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Watersheds in Baltimore, Maryland: Understanding and Application of Integrated Ecological and Social Processes

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The Water and Watersheds program has made significant and lasting contributions to the basic understanding of the complex ecological system of Baltimore, MD. Funded at roughly the same time as the urban Long-Term Ecological Research (LTER) project in Baltimore, the Water and Watersheds grant and the LTER grant together established the Baltimore Ecosystem Study (BES) in 1997. This joint project took advantage of three conspicuous stream catchments and the direct harbor drainage in metropolitan Baltimore. Not only the watersheds themselves, but the community and political interest in those watersheds were crucial to the success and application of our project. In fact, a prior decade's worth of community interactions by the Parks & People Foundation focusing on the watersheds provided an excellent base for the social understanding of a complex, coupled human-natural system. In addition, the policy and management activities by the City of Baltimore and Baltimore County, focusing on water quality and managing urban growth, provided an important foundation for our work. BES aims to provide ecological knowledge that complements the work of these and other organizations in the Baltimore region.

In this context, the goals of the BES, as a contribution to the Water and Watersheds program, were 1) to apply the watershed ecosystem approach pioneered in natural areas to an urban setting; 2) to understand the linkages and feedbacks between the social and biophysical components of the system, and 3) to contribute knowledge of integrated social-ecological landscapes to the ongoing efforts by Baltimore City and Baltimore County to improve the quality of water draining into the Chesapeake Bay. Nonpoint source pollution has been a management focus in the Baltimore region for some time. For example, the Baltimore County Department of Environmental Protection and Resource Management (DEPRM) has addressed nonpoint source pollution through its capital improvement program since 1987. This practical concern reinforced our theoretical interest in the internal structure of the Baltimore ecosystem, including spatial heterogeneity of social and biophysical components and the interaction of human agency and biophysical structure and processes. These were, and remain, key interests in the pioneering study of human-dominated ecosystems. The integration stimulated by the Water and Watersheds program goes beyond the traditional concerns of either social science or biological ecology.

Why Urban?

A 34 percent increase in the amount of urbanized land in the U.S. between 1982 and 1997 (Natural Resources Conservation Service 1999) and a projected increase in the amount of developed land from 5.2 percent to 9.2 percent by 2025 (Alig et al. 2004), suggest that urbanization is a major domestic trend and issue. Globally, human population is estimated to shift from predominantly rural and agricultural to urban some time before 2010 (United Nations 1995). The global trend toward urbanization is creating new urban forms in both industrial countries and in countries that still retain resource extraction or agricultural economies. New megacities, shanty towns, sprawling suburbs, thinning urban cores, edge cities, and transplantation of urban culture to the exurban fringe are some of the major forms that this global change takes. The Baltimore region partakes of several of these trends: a thinning and reorganizing urban core, and rapid suburban and exurban development. The Baltimore County population was projected to grow from 756,000 in 2000 to 786,113 in 2005, while Baltimore City was estimated to decline in population from 651,154 in 2000 to 635,815 in 2005 (U.S. Census Bureau 2007).

The ecosystem alterations, including new structures, and unprecedented environmental conditions that accompany urban change, mimic key features of global climate change (Sukopp et al. 1990, Carreiro and Tripler 2005), and present citizens and policy makers with environmental problems and challenges. How urban watersheds function under these changing conditions is a crucial societal concern, as well as an opportunity to explore new theories and models in an integrated social-ecological arena. The Baltimore region provides a case in which to examine in detail the ecological understanding of urban areas in general.

Building an Ecological Research Platform

The first accomplishment of the Baltimore Water and Watersheds grant, in association with the NSF LTER grant, substantial USDA Forest Service contributions, and partnerships with the U.S. Geological Survey, Baltimore City, Baltimore County, and key Baltimore institutions such as the Parks & People Foundation and the University of Maryland, Baltimore County, was to establish a novel urban ecological research platform. The establishment of such a research capacity was crucial because American ecology had largely neglected urban ecosystems (McDonnell and Pickett 1993, Grimm et al. 2000). New approaches, partnerships, and research methodologies were required to effectively address urban areas as ecological systems.

The watershed concept (Likens 1984) was central to the success of this effort (Cadenasso et al. 2006). First, it provided all disciplines a shared, comprehensible spatial arena in which to work. Furthermore, the watershed concept is scalable, with larger catchments containing smaller catchments. Hence, various studies could be conducted at different scales, and related to one another at particular scales. The modeling of hydrological functions and physical processes, bioecological dynamics, and social interactions have also been able to take advantage of the watershed concept. In addition, the watershed concept permits water quality to serve as a powerful integrator of biophysical structure and dynamics, and of social actions and structures. The wide concern in the Baltimore region with the quality of the Chesapeake Bay waters is also clearly related to watershed structure and function.

We began applying the watershed approach by establishing a long-term stream sampling network in the Gwynns Falls Watershed (Groffman et al. 2003). This 17,150 ha watershed, drained by the Gwynns Falls stream, traverses an urban to rural gradient from downtown Baltimore City to the rural-suburban fringe in Baltimore County. The extensive sampling network was established in 1998 and is supported only partially by the BES. Stream monitoring relies on the support and assistance of a partnership that encompasses the city, county, state, and federal agencies listed earlier. The sampling network includes four longitudinal sampling sites along the Gwynns Falls and four small (40 – 100 ha) watersheds, located within or near the Gwynns Falls (Figure 1). The longitudinal sites provide data on water and nutrient fluxes in the different land use zones of the watershed, which can be characterized as rural/suburban, rapidly suburbanizing, old suburban, and the urban core. The small watersheds provide more focused data on specific land use areas such as forest, agriculture, rural/suburban, and urban in the strict sense. A forested reference watershed (Pond Branch) is sampled in Oregon Ridge County Park located to the northeast of Gwynns Falls. Each of the gauging sites is continuously monitored for discharge by the USGS, and is sampled weekly for water chemistry. Water quality analysis includes inorganic and organic forms of major nutrients, total suspended solids, temperature and dissolved

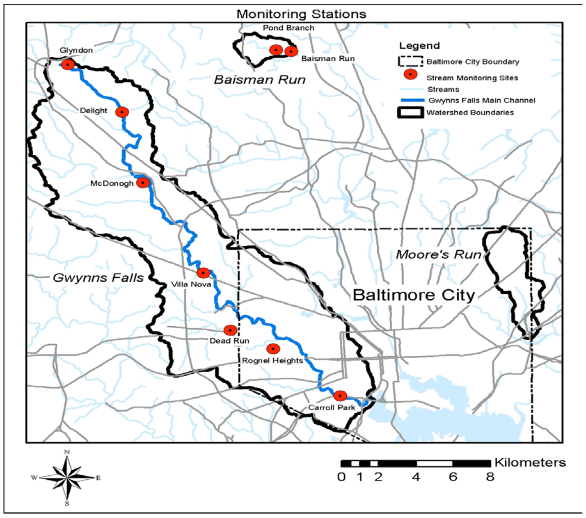


Figure 1. Map of water quality sampling stations in the Gwynns Falls and Baisman Run catchments in metropolitan Baltimore, MD. Within the Baisman Run catchment is the smaller forested reference watershed of Pond Branch.

oxygen. Data are used to compute input-output budgets. All streamflow and chemistry data are posted on the BES Website (beslter.org).

Water Quality And Urban Riparian Zones

Results from our studies show that urban and suburban watersheds consistently have nitrate concentrations that are higher than forested watersheds, but lower than agricultural watersheds (Groffman et al. 2004, Figure 2). These results are of great interest, as nitrate is a primary concern in the eutrophication of the Chesapeake Bay. The mix of land use that might affect nitrate yield is changing quite rapidly in the region.

Our long-term monitoring results have motivated ongoing, detailed analysis of different sources and sinks for nitrogen in the watersheds. Potential sources include the atmosphere, fertilizer, and sewage, while sinks, or areas that prevent the movement of reactive nitrogen to surface water, include riparian zones, in-stream processes, and soil organic matter. Urban watershed input/output budgets for nitrogen showed surprisingly high retention (Groffman et al. 2004, Table 1). Despite the high percentage retention, nitrogen loading from the nonforested watersheds remains high.

Do riparian zones, thought to be an important

Table 1. Inputs, outputs and retention of N for suburban (Glyndon), forested (Pond Branch) and agricultural (McDonogh) watersheds. From Groffman et al. (2004).

Inputs	**Suburban**	**Forested**	**Agriculture**
		kg N ha^{-1} y^{-1}	
Atmosphere[1]	11.2	11.2	11.2
Fertilizer[2]	14.4	0	60
Total	25.6	11.2	71.2
Outputs			
Stream-flow[3]	06.5	00.52	16.4
Retention			
Mass	19.1	10.7	54.8
Percent	75	95	77

[1]Mean deposition (wet plus dry) for 1998 and 1999, the latest data available for the CASTNET site at Beltsville.

[2]For the suburban watershed, values are based on a home lawn survey (Law et al. 2004). For the agricultural watershed, values are estimated from Maryland Department of Agricultural recommended fertilizer rates for corn (120 kg N ha^{-1} y^{-1} in water year 2000) and estimated N fixation rates for soybeans (30 kg N ha^{-1} y^{-1} in water years 1999 and 2001).

[3]Mean total N loads from 1999, 2000, and 2001 from Groffman et al. (2004).

sink for N in many non-urban watersheds provide this critical function in urban and suburban watersheds? Somewhat surprisingly, our analyses suggested that rather than sinks, riparian areas have the potential to be sources of nitrogen in urban and suburban watersheds. Hydrologic changes in urban watersheds, particularly incision of stream channels and reductions in infiltration in uplands due to stormwater collection infrastructure lead to lower water tables in riparian zones (Figure 3). This "hydrologic drought" creates aerobic conditions in urban riparian soils which decreases denitrification, an anaerobic microbial process that converts reactive nitrogen into nitrogen gases and removes it from the terrestrial system (Groffman et al. 2002, 2003, Groffman and Crawford 2003).

Our urban riparian results were used by the Chesapeake Bay Program to reassess their goals for riparian forest restoration in urban areas. Given

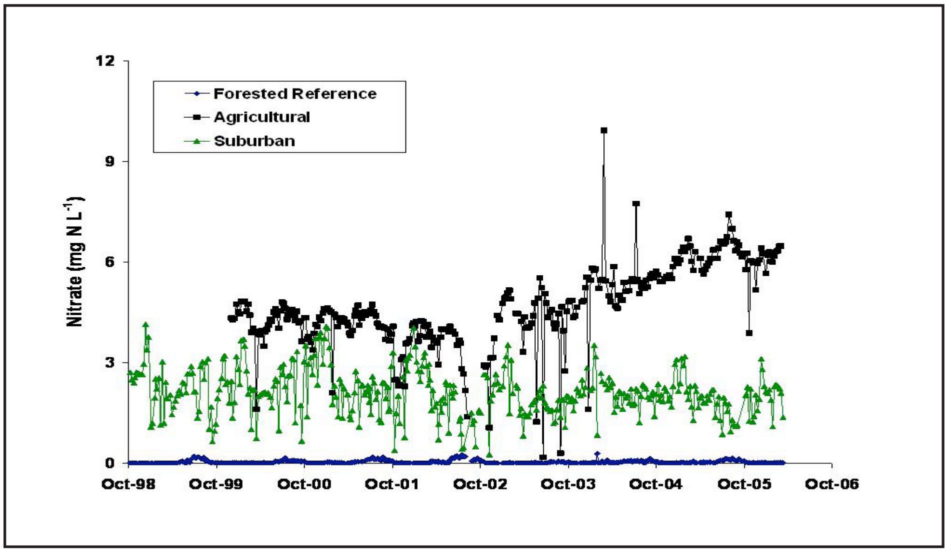


Figure 2. Nitrate concentrations in streams draining forested reference (Pond Branch), agricultural (McDonogh), and suburban watersheds (Gwynns Falls at Glyndon) in the Baltimore metropolitan area from October 1998 through December 2004. Data through 2002 published in Groffman et al. 2002).

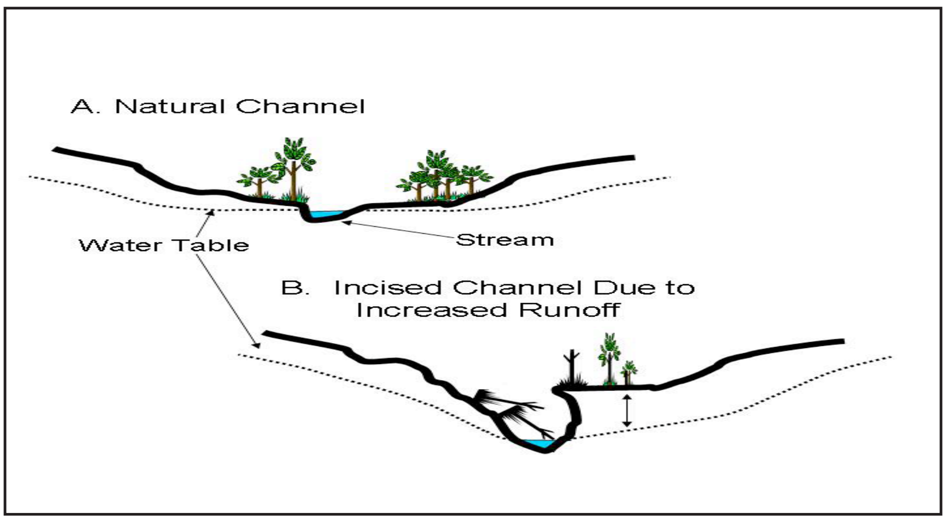


Figure 3. An idealized diagram of stream cross section and water table profile for (A) a non-urbanized stream and (B) an urbanized stream. In the natural channel, the water table (dashed line) is hydrologically connected to the surface vegetation, and stream incision is minimal. In the incised channel, the water table has dropped, hydrolically isolating it from the surface vegetation. Mortality of riparian tree may result. Additional mortality may result from erosion of the banks.

that riparian zones in deeply incised urban channels were not likely to be functionally important for nitrate attenuation in urban watersheds, the program instead focused on establishing broader urban tree canopy goals, with the idea that increases in canopy cover across the city will have important hydrologic and nutrient cycling effects (Raciti et al. 2006). This research does not question the other values of urban riparian vegetation, such as stream temperature reduction, channel stability, habitat and food for aquatic organisms, improved air quality, and aesthetics.

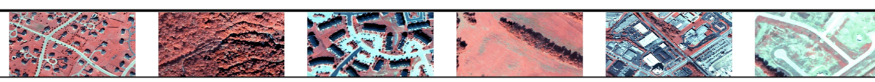
While understanding how land cover change affects biogeochemical cycles is important for informing policy, many other factors are also of concern. Additional ecological factors may include sediment and phosphorus loadings. In an integrated system, however, social, economic, and management constraints and opportunities also play a significant role in policy decisions.

Inadequate Land Cover Theory

The previous kinds of results emerging from studies started by the Water and Watersheds project are an example of opening the "closed box" of the urban ecosystem. Understanding the outputs of the system required knowing how it was structured internally. This contrasts with the traditional ecosystem approach, which viewed systems as closed boxes whose internal structure is not addressed in examining their input-output budgets or other aggregated behaviors. Our initial explorations of the physical, biological, and built patterns in both Baltimore City and County suggested an additional way in which the contents of the closed box needed to be examined – that of land use / land cover.

Urbanists, those who study the social and humanistic aspects of cities and other urban areas, have long commented on the fine-scaled spatial heterogeneity of cities and towns (Jacobs 1961). However, when we attempted to employ the standard land use / land cover classifications that were available for the Baltimore region (e.g., Maryland Department of Planning 1999), we were struck by how little of the heterogeneity that we observed in the system was modeled by those classifications. In order to assess the effects of watershed structure on watershed function, we wished to correlate key ecosystem variables, such as nitrate yield in stream waters, with the land cover of the watersheds. An initial attempt at such correlation, using the standard classifications, failed to produce significant results. Even with refinement of the land use / land cover data by accounting for residential densities, only poor and insignificant correlations were obtained (Groffman et al. 2004).

Cadenasso et al. (2007) examined the tacit assumptions behind the standard urban land classifications, and established a new model. Their system, High Ecological Resolution Classification for Urban Lands and Environmental Systems (HERCULES), focuses on the biophysical



Coarse Vegetation	1	4	1	2	1	1
Fine Vegetation	4	1	2	4	1	1
Bare Soil	0	0	0	0	0	4
Pavement	1	1	2	0	3	1
Building Proportion	2	0	3	0	3	0
Building Type	**S**	**N**	**C**	**N**	**M**	**N**

Figure 4. Examples of the application of HERCULES to classify six contrasting patch types from the Baltimore, MD region. Each patch is classified according to six elements, shown on the left hand column of the figure. The first five elements, representing continuous cover, divided into four ranges: 0) absent, 1) 1% to 10 % cover, 2) 11-35 % cover, 3) 36-75% cover, and 4) >75% cover. The sixth element, building typology, has five recognized types: 1) single structures in rows or clusters, 2) connected structures that share a wall or are associated with multiple walk-ways while sharing the same roofline, 3) mixed, i.e., with multiple wings, or connections by courtyards or arcades, or a group of buildings with different structural footprints, 4) high-rises that are between 4-10 stories, and 5) towers, which are greater than 10 stories. The vertical dimension of buildings is determined by shadow length or can be acquired from LIDAR data when available. Details in the text and in Cadenasso et al. (2007).

structure of urban environments and uses the recognized elements of urban heterogeneity – buildings, surface materials, and vegetation (Ridd 1995) – as its core elements. These three elements are divided into six more refined features in HERCULES: 1) coarse textured vegetation (trees and shrubs), 2) fine textured vegetation (herbs and grasses), 3) bare soil, 4) pavement, 5) buildings, and 6) building typology. Patches in the landscape are classified according to the proportional cover of each of the first five features, and the building type (Figure 4).

This new classification system accounts for the so-called natural features of urban ecosystems in the form of vegetation structure, as well as for anthropogenic components including buildings, pavement, and denuded surfaces. It also permits the cover of each of the six features to be described independently. Vegetation, surfaces, and buildings can vary in complex ways relative to one another, permitting the degree of integration between anthropogenic and natural features to be captured.

When stream nitrate yield was regressed against the components of HERCULES, both high correlation coefficients and statistical significance were obtained (Cadenasso et al. 2007). This is in contrast to the inability of the standard land classification to expose any statistical relationships with nitrate yield. Thus HERCULES, as a new land cover model constructed on the empirical and conceptual foundation of the Water and Watersheds project, is a major advance in the theory of urban landscape ecology and an important tool for urban ecosystem studies. In addition, HERCULES may be a useful tool for policy and management, because it gives a more refined model of urban land cover as compared to standard land cover models derived from Anderson et al. (1976). Management and development decisions that incorporate land cover will be more usefully informed by a model that better represents the heterogeneity of urban landscapes.

New Social Theory for Urban Watersheds

The Baltimore Ecosystem Study has relied on a strong social component from its beginning. In fact, the social capital provided by the Parks & People Foundation and the social science interns who worked on community forestry projects there since 1989, were a key motivation for locating ecologically based watershed studies in the Baltimore region. Community involvement in greening activities were seen as strategies to improve both the biophysical environment and the social environment of underserved neighborhoods. The coupling of social patterns and processes with the vegetation structure of Baltimore neighborhoods and watersheds, therefore, has roots deeper than BES. However, this background motivates a desire to understand how social and vegetation structures are linked.

Several advances have emerged from the basic social science research and the integration with biological ecology facilitated by the water and watershed project. In attempting to discover how vegetation structure and cover were related to social characteristics across Baltimore City, we studied three social theories: 1) property regimes, 2) lifestyle characteristics, and 3) the standard social variables of stratification based on income and education. We hypothesized that these three theories would be differentially linked to vegetation structure in public rights of way (PROW), private property, and riparian areas, respectively (Grove et al. 2006). Using a multi-model inferential approach (Burnham and Anderson 2002), we found that variation of vegetation cover in riparian areas was not explained by any of the three theories, while lifestyle behavior was the best predictor of vegetation cover on private lands. Surprisingly, lifestyle behavior was also the best predictor of vegetation cover in PROWs. The inclusion of a quadratic term for housing age significantly improved the statistical models. These results question the exclusive use of income and education as standard variables to explain variations in vegetation cover in urban ecological systems. Furthermore, understanding of the management of urban vegetation can be improved by accounting for how lifestyle, as indexed by marketing differentiation, underlies household motivations for and participation in local land management.

The Role of Complex Household Structure

Ecologists and demographers have come to recognize the importance of households as agents of environmental change (Liu et al. 2003). Private lands under the control of households are a critical component to achieving any vegetation management goals in urban areas. In Baltimore City, total canopy cover is 20 percent, with 90 percent of that cover located on private lands. Likewise, about 85 percent of the unplanted land area where potential planting could occur in the future is on private land, as compared to under 15 percent on public rights of way. Based on our research, Baltimore City has adopted a goal to double Urban Tree Canopy (UTC) cover to 40 percent by 2036. Maryland's State Capital, Annapolis, has also adopted a goal to increase UTC from 41 percent to 50 percent by 2036. Both analyses reveal that increasing UTC on private lands is essential to success (Galvin et al. 2006a, b).

In order to determine how households in Baltimore can affect vegetation management, we generated two measures (Troy et al. in press). "Possible stewardship" refers to the proportion of private land that does not have built structures on it, and hence has the possibility of supporting vegetation. "Realized stewardship" refers to the proportion of possible stewardship land upon which vegetation is actually growing. These measures were generated at the parcel level and averaged by U.S. Census block group. Realized stewardship was further defined by proportion of woody vegetation and grass. Data about expenditures on yard supplies and services by census block group were used to improve understanding of where current vegetation conditions appear to be the result of current activity, past legacies, or lack of active management.

To evaluate whether lifestyle characteristics were predictors of possible and realized stewardship and of yard expenditures at the Block Group level, PRIZM™ market segmentation data were used. PRIZM segmentations are hierarchically clustered into 5, 15, and 62 categories, with each level of categorical resolution corresponding to population density, social stratification (i.e., income and education), and lifestyle clusters, respectively. We found that PRIZM resolved to the level of 15 categories best predicted variation in possible stewardship, while PRIZM resolved to 62 categories best predicted variation in realized stewardship. These results were further analyzed by regressing potential or realized stewardship against a set of continuous variables reflective of each of the three PRIZM groupings. Housing age, vacancy, and crime were found to be critical determinants of both stewardship metrics. In addition, the percentage of African Americans was positively related to realized stewardship but negatively related to yard expenditures (Troy et al. in press).

This research also indicated that realized stewardship does not vary as a constant proportion of possible stewardship. Therefore, modelers, for example, cannot assume that vegetation will always be 20 percent of plantable space on a parcel. Instead, modelers will need to know the household socio-demographic characteristics of areas they would like to represent. Our research suggests that realized vegetation, as a percentage of possible stewardship, can be predicted based upon lifestyle behavior characteristics.

Environmental Quality in a Center City Storm Drain Catchment

In this example, the knowledge gained from biophysical studies on watershed function, community organization on a watershed basis, and the interaction of scientists and policy makers come together. The specific project is the environmental improvement and mitigation of storm water in a 932 acre storm drain catchment in west Baltimore City. The Watershed 263 (WS 263) Environmental Improvement Project is named for the storm drain catchment in which it occurs. The primary question is "Can we change how government goes about its daily business, e.g., teaching our children, repaving and cleaning our streets, redeveloping our neighborhoods, etc., in a way that supports a common environmental theme of a functioning urban ecosystem? The goal is to improve the storm water management and the quality of life of the inhabitants by focusing on activities that do both. Key environmental actions include the implementation of innovative structural Best Management Practices resulting in modified curb inlets for storm water, reducing the amount of impervious surface in the catchment, and increasing vegetation cover.

Because the environmental actions cannot be done immediately in all sections of WS 263, comparisons are possible. We have installed ISCO automated flow samplers in the main storm sewers in two subcatchments in WS 263; both are approximately 15 ha and contain similar amounts of impervious surfaces. One subcatchment is currently undergoing environmental improvements, and the other is to experience mitigation at a later time. Continuous water monitoring of both subcatchments has occurred since 2003 to establish a baseline of water quality and quantity. Preliminary data suggest that WS 263 has very poor water quality in comparison to other watersheds in Baltimore City and County. For 19 storm events, water quality in WS 263 exceeded EPA criteria for Cu, Pb, and Zn up to 90 percent, 80 percent, and 25 percent,of the time, respectively. Concentrations of nitrate-N were as high as 6 mg/L during low flow periods, which is comparable to agricultural watersheds in the Chesapeake Bay Watershed. These findings are important because untreated stormwater runoff from WS 263 goes directly into the Bay.

Investigations of vegetation, soils, and meteorological conditions are also underway in WS 263. Preliminary results show that soils of WS 263 are moderately contaminated, with relatively high levels of Pb occurring in disturbed sites (e.g., vacant lots). Approximately 17 percent of plots sampled had Pb concentrations that exceed EPA soil screening guidelines (400 ppm). The majority of these plots were located on abandoned lots. WS 263 tree stem densities are similar to other high density residential areas in Baltimore; however, they are considerably lower than medium density housing areas. Existing canopy is made up largely of invasive species (e.g., Tree of Heaven) rather than planted and managed volunteer trees. Total canopy is comparable to canopy cover in 1957; however, the 1957 landscape was dominated by planted and well maintained trees while the current landscape is dominated by invasive trees.

The activities and partnerships supported initially by the Water and Watershed project were significant to developing the WS 263 project. The project involves schools, community groups, neighborhood associations, and City agencies in environmental improvements. This project was initiated by the City and inspired by BES through discussions in the Revitalizing Baltimore Technical Committee.

A Research-Decision Making Cycle

The Water and Watershed project that contributed to the BES from 1997 through 2000 has produced important research and significant applications for environmental quality in metropolitan Baltimore and downstream. A powerful feedback has developed between research and decision making as a result of this project and the partnerships in which it is engaged. We can now indicate how some of the research and decision-making outcomes are related to one another.

Although a cycle can be entered at any point, an historical approach is perhaps most understandable. Research in wild and agricultural lands demonstrated the sink function of riparian zones for nitrate pollution in streams (Peterjohn and Correll 1984). This stimulated the traditional policy of planting tree buffers along streams. Our finding that urban riparian zones experiencing hydrologically-induced drought are not sinks for nitrate, but in fact may be nitrate sources, helped lead policy makers concerned with the water quality of the Chesapeake Bay to reduce their reliance on stream corridor tree planting as a primary mitigation strategy. Rather, it became clear that if tree planting was to have an impact, it would have to be extended beyond the riparian fringe in settled areas. The Chesapeake Bay Program, which is responsible for promoting the EPA mandate of a 40 percent reduction in nitrate loading to the Bay by 2011, responded by increasing its reliance on tree planting in the landscape as a whole. In urban areas, the results included the Watershed 263 Environmental Improvement Project, and the consultation with research and community foresters for a city-wide goal of significantly increasing cover by tree canopy (Galvin et al. 2006a, b). Other cities have how begun to establish Urban Tree Canopy (UTC) goals. The policy and research link for UTC goals is shown in Figure 5.

Conclusions

The Baltimore Water and Watersheds project was integrated with the nearly simultaneous award of support from NSF's LTER program to establish the BES in 1997. This interdisciplinary, long-term study is one of only two such studies in the United States (Collins et al. 2000, Grimm et al. 2000). Combining these sources of support led to several important outcomes that ramped up the capacity for urban ecological research and application of the new knowledge gained.

1. A long-term research platform was established.

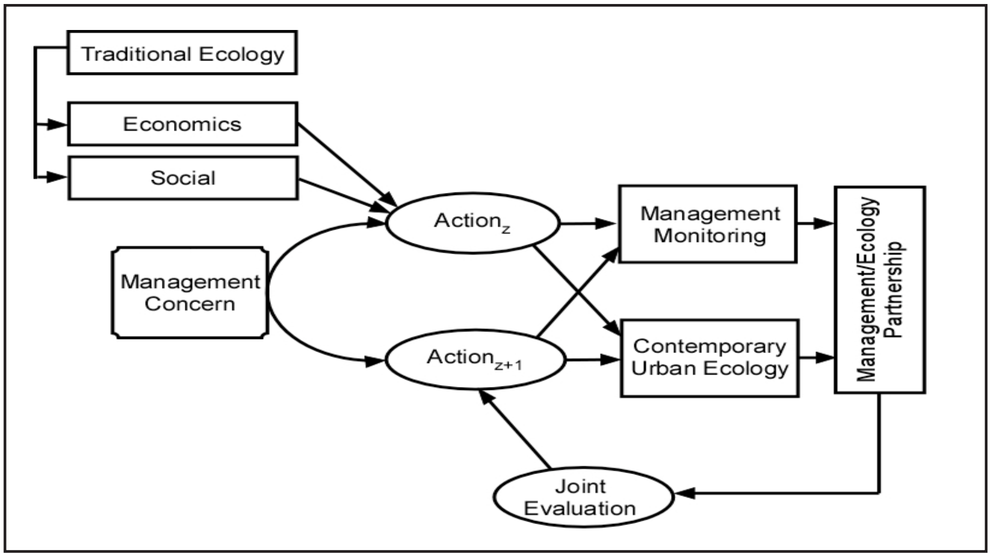


Figure 5a. An abstracted cycle of interaction between research and management. The cycle begins with the separate disciplines of ecology, economics and social sciences interacting with a management or policy concern. In the past, ecology has neglected the urban realm as a subject of study, leaving other disciplines to interpret how ecological understanding would apply to an urban setting. A management or policy action (Action$_z$) results. Management monitors the results of the action to determine whether the motivating concern was satisfied. Contemporary urban ecology, which integrates with economics and social sciences, is now available to conduct research that recognizes the meshing of natural processes with management and policy actions. Combining this broad, human ecosystem and landscape perspective with the concerns of managers can generate a partnership to enhance the evaluation of management actions. New or alternative management actions can result (Actions$_{z+1}$).

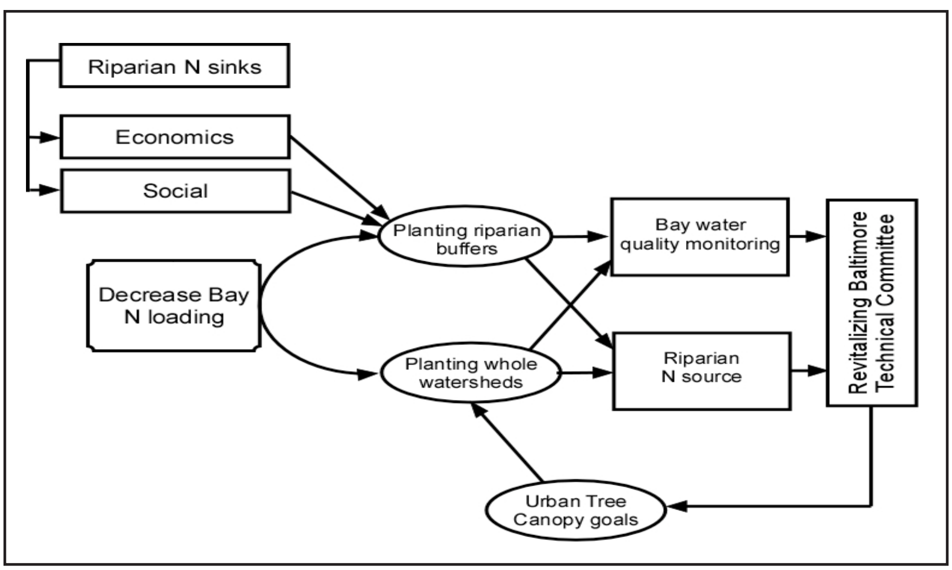


Figure 5b. An example of the management-research interaction in Baltimore City watersheds. Traditional ecological information indicated that riparian zones are nitrate sinks. The management concern was to decrease nitrate loading into the Chesapeake Bay. In an effort to achieve that goal, an action of planting trees in riparian zones was proposed. Management monitoring indicated that progress toward decreasing Bay nitrate loadings was slow. Results from BES research suggested that stream channel incision in urban areas has resulted in riparian zones functioning as nitrate sources rather than sinks. In partnership with managers and policy makers in Baltimore City and the Maryland Department of Natural Resources, a reevaluation of strategies to mitigate nitrate loading was conducted. This led to a decision to increase tree canopy throughout the entire Chesapeake Bay watershed. Baltimore City adopted an Urban Tree Canopy goal, recognizing both the storm water mitigation and other ecological services such canopy would provide.

2. The social-natural linkage was cemented right from the start, rather than having to be cobbled together on an ad hoc basis, as is often the case.
3. The watershed monitoring system in cooperation with USGS and City and County environmental agencies was established.
4. The validity of the watershed approach in urban areas was confirmed.

The Water and Watersheds program acted as seed funding for the BES, and although it lasted only 3 years, it produced a lasting legacy in the form of our research platform and ongoing studies and important practical applications to environmental decision making for the Baltimore region and the Chesapeake Bay.

Acknowledgments

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