter-bes.594.12	Stream Temperature - Powder Mill Run (PDML) Water year 2006-2007
BES_1600	knb-lter-bes.1600.11	Stream Temperature - Reservoir Hill (RRHL) Water year 2004-2005
BES_1910	knb-lter-bes.1910.12	Stream Temperature - Reservoir Hill (RRHL) Water year 2007-2008
BES_1900	knb-lter-bes.1900.12	Stream Temperature - Rognel Heights (RGHT) Water year 2007-2008
BES_0596	knb-lter-bes.596.12	Stream Temperature - Scotts Level Branch (SCLB) Water year 2006-2007

BES ID	PASTA ID	Title and Description
BES_1610	knb-lter-bes.1610.11	Stream Temperature - Tarleton (TLTN) Water year 2004-
BES_1930	knb-lter-bes.1930.12	Stream Temperature - Tarleton (TLTN) Water year 2007-
BES_1200	knb-lter-bes.1200.11	Synoptic water chemistry and discharge data for the Baismans Run sampling sites - 2007 - 2008 Stream water quality and discharge data collected by Monica Smith using flow velocity measurment method. These data are for the BARN sampling site.