Deriving Reliable Pollutant Removal Rates for Municipal Street Sweeping and Storm Drain Cleanout Programs in the Chesapeake Bay Basin

Principle Investigators

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Project Background and Objectives

Despite the fact that street sweeping and storm drain cleanouts rank among the oldest practices used to control storm water pollution, very limited and sometimes conflicting data has been published in regard to their performance in removing nutrients and other pollutants (Burton and Pitt, 2002, EPA, 1983, Mineart and Singh, 1994, Sutherland and Jelen, 1997). Despite this uncertainty, many Chesapeake Bay municipalities routinely use one or both practices to comply with their NPDES storm water permits. Sweeping and storm drain cleanouts may be of particular value in reducing pollutants from ultra-urban areas, where few other best management practices are feasible.

The Urban Storm Water Work Group of the Chesapeake Bay Program has recognized the importance of defining more accurate pollutant removal rates for these practices as a top priority for its BMP tracking system. The objective of this two-year research project is to develop improved estimates of the potential nutrient and sediment reductions achievable through municipal street sweeping and storm drain cleanouts, based on a literature review, a basin-wide municipal survey of existing programs and an intensive field monitoring program within paired catchments located in Watershed 263 in Baltimore, MD.

The Center for Watershed Protection (CWP) will head up the project research team, which includes City of Baltimore Department of Public Works (DPW), Baltimore County Department of Environmental Protection and Resource Management (DEPRM), the Department of Civil and Environmental Engineering at the University of Maryland-Baltimore County (UMBC). Other partners on the project team include the Center for Urban Environmental Research and Education within UMBC and the U.S. Forest Service Northeastern Experiment Station (FS-

NES), which is currently monitoring the paired catchments as part of the ongoing Baltimore Ecosystem Study, which is one of two urban long-term ecological research stations in the country.

This unique group of partners and the focus on Watershed 263 create synergies that enable the research team to produce a great deal more research and analysis than could be conducted otherwise. Some examples of the project synergies include:

- The two pilot catchments are already being monitored in Watershed 263 by FS-NES as part of the ongoing BES study, so sampling, instrumentation and station maintenance costs are minimal for the study.

- DEPRM water quality monitoring laboratory will process storm water and sediment samples as a contributed service to the project.

- DPW will provide contributed staff for field work and to coordinate the schedules for street sweeping and storm drain cleanouts within the pilot catchments for better operational control over the experimental treatments. DPW has also developed exellent aerial photos and GIS data layers for the two pilot catchments through prior watershed 263 studies. DPW's water quality monitoring laboratory will also process storm water and sediment samples as a contributed service to the project.

- CWP is already conducting detailed assessments of the pilot catchments under an existing Chesapeake Bay Trust Pioneer Grant. These include detailed Street and Storm Drain (SSD), Neighborhood Source Assessment (NSA), Hotspot Source Identification and Pervious Area Assessment (PAA) surveys.

More details on the project approach are provided in the task descriptions below:

Task 1 Literature Research on Street Sweeping and Storm Drain Cleanout Performance

Under this task, CWP, with assistance from UMBC, will perform an intensive survey of published and unpublished national and international literature on the pollutant removal performance of street sweeping and storm drain cleanouts from 1980 to the present. The survey period roughly coincides with the first Nationwide Urban Runoff Project (NURP) studies on sweeper effectiveness, and will include forthcoming research from California, Wisconsin and Australia. Street sweeping and vacuum truck vendors will also be consulted to determine if any independent industry research exists. The literature search will focus on three areas that:

- Evaluate the performance of street sweeping in removing nutrients and other pollutants.
- Evaluate the performance of storm drain cleanouts in removing nutrients, and characterize the quality of trapped sediment and pool water.
- Characterize the nutrient and metal composition and particle size distribution of sediments in roads, curbs, catch basins and storm water runoff

In addition, the review will include a characterization of existing urban storm water concentrations of sediment, nutrients and carbon from Phase I NPDES permit holders in the

basin, as part of the ongoing National Stormwater Quality Database (NSQD) maintained by the Center and University of Alabama (Pitt et al, 2003).

The product of this task will be a technical memorandum that synthesizes available scientific research on the effectiveness of street sweeping and storm drain cleanouts, and presents recommendations for interim pollutant removal rates for use in the BMP tracking system. The memo will be presented for review by the Urban Storm Water Work Group (USWG).

Task 2 Survey of Current Municipal Street Sweeping and Storm Drain Cleanout Practice in the Chesapeake Bay Basin

The second task will entail an extensive survey of current municipal practice for the 30 NPDES storm water Phase I permit holders located in the basin. A survey instrument will be developed in consultation with appropriate state storm water NPDES coordinators and USWG members in each Bay state, and current municipal contact information and permit reports will be obtained. The survey will then be mailed to individual Phase I and selected Phase II municipal permit holders to get current data on:

- Current street sweeping practices (miles/frequency)
- Current storm drain cleanout practices (number/frequency)
- How communities compute nutrient removal efficiency for each practices in their annual NPDES storm water permit reporting, if at all.
- Whether they have any supplemental data on solids removed and their chemical composition.

In addition, Phase I communities will be asked if they want to participate in the study by providing stormwater EMC data from swept and unswept catchments that are monitored as part of their ongoing NPDES stormwater permit monitoring requirements. Such data, if available, would provide a valuable regional comparison for the more intensive data collected as part of this project. Written surveys may be followed up with phone interviews to verify and standardize survey data. After the survey responses are analyzed, a technical memorandum will be produced that characterizes the aggregate municipal street sweeping/cleanout effort in the Chesapeake Bay Basin.

Task 3 Field Monitoring to Define Pollutant Removal Performance of the Practices

The third task involves a major research program to collect monitoring data to obtain a more reliable estimate of pollutant reductions associated with street sweeping and storm drain cleanouts in Baltimore City and County. The design of the research program will be finalized in a technical memo to be produced within a month of grant award, and may be modified based on the Quality Assurance and Project Plan (QAPP) and a Quality Management Plan (QMP). All sampling data collected during the project will be managed in conformance with the data management requirements of the Chesapeake Bay Program.

The proposed research plan has four primary monitoring elements that are described below. Together, the four monitoring elements will provide a clearer picture of the accumulation, storage and movement of nutrients and other pollutants within street and storm drain inlets that

are needed to prepare mass balances to estimate the effectiveness of street sweeping and storm drain cleanouts. Table 1 illustrates the role of each research partner in the four monitoring elements. Table 2 characterizes the scope of sampling and laboratory analysis proposed for each of the four monitoring elements.

Table 1: Research Partner Roles in Monitoring Effort

	Element 1 Catchment O and F Treatment	**Element 2** Street Source Area Monitoring	**Element 3** Pipe Bedload Transport	**Element 4** Catch Basin Sediment Quality
Study Design	DPW – lead FS-NE, CWP	CWP- lead DPW, UMBC	FS-NE- lead DPW	CWP-lead UMBC/DEPRM
Site Selection and Instrumentation	N/a	UMBC DPW, CWP	FS-NE- lead DPW	UMBC DEPRM
Sample Collection	FS-NE DPW + UMBC	UMBC DPW	FS-NE- lead DPW	UMBC
Field Maintenance	FS-NE UMBC	UMBC DPW	FS-NE	UMBC DEPRM
Transport to Lab	DPW	DEPRM	FS-NE	DEPRM
Laboratory Analysis	DPW	DEPRM	DPW	DEPRM
Data Storage	FS-NE	DEPRM	FS-NE	DEPRM
QA/QC	UMBC	UMBC Lab splits	UMBC	UMBC Lab splits

DEPRM (Baltimore County) DPW (City of Baltimore) CWP (Center for Watershed Protection) UMBC (University of Maryland-Baltimore County) FS NES (Forest Service Northeast Experiment Station)

Element 1. Alternating Treatments in Paired Catchments in Watershed 263

Catchments F and O are being intensively monitored within Watershed 263, each of which drains about 38 acres of highly urban land use. Stormwater monitoring stations have been established in each catchment operated by the Baltimore DPW and the FS Northeastern Experiment Station. Initial sampling has created an excellent baseline of both stormflow and baseflow quality. The two catchments provide an unusually good situation to employ a paired catchment/alternating treatment study design. The basic concept is alternate treatments in each catchment on an offset rotation every five months to minimize natural variation in storm water runoff. Therefore, over a 15-month period, runoff samples would be collected under three kinds of treatment in Catchment O, using the following sequence of treatment. The sequence of treatment would be reversed in Catchment F.

1. No increase in sweeping, all storm drains initially cleaned out (months 1 to 5)
2. More intensive sweeping frequency (months 6 to 10)
3. More extensive sweeping frequency (months 11 to 15)

Table 2: General Description of Proposed Monitoring Elements				
	Element 1 Catchment O and F Treatment	**Element 2** Street Source Area Monitoring	**Element 3** Pipe Bedload Transport	**Element 4** Catch Basin Sediment Quality
Duration of Sampling	15 months	20 weeks	6 months	12 months
Frequency of Collection	Storms/baseflow	Weekly retrieval	Weekly sump measurements	Monthly Samples
Water Quality Parameters	N, P, SS, Zn, Cu BOD5, Fl and others	N, P, SS, TOC	TSS, Bedload	N, P and HC of pool water samples (N=20)
Sediment Analysis	storm particle size analyses	particle size analysis	Mass, bulk density and particle size	bulk density analyses, sediment N, P, TOC, sieve analysis
No. of Stations	2 existing stations	6 street sections 3 source areas	1 existing station	16 catch basins
Total WQ samples	128 base ~128 storms	360 samples	64 storms	~60 pool water
Total Sediment Samples	10	20	20	48
Note: the precise scope of each monitoring element will be finalized in the Task 2 final monitoring plan.				

Baltimore DPW will coordinate with its sweeping and cleanouts crews to provide the desired levels of treatment, and will provide a monthly report on treatment activity in each catchment. Intensive treatment is defined as increasing the frequency that major streets are swept each month, at intervals to be provided by DPW. Extensive treatment is defined as increasing the total length of streets and alleys that are swept.

The sequence of treatments is designed to get an initial "no treatment" baseline, followed immediately thereafter by different levels of treatment. This allows successive intermediate treatments to be compared against a relatively clean slate. Some sweeping routes and cleanout schedules may need to be adjusted by DPW to provide greater experimental control and catchment coverage. Baltimore DPW may need to modify treatment schedules somewhat to meet the needs of the public and city maintenance crews.

A rainfall gage will be installed near the pilot catchments so that rainfall depths can be matched to individual storm runoff samples. Flow-composited runoff samples collected from each pilot catchment will be analyzed for sediment, nitrogen, and phosphorus to establish event mean concentrations (EMC) for each storm event and treatment condition.

In addition, particle size data and nutrient composition will be sampled for solids that are picked up during the sweeping and cleanout treatments within the pilot catchment. Laboratory analysis will be conducted at facilities operated by Baltimore County DEPRM as a contributed service.

Storm water EMC data collected during each catchment treatment condition will be statistically analyzed to evaluate the effect of treatment in the context of other variables such as rainfall depth, catchment type, season of year and antecedent dry weather periods. The study design also permits independent and combined evaluations of sweeping and cleanout treatments at different frequencies.

Element 2. Source Area Monitoring of Bedload Movement in Curbs and Streets

The objective of the second monitoring element is to obtain source area monitoring data within streets, curbs, and yard controls to characterize the sources and variability of street pollutants. Source area monitoring has become a powerful monitoring tool to define the pollutant contributions from areas such as rooftops, roadways, lawns and parking lots (Bannerman et al, 1993). The source area monitoring design proposed in this study would consist of six standard street sections that have similar curb length leading to a standard storm drain inlet. Three standard street sections will be located in Catchments F and O, respectively, each reflecting the range of expected sweeping frequencies (e.g., not swept, swept once a month, swept weekly).

The basic design is to identify source area collection points at three equidistant points along the curb leading to the inlet, with adjacent points in the road, yard and storm drain inlets serving as "controls". A series of source area monitoring techniques will be investigated to complex runoff and sediment quality samples from these points. One approach will be to use 1-liter Nalgene Stormwater Samplers installed flush within the curb or curb inlet to trap sediment and other coarse material flowing along the curb. Alternatively, sediment samples may be collected from fixed points using hand-held vacuum samplers during dry weather.

Samples will be retrieved periodically to characterize source area runoff quality, and a subset of sediment samples will be analyzed for sediment particle size distribution, and their nitrogen, phosphorus and carbon content. The stratified study design will evaluate the effect of different levels of sweeping, overhead tree cover, parking density, traffic volume and other factors on sediment loading within the standard street sections.

Element 3. Testing Automated Samplers to Address the Sediment Bedload Bypass Issue

The third monitoring element is intended to address one of the major methodological issues plaguing the interpretation of street sweeping and inlet monitoring data for the last two decades. The basic problem is that automated samplers are specifically designed not to capture bedload, coarse sediments, organic matter and trash/debris that moves through the storm drain system (so as to prevent clogging of the sampler intake). Much of the material that is trapped in storm drain inlets or removed through sweeping, however, tends to be coarse-grained bedload. Consequently, researchers have debated the significance of the bypassed load that is not sampled, in terms of its effect on urban sediment and nutrient loads.

The proposed study would address the issue by installing a bedload trap and organic filter bag immediately one of the in-pipe automated storm water samplers currently in operation within Watershed 263, and take periodic samples of the volume and nutrient composition of trapped materials. The significance of the bypassed bedload can then be directly tested by comparing the

mass of pollutants trapped in the bedload sampler with the mass of pollutants measured by the upstream, automated sampler.

Element 4. Characterization of Storm Drain Inlet Behavior

The fourth element of the monitoring program involves extensive sampling of sediment behavior within catch basins in Baltimore County, MD. The County maintains a nine-year old geo-referenced database on cleanout operations at more than 14,000 storm drains which will be statistically analyzed for spatial and seasonal patterns in the volume of sediment removed, refill rate and gross composition. The cleanout database will be used to identify and select up to 16 representative test inlets for subsequent monitoring, based on a stratified random sampling design.

The depth of sediment accumulation and pool water will be measured on a monthly basis to determine rates of change, using methods originally developed by Schueler and Shepp (1993) and Schueler (1995). Quarterly samples will be collected to characterize sediment and pool water quality in each test inlet, with an emphasis on particle size, bulk density, and organic carbon. The data will then be statistically analyzed to determine average variables relating to inlet capture rates and nutrient content over time.

Deliverables: Five major products are anticipated to be delivered during the project.

1. Technical memo summarizing study design for the four monitoring elements, along with supporting QAPP and QMP.

2. Technical memo synthesizing the literature search and recommending interim sediment and nutrient reduction rates for both practices, along with a basin-wide estimate of total reduction, based on Task 2 practice survey.

3. Technical memo summarizing current municipal practice by municipalities in the Chesapeake Bay Basin

4. Draft and final research report presenting the findings from all four monitoring elements, and recommending a final pollutant reduction rate for street sweeping and storm drain cleanout practices.

5. A peer-review paper submission based on the research findings.

Schedule: The proposed milestones for the research project are outlined in Table 3**.** The literature review and basin-wide municipal practice survey tasks will be completed during the first year of the project, along with the design and implementation of the monitoring effort. Monitoring will extend into the second year, which will also see the completion of the final report recommending final removal rates for inclusion into the Bay Program's BMP tracking system. The Center will prepare written quarterly progress reports and submit them to the EPA Project Officer, and will conduct a full research progress meeting at the end of the first year.

Table 3: Proposed Schedule for Project *	
Subtasks	**Month from Award**
Complete Literature Review	December 2005
Complete Basin-wide Municipal Practice Survey	February 2006
Present Results to USWG	March 2006
Develop Final Monitoring Design Plan	August 2005
Develop QAPP and QMP	July 2005
Commence Monitoring Element 1	September 2005
Testing of Source Area Monitoring Techniques	September 2005
Commence Monitoring 4	April 2006
Commence Monitoring Element 2 and 3	July 2006
Complete All Monitoring Elements	April 2007
Data Processing and Statistical Analysis	May 2007
Draft Research Report Submitted to USWG	May 2007
Final Research Report to USWG	June 2007
* schedule is contingent on a July 2005 grant start date; indicated dates should be shifted back accordingly for start dates beyond July.	

Detailed Budget: The proposed budget for the two-year project is provided in Tables 4 and 5.

Table 4: First Year Budget for Project				
Budget Categories	**1. Review**	**2. Survey**	**3.Monitoring**	**Total**
Personnel (a)	$ 5,654.21	$ 8,235.17	$ 3,108.06	$16,997.00
Fringe Benefits (b)	$ 1,696.26	$ 2,470.55	$ 932.42	$ 5,099.00
Travel (c)	$ 90.00	-0-	$ 100.00	$ 190.00
Equipment (d)	-0-	-0-	$ 2,300.00	$ 2,300.00
Supplies (e)	-0-	$ 33.00	$ 1,000.00	$ 1,033.00
Contractual (f)	$10,000.00	$10,000.00	$65,000.00	$85,000.00
Other: (g)	-0-	$ 422.00	-0-	$ 422.00
Total Direct	$17,440.47	$21,160.72	$72,440.48	$111,042.00
Indirect (h)	$ 2,559.52	$ 3,839.28	$ 2,559.52	$ 8,958.00
TOTAL	20,000.00	25,000.00	35,000.00	120,000.00
Total EPA Allocation	20,000.00	25,000.00	35,000.00	80,000.00
Partner Match (i)	-0-	-0-	80,000.00	40,000.00

Budget Notes:

a. Personnel based on 850 hours of direct CWP labor to support projects.
b. Fringe benefits are based on 30% of base salary
c. Travel is based on local mileage to and from monitoring sites and coordination meetings
d. Equipment includes purchase of two tipping bucket rain gages and peripheral equipment/ software
e. Supplies include sample bottles, sample preservatives, field gear, and hand held vacuum unit
f. Contractual: Subcontract to CUERE to support one graduate research assistant over two years to assist in each task and perform field monitoring (45K) + partner contributed services (40K).
g. Postage and envelopes for Task 2 survey
h. Our federal provisional indirect rate is 34.4% for CWP Direct Costs; not applied to contractual services
i. See text for full description of the partner matches to the study.

Table 5: Second Year Budget for Project				
Budget Categories	**1. Review**	**2. Survey**	**3.Monitoring**	**Total**
Personnel (a)	-0-	-0-	$13,309.00	$ 13,309.00
Fringe Benefits (b)	-0-	-0-	3,993.00	3,933.00
Travel (c)	-0-	-0-	300.00	300.00
Equipment (d)	-0-	-0-	-0-	-0-
Supplies (e)	-0-	-0-	1,000.00	1,000.00
Contractual (f)	-0-	-0-	95,000.00	95,000.00
Other: (g)	-0-	-0-	-0-	-0-
Total Direct	-0-	-0-	113,601.00	113,601.00
Indirect (h)	-0-	-0-	6,398.81	6,398.81
TOTAL	-0-	-0-	120,000.00	120,000.00
Total EPA Allocation	-0-	-0-	80,000.00	80,000.00
Partner Match (i)	-0-	-0-	40,000.00	40,000.00

We have conservatively estimated that a minimum of $80,000 of direct match will be provided in the form of contributed staff services and laboratory analysis by the research team partners to support the project, which will be documented in the initial monitoring plan, and through memorandum of agreements among the research partners.

CWP: $12,000 of direct match to provide a detailed field analysis of the pilot catchments, using NSA, HSI and SSD survey methods.

City of Baltimore DPW: $75,000 of contributed staff services, amounting to 1.1 FTE per year for fieldwork, sample collection and project coordination.

Baltimore County DEPRM: An estimated $60,000 in contributed laboratory analysis of storm water and sediment samples, and 0.1 FTE of contributed staff services for project coordination

Measure of Success: The key measure of success associated with the research project will be statistically reliable and scientifically sound estimates of the pollutant removal efficiency of municipal street sweeping and storm drain cleanout operations, as well as estimates of the aggregate municipal effort within the Chesapeake Bay basin. Taken together, these estimates will support ongoing management and modeling efforts of the EPA Chesapeake Bay Program, particularly in regard to the BMP tracking system. From a larger perspective, the research effort will demonstrate the value (or lack thereof) of expanded municipal operations as a nutrient reduction strategy in highly urban watersheds.

If either municipal operation is found to have a significant nutrient reduction capability, the success of the project will be measured by the degree research results are disseminated to both Phase I and Phase II NPDES storm water communities so that they can optimize their operations to achieve maximum nutrient reductions. A related goal of the research project is to provide greater linkage and integration between municipal NPDES storm water permittees and Chesapeake Bay tributary nutrient reduction efforts.

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Qualifications of Research Team:

The Center for Watershed Protection is a nonprofit organization dedicated to the protection, restoration of our nation's watersheds by advancing innovative and effective watershed management techniques. Founded in 1992, the Center is registered as a non-membership 501(c)(3) corporation in Virginia, and is registered as a foreign corporation in Maryland, where it maintains its headquarters with 20 full-time professional staff. The Center's mission is to protect and restore our nations streams, lakes, estuaries and wetlands through improved management and stewardship of the land.

The mission is accomplished by work in five broad watershed program areas – research, practices, applications, learning and capacity building. Our work is based on scientific research; practical field experience; publications which define and illustrate our approach; and partnerships with communities to improve the effectiveness of their storm water management programs. As the nation's leading storm water clearinghouse, the Center staff can quickly access primary research on diverse topics as pollutant loadings, pollutant removal performance and rainfall/runoff relationships.

Tom Schueler is the Director of Watershed Research and Practice, and directs research on the science and management of urban streams, and has worked for more than twenty years on developing innovative techniques to protect and restore them. Tom has authored several widely-used references, including the *Small Watershed Restoration Manual Series*, *The Practice of Watershed Protection, Rapid Watershed Planning Handbook*, and the *Impacts of Impervious Cover on Aquatic Systems*. Tom has also produced the Washington Area National Urban Runoff Project Final Report and directed more than ten performance studies on urban best management practices while at Metropolitan Washington Council of Governments from 1982 to 1992. Tom will serve as the principal investigator and coordinator of the research team.

The Center for Urban Environmental Research and Education (CUERE, http://www.umbc.edu/cuere) at University of Maryland, Baltimore County was established in 2001 with grants from EPA and HUD. The mission of the center is to advance the understanding of the environmental, social, and economic consequences of changes to the urban and suburban landscape. CUERE is host to the field offices of the NSF-funded **Baltimore Ecosystem Study**. The **Department of Civil and Environmental Engineering** was established at UMBC in 2000 with MS and PhD degrees having been approved in 2003-04. CEE faculty expertise includes water quality, stormwater management, watershed hydrology, groundwater transport, water and wastewater treatment, soil and sediment remediation, environmental risk assessment, sediment geochemistry, and contaminant bioavailability. Offices and laboratories of CUERE, BES, and CEE are co-located in the Technology Research Center at UMBC. Researchers of these three entities interact on a daily basis.

Brian Reed is Professor and Chair of Civil and Environmental Engineering at UMBC. His major research area is physicochemical processes with an emphasis on the fate of heavy metals on natural and anthropogenic materials and hazardous waste site remediation.

Upal Ghosh is Assistant Professor of Civil and Environmental Engineering. His research explores fundamental process mechanisms that control organic contaminant fate in soils, sediments, and aquatic environments.

Claire Welty is the Director of the Center for Urban Environmental Research and Education and Professor of Civil and Environmental Engineering. She oversees hosting of the BES field offices on campus of UMBC and is a co-PI on the Baltimore Ecosystem Study. Her research interests are in urban hydrology and quantifying fate and transport of contaminants in aquifers.

Steve Stewart is the Manager of the Watershed Management and Monitoring Section of the Baltimore County Department of Environmental Protection and Resource Management. Steve has been the NPDES MS4 Permit coordinator for the last thirteen years and serves as the TMDL coordinator for Baltimore County. Steve has served as principle investigator for a number of research projects that have focused on BMP effectiveness including, effectiveness of stream restoration on pollutant load reduction, and a study on Effectiveness and Function of Riparian Forest Buffers in an Urban Setting. Steve holds Bachelor's and a Master's degrees in biological sciences. Steve will provide input on research design and provide reviews of the final products.

Eldon Gemmill is the supervisor of the Baltimore County Department of Environmental Protection and Resource Management (DEPRM) Watershed Monitoring Unit. This unit monitors the health and stability of Baltimore County's streams in terms of stability, chemistry, biology, and physical attributes in compliance with State and Federal mandates. He is also the designated Watershed Manager for the Patapsco and Back River Watersheds and has been the project manager for several large watershed studies covering these and other basins in the County. He has also authored or co-authored several research papers in the field. Eldon holds a Bachelor's and a Master's degree in the biological sciences and has 22 years as an environmental professional for local government. Eldon will be the Baltimore County coordinator for fieldwork conducted by Baltimore County.

The rest of the principal investigators will include Bill Stack (Baltimore City DPW), and Ken Belt and Richard Pouyat (U.S. Forest Service NES). The research team will meet frequently to coordinate efforts on the project.