United States
Environmental Protection
Agency

Using Economic Incentives to Manage Stormwater Runoff in the Shepherd Creek Watershed, Part I

EPA/600/R-08-129
October 2008

Using Economic Incentives to Manage Stormwater Runoff in the Shepherd Creek Watershed, Part I

By

Hale W. Thurston, Allison H. Roy, William D. Shuster, Matthew A. Morrison*,
Michael A. Taylor, and Heriberto Cabezas

A portion of the work outlined in this report was done under
Contract number EP-C-05-061 Task Order #08
Project Officer Hale W. Thurston, PhD.

Sustainable Technology Division
*Land Remediation and Pollution Control Division
National Risk Management Research Laboratory
US Environmental Protection Agency
Cincinnati, OH 45268

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Acknowledgments

The U.S. Environmental Protection Agency through its Office of Research and Development funded and collaborated in the research described here under the Scientific, Technical, Research, Engineering and Modeling Support (STREAMS) contract EP-C-05-061, Task Order 8: "Implementing Dispersed Best Management Practices in the Shepherd Creek Area of Cincinnati." Support for water quality sampling and analysis was provided by Pegasus Technical Services, Inc. under EPA Contract # EP-C-05-056. The U.S. EPA's Central Regional Laboratory in Chicago, IL provided critical and timely analytical services for the majority of the water quality analyses. Periphyton and macroinvertebrate identifications and chlorophyll analyses were performed in 2003-04 by PhycoTech, Inc. under simplified acquisition 3C-R312-TTSA and in 2005-06 by EnviroScience, Inc. under simplified acquisition EP05C00134. Directly connected impervious area (DCIA) data entry and assessment were performed under STREAMS Contract EP-C-05-059, task order 0009, to Eastern Research Group, Inc. Support for some of the hydrologic monitoring was made available through an Interagency Agreement (IAG) with the U. S. Department of Agriculture-National Resources Conservation Service (USDA-NRCS) for "Hydroecological benefits and economic attributes of on-lot stormwater best management practices", DW12921597-01-0, 2004 and an IAG with the US Geological Survey (USGS) titled "Hydroecological benefits and economic attributes of on-lot stormwater best management practices", DW-14-921600-01-0, 2004-2007.

This report would not be possible without the work of many people along the way. Haynes C. Goddard, David Szlag, Beth Lemberg, Michael Miller, and Jamie C. Coleman had significant intellectual input at the inception of this project. Laura Boczek of ORD's Water Supply and Water Resources Division coordinated microbial assessments for all water samples. Ward Wilson, Mike Valerius and David Snook provided invaluable work in the field.

Foreword

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Sally Gutierrez, Director
National Risk Management Research Laboratory

Abstract

Communities nationwide are facing increased responsibility for controlling stormwater runoff, and, subsequently, rising costs of stormwater management. In this report we describe and test a methodology that can be used by communities to focus limited budgets on the most efficient and ecologically-effective installation of stormwater management practices. The overall project has two primary objectives: (1) to test the use of an auction to cost-effectively allocate stormwater management practices among landowners, and (2) to determine the effectiveness of the resulting implementation in terms of hydrological, water quality, and ecological measures. Here, we describe the theories, methods, and criteria used to distribute rain gardens and rain barrels to homeowners in a small, midwestern watershed. The first round of the reverse auction in 2007 resulted in 50 rain gardens and 100 rain barrels installed at 67 of the approximately 350 residential properties in the experimental watershed. In 2008, the auction was repeated and we accepted bids for an additional 35 rain gardens and 74 rain barrels. Stormwater management practices were distributed relatively evenly throughout the watershed and are expected to result in significant improvements in stream quality. We describe our monitoring approach, including 1) parcel-scale hydrology and water quality monitoring of selected rain gardens, and 2) stream monitoring following before-after-control-impact approach for assessing the hydrological, water quality, and biotic responses to stormwater management installation. By employing a multidisciplinary approach to watershed management, the case study offers an example of stormwater management that should be readily transferable to other residential watersheds.

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CHAPTER 1 Introduction

1.1 Background

Traditional stormwater control policies have concentrated on solutions that build centralized capacity to direct and hold excess runoff within a storm sewer system. However, such centralized infrastructures do not sufficiently alleviate water quality problems for receiving waters, and can be expensive for municipalities who must work within budget constraints. This project tests an alternative approach to stormwater control using a decentralized approach that disperses retrofit runoff detention practices throughout a small suburban watershed, thus reducing runoff before it reaches the sewer system. By distributing decentralized stormwater detention through market mechanisms, we concurrently study the hydrological, water quality, and ecological benefits of stormwater management practice implementation and explicitly evaluate the cost of meeting environmental quality standards through this type of approach.

1.2 Purpose

The overall project has two primary objectives: (1) to test the use of an auction to cost-effectively allocate stormwater management practices among landowners, and (2) to determine the effectiveness of the resulting implementation in terms of hydrological, water quality, and ecological measures. The stormwater management practices used in this project were limited to rain barrels and rain gardens. A voluntary, sealed-bid auction was used to allocate stormwater management practices and determine the compensation private landowners will receive in exchange for accepting the installation of a stormwater management practice on their property. The winners of the auction were those who offered to accept stormwater management practices with the greatest environmental benefits at the lowest price. The auction provided a means of identifying willing landowners and offers a mechanism by which these stormwater management practices can be systematically allocated to these landowners within the watershed.

1.3 Study setting

The study took place in the Shepherd Creek watershed, a tributary to the West Fork Mill Creek, located in Mt. Airy, Cincinnati, Ohio. The watershed is 1.85 km^2 (457 acres), approximately one-third of which lies within a city park with mature deciduous forest. The other two-thirds of the watershed represent a mix of 1960-1980s residential parcels in the headwaters, and horse pastures at downstream locations. The residential area consists primarily of single family homes and has a median lot size of 880 m^2 (0.22 acres). Over three-quarters of the 406 houses in the catchment were built between 1950 and 1990. There are also three apartment complexes (27 buildings) in the headwaters and several public buildings with parking lots (e.g., a church, police station, park arboretum). The watershed sits on calcareous shale and limestone formations with moderate slopes, and silt and silty clay loam soils dominate.

CHAPTER 2 Developing a Retrofit Watershed Management Strategy

2.1 Characterizing the impairment

Cincinnati's Mill Creek is considered by the Ohio Environmental Protection Agency to be among the most polluted waterways in the state (OEPA, 1994), with stormwater runoff being a major direct and indirect contributor to the pollution. The Shepherd Creek is similarly impaired by stormwater runoff, as evidenced by hydrologic, geomorphic, water quality, and biotic assessments of the stream and its tributaries (Figure 2.1.1).

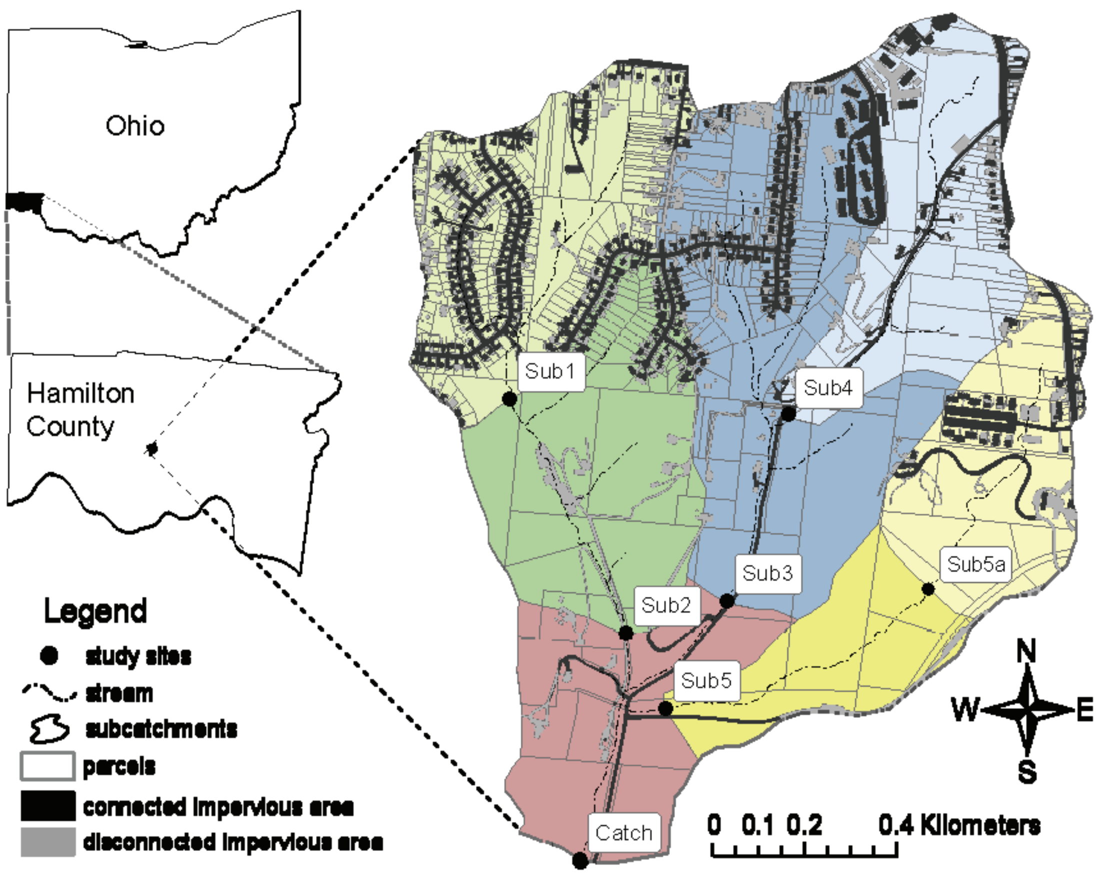

Figure 2.1.1 Map of impervious areas and parcels within the Shepherd Creek study watersheds.

In terms of stream geomorphology, the cobble/gravel riffles are highly embedded with silts and other smaller-sized eroded sediments. A high percentage of total streambed area is observed to be highly scoured and entrenched, leaving platy formations of bedrock which are in an active process of rotting, and these surfaces are typically found to be covered with a thin layer of silt. Since the streambeds have been down cut to bedrock, stream reaches have attempted to adjust to present stream flow patterns through lateral expansion. This process involves the erosion of soils and wearing away of bedrock to each side of the original streambed. For areas where roads are adjacent to the streams, some banks have been fortified with concrete, limiting lateral expansion to one stream bank only.

Developed areas exhibit the predictable flashy behavior found in urban streams, which was much more pronounced than the more gradual rise and fall hydrograph shape for adjacent forested areas in Mt. Airy park (Sub5). Storm runoff from urban areas is flashy and delivered quickly and in great volumes to stream reaches (Paul and Meyer 2001). These small urban streams may also lack natural baseflows, resulting in streambeds that are dry in the summer months such that stream flows that can be sporadic and limited to storm events.

Water chemistry in the sub-watersheds is characterized by neutral to alkaline pH (average values range from 7.7 to 7.9), with high average alkalinity (225 to 295 mg $CaCO_3 \cdot l^{-1}$) from natural dissolution of the calcareous shale bedrock that is extant throughout the watershed. As in many established urban watersheds, chloride (Cl) concentrations are elevated at some stream locations mostly because of road salt application (Godwin et al. 2003, Kaushal et al. 2005). Sub4, which receives direct street runoff and is downstream from a moderately steep hill (where salt application would be expected to be heavy during the winter months), averages 280 mg/L year round. This value is above the chronic toxicity limit for Cl in freshwater (250 mg/L), and much higher than the approximately 50 mg/L average measured at Sub1 and Sub2. Sub5 also receives road runoff and has an average Cl concentration of 161 mg/L that appears to cycle throughout the year as salt is loaded into the stream during the winter and flushed out in the summer. Nitrogen and phosphorus concentrations fall within the range of values expected for urban land uses (Figure 2.1.2 A and B) (e.g., Schoonover et al. 2005). Average baseflow values for dissolved inorganic nitrogen (DIN) and total phosphorus (TP) ranging from 0.20 to 0.98 $mg \cdot l^{-1}$ and 0.17 to 0.37 $mg \cdot l^{-1}$ respectively for the years 2005-2006.

Since hydrology and water chemistry tend to regulate biological activity in aquatic ecosystems, we were not surprised to find that our periphyton samples contained high concentrations of chlorophyll *a* (average 4.3 to 10.2 mg/m^2 across sites, 2003-2006). Average algal ash-free-dry-mass in 2005-2006 ranged from 57.1 (Catch) to 87.9 (Sub5a) g/m^2. A majority of the algal cells sampled were cyanobacteria, which reflects overall poor water quality. Macroinvertebrate assemblages were typically dominated by isopods, amphipods, and chironomids. In 2005-2006, there was an average richness of 18.0 (Sub4) to 24.1 (Sub2) taxa per site. Sensitive taxa in the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) constituted a mere 0.5% (Sub2) to 5.4% (Catch) of the samples by abundance, further reflecting poor biotic integrity within the tributary streams. Hilsenhoff's Family Biotic Index scores for macroinvertebrates suggest fairly poor (5.76–6.50) or poor (6.51–7.25) water quality (Hilsenhoff 1988), which is consistent with water quality and periphyton samples.

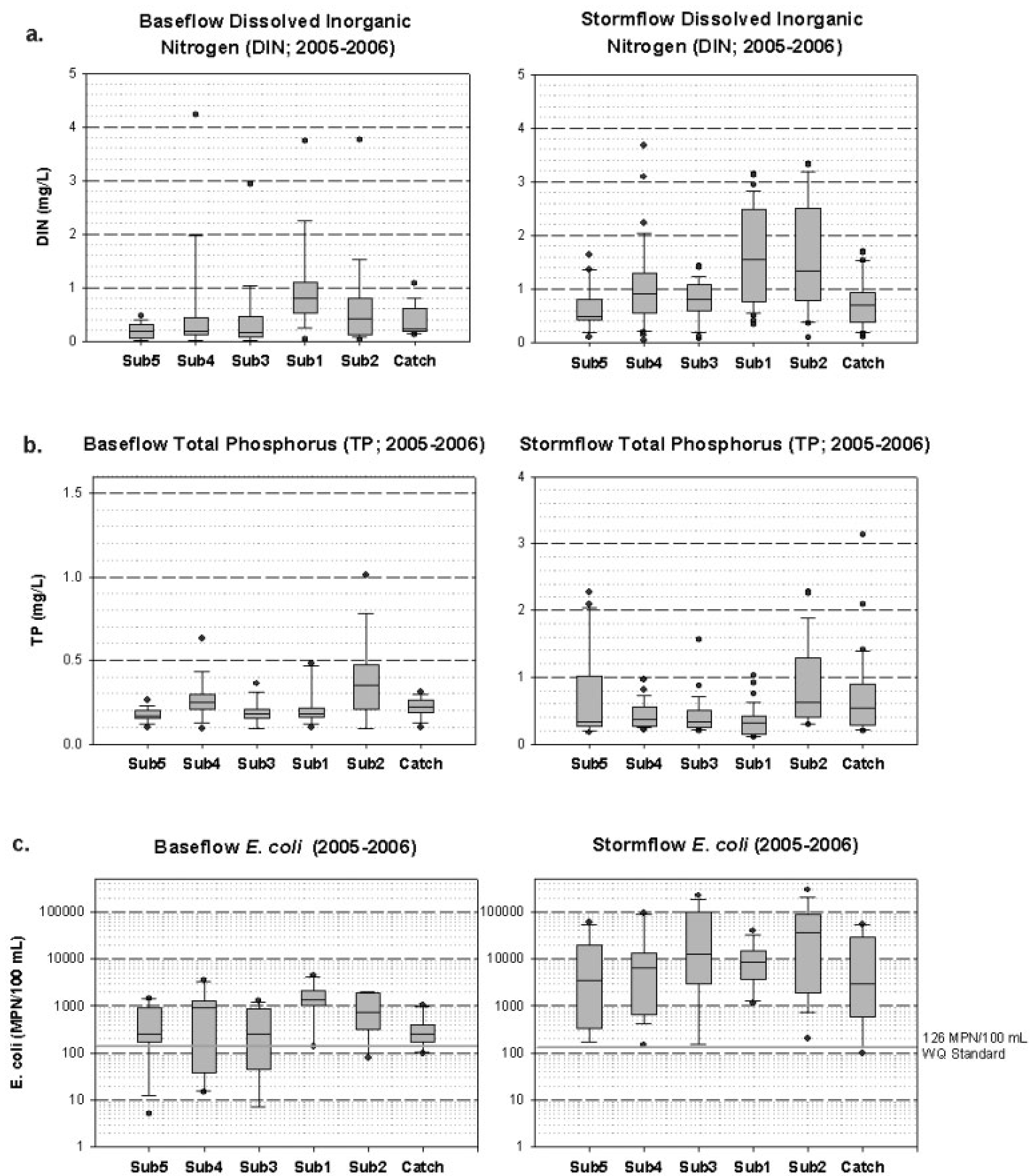

Figure 2.1.2 Pre-implementation data for Shepherd Creek sites, comparing baseflow and stormflow water quality data for the years 2005 and 2006. (A) Dissolved Inorganic Nitrogen; (B) Total Phosphorus and (C) Extent of bacterial contamination (as *Escherichia coli*); note log scale for y axis on these plots.

Of great interest to public health interests in stormwater and watershed management, we observed average fecal coliform bacteria and *Escherichia coli* counts derived from baseflow water samples that were 1–2 orders of magnitude higher than Ohio EPA's ambient surface water quality criteria (e.g., mean limit 126 CFU 100 ml^{-1} for *Escherichia coli*). These high counts of pathogens were observed at both baseflow and, more recently, in storm flow samples; Figure 2.1.2 (C) shows that median baseflow concentrations of *Escherichia coli* are highest at Sub1 (1,400 CFU/100 mL), while median stormflow concentrations are highest at Sub2 (37,500 MPN/100 mL). After further investigation we concluded that the most likely sources are: a) wastewater infrastructure, which is sometimes improperly connected from residences, leaking flows to stormwater conveyances; b) exfiltration from septic fields that were hydrologically-connected to headwater reaches in the north-central area of the watershed; and c) improper storage of horse manure in the lower part of the watershed. Additional investigation is needed to clearly identify and allocate bacterial loads among these, and possible wildlife sources.

2.2 Assessing the source of impairment and potential for improvement

Impervious area

Impervious surfaces are a primary source of impairment in urban and suburban areas, resulting in increased stormwater runoff and reduced infiltration compared to more natural settings (Arnold and Gibbons 1996). This exacerbated amount of stormwater runoff translates to hydrologic impairments in streams such as increased volume of peak flow and storm "flashiness" (Konrad and Booth 2005), which subsequently alters stream morphology and sediments (Booth and Jackson 1997, Bledsoe and Watson 2001). Stormwater runoff also carries pollutants from the landscape, resulting in altered water quality in urban streams (Hatt et al. 2004). The combined physical effects of impervious surfaces in streams has led to impaired biotic communities and reduced ecosystem functioning in urban streams (Paul and Meyer 2001; Walsh et al. 2005b).

Percent urban land cover and total impervious area (TIA) are commonly used as indicators of urban disturbance. More recently, studies have shown that the subset of impervious surfaces that route stormwater runoff directly to streams via stormwater pipes, called directly connected impervious area (DCIA), may be responsible for the majority of stream alteration due to urbanization (Booth and Jackson 1997, Brabec et al. 2002, Walsh 2004, Walsh et al. 2005a). For this project, we used a combination of field assessments, aerial photography, and GIS data to determine both TIA and DCIA in the Shepherd Creek watershed.

Impervious (22.1 ha) and semi-impervious (1.8 ha) areas comprise 13.1% of the Shepherd Creek catchment (Catch; Figure 2.1.1). Of the impervious area, 56.3% was connected, although percent connectivity varied widely across parcels. Across watersheds, the lowest percent TIA (11.2%) and DCIA (5.4%) were at Sub4, and the highest percent TIA (19.9%) and DCIA (11.6%) were at Sub1. A majority of the TIA in Shepherd Creek was on private land (70.5%) compared to public land (29.5%). Public properties (e.g., roads, city park) encompassed a larger proportion of the connected (37.4%) versus disconnected (19.4%) impervious area. Conversely, single-family residential properties comprised a higher proportion of the total impervious area found to be disconnected (68.1%) than connected (42.1%). The public parcels and the private, multi-family residential parcels both had more than double the total amount of connected versus disconnected impervious area; whereas single-family residential parcels had overall lower amounts of connected than disconnected impervious area (Figure 2.2.1).

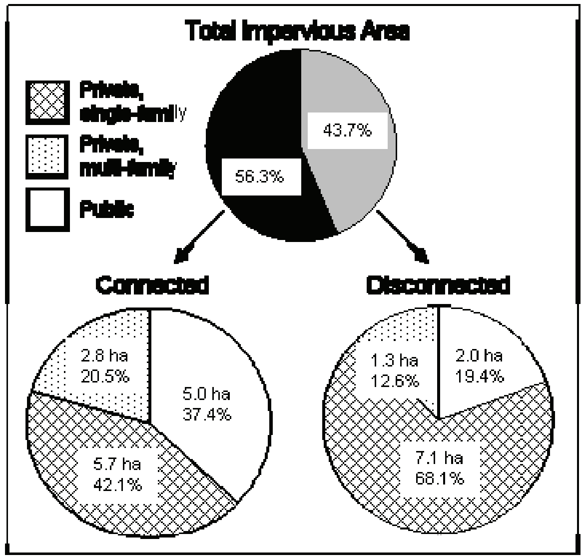

Figure 2.2.1 Total connected and disconnected impervious area in the Shepherd Creek watershed based on property ownership.

We evaluated the primary types of impervious surfaces and percent connectivity of those surfaces to assess types of stormwater management practices that may result in best potential for retrofit. The highest amounts of TIA were due to buildings (i.e., rooftops; 27.6%), driveways (24.6%), streets (22.7%), and parking areas (12.3%; Table 2.2.1). A majority (89.2%) of the streets were connected, so that streets composed the highest percent DCIA (36.0%) in the catchment, followed by buildings (32.9%), driveways (17.4%), and parking areas (13.5%). The remaining impervious surface types (e.g., sidewalks, concrete patios, etc.) comprised less than 13% of TIA and 0.2% of DCIA.

Table 2.2.1 Total (TIA) and Directly Connected (DCIA) Impervious Area Categorized by Impervious Surface Type.

Surface Type	TIA (m^2)	TIA (%)	DCIA (m^2)	DCIA (%)	% Connected
Building	66168	27.6	44364	32.9	67.0
Driveway	58918	24.6	23525	17.4	39.9
Street	54432	22.7	48551	36.0	89.2
Parking area	29473	12.3	18144	13.5	61.6
Sidewalk	13097	5.5	3	0.0	0.0
Concrete	6963	2.9	211	0.2	3.0
Wooden deck	4984	2.1	0	0.0	0.0
Pool	2363	1.0	0	0.0	0.0
Shed	882	0.4	12	0.0	1.3
Other	2047	0.1	4	0.0	6.7

Selected stormwater management practices

Because a majority of TIA was on private property (70.5%) and in buildings and driveways (52.2%), we targeted private properties for installation of stormwater management practices in the form of rain gardens and rain barrels. Parcels in Shepherd Creek are of adequate size (median lot size = 880 m^2 or 0.22 acres) to permit placement of rain gardens within lawns and rain barrels on roof gutter downspouts. Rain gardens are engineered bioretention cells that have porous substrate and soils designed to allow rain and snowmelt to seep naturally into the ground. Rain gardens typically have a concave surface to increase the capacity for holding rain water, and they are planted with hearty plant species that are selected for their tolerance of local climate and extremes in root zone water content. They are ideally located downslope of impervious surfaces to capture stormwater runoff generated from rooftops, driveways, sidewalks, and patios. By encouraging infiltration, rain gardens reduce flooding and pollution in local streams and rivers, and can help to recharge local water tables. Rain barrels, or cisterns, are tanks attached to roof gutter downspouts which are used to collect rainwater from rooftops. Water from rain barrels can be used to water gardens and lawns and other domestic uses and, therefore, may diminish other household demands on potable water. By storing stormwater runoff during storm events, rain barrels reduce downstream flooding. Furthermore, if barrels are emptied into the landscape after storms (i.e., then the soil is no longer saturated), they can effectively recharge local water tables. The combination of stormwater management practices were selected for their ease of implementation in an existing neighborhood and potential for addressing the major sources of impairment in the Shepherd Creek watershed.

Potential for improvement

Previous studies have reported that biotic impairment of streams typically occurs around 15-20% urban land cover or 8-12% impervious surface cover (see reviews by Schueler, 1994; Paul and Meyer, 2001; Walsh *et al*., 2005b). In Figure 2.2.2, we report % TIA in each of the six subcatchments (black bars), and projected % TIA (effective) with various rates of stormwater management practice acceptance. The calculations assume that rain barrels and rain gardens effectively eliminate runoff effects from both rooftops and driveways. With 100% homeowner acceptance rates, these stormwater management practices have the combined potential to reduce effective impervious area in sites 2–5 from above the 8–12% impervious area threshold to well below the threshold (Booth and Jackson 1997). If 50% of the homeowners have stormwater management practices installed, it is still likely that some subwatersheds will exhibit improvements in stream condition.

Some important caveats should be noted regarding the estimates of potential improvement. First, it is unlikely that all runoff from impervious surfaces will be routed to rain gardens and rain barrels, and there is a limited capacity for storing and infiltrating runoff. Detailed rainfall-runoff modeling is necessary to determine actual amounts of stormwater detained or infiltrated following various size precipitation events. Estimated reductions in DCIA may more effectively capture the potential improvements with retrofit; however, thresholds of biotic impairment for DCIA are limited and variable (Wang et al. 2001, Walsh et al. 2005a, Wenger et al. 2008). Further, there are no empirical models that provide data on expected responses of hydrology and water quality to changes in TIA or DCIA. Given the mechanism of stream impairment via stormwater runoff, we expect that changes will first be detected in surface hydrology parameters, followed by water quality, and, lastly, biotic assemblages. Thus, our estimates of potential improvement may be conservative with respect to hydrology and water quality. Finally, we

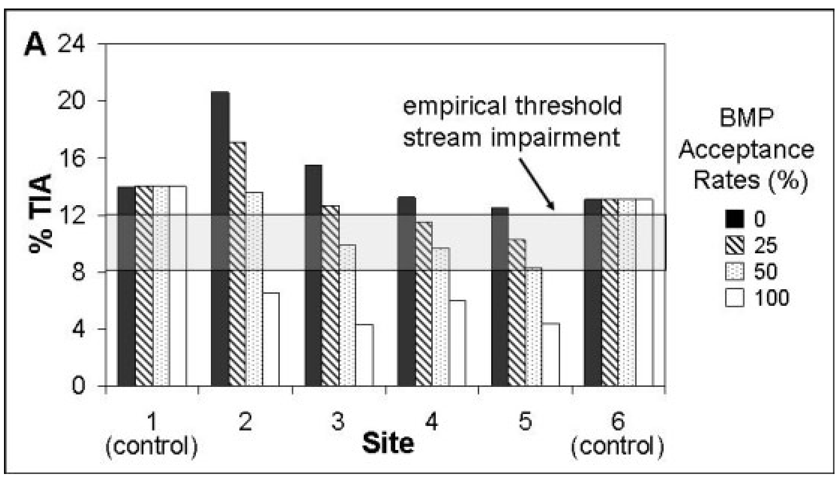

Figure 2.2.2 Percent TIA given 0, 25, 50, and 100% landowner acceptance rates of rain gardens and rain barrels.

expect the potential for detecting change to be highest in the smallest catchments (e.g., the stormwater outfalls and Sub1), as larger catchments are more likely to have additional sources of impairment and mediating factors. Although stream sampling will be necessary to determine actual changes associated with retrofit, it is important that our selection of stormwater management practices addressed the primary sources of imperviousness, and that the subcatchments do not have excessive amounts of imperviousness (e.g., >50%, Walsh et al. 2005a), such that stream improvement following retrofit is possible.

2.3 Evaluating economic incentive mechanisms

Command-and-control

The economic portion of the study began with a theoretical examination of the potential cost savings from using various market based mechanisms to provide economic incentive for widespread participation in a dispersed storm water retention exercise. This was a necessary first step because we wanted to see if there was any potential savings over current policy before proceeding to the actual implementation. To evaluate the cost effectiveness of various market mechanisms we wanted first to determine, in a case study setting, the cost of a command and control mechanism. Command and control is a mechanism that allows for very little flexibility among the regulated entity; the regulating agency sets a standard and the regulated must meet the standard under penalty of fines. Below we compare, in a real setting, using realistic cost and hydrology figures, the costs in per unit runoff detention under a command and control situation or either of two market based incentive mechanisms: tradable credits, and fee and rebate. We conclude by proposing a market mechanism that will fit legally with our study area, a procurement auction.

Using the parcels from the actual Shepherd Creek area the type of stormwater management practice, concomitant detention cost (DC) functions and inverse cost functions, were assigned to parcels in the watershed based on land use and soil type to calculate what the cost would be, in the absence of any market incentives, to control the excess stormwater runoff from watershed areas with dispersed, small-scale stormwater management practices. To calculate the cost of a dispersed set of stormwater management practices to store all of the excess runoff discharge from a one and a half year storm event of 3.12 cm (1.23 inches) on site, we assigned the appropriate least-cost stormwater management practice technologies on a parcel-by-parcel basis in our small case area and solve each landowner's cost equation.

- Parcels with residential land use and hydrologic soil group (HSG) B, which are soils of silt or loam, are assumed to employ sand filters. The cost function is: $DC_{\mathrm{Res}B} = 26.6Q^{0.64} + 0.126\mathrm{Q}$
- Residential parcels with HSG C or D, soils with lower infiltration capabilities due to existence of more clay, are assumed to use rain gardens/grassed swales, the relevant cost function of which is $DC_{\mathrm{Res}C} = 4.94\mathrm{Q} + 0.126\mathrm{Q}$

Where Q is the quantity of stormwater runoff detained in cubic feet, and second term in each is the log-linear estimated opportunity cost of land. We choose to not include a quadratic term estimated from a previous paper because while it is statistically significant, it is not economically significant at the stormwater management practice sizes we are concerned with. The cost functions are modified from Schueler (1987) and Heaney et al (2002).

This calculation presumes that the parcel owner is responsible for *all* the runoff over and above that which would result if the parcel were in its undeveloped state. This in effect is a command-and-control regime with no rebate and the water detained with this constraint is 2344 m^3 (82,767 ft^3), at an average cost of \$950 per homeowner. When we considered only construction costs of stormwater management practices, we calculated an average cost of \$4.62 per cubic foot of stormwater runoff detained via stormwater management practices over all properties in the study area. Finally, we recalculated the cost to include the opportunity cost of land, which was estimated from the hedonic price function and noted in the cost functions above; for the log-linear case this adds \$0.126 per ft^2. Assuming again that command-and-control policy is implemented that causes all parcel owners to use stormwater management practices to manage all excess stormwater runoff, the recalculated cost was \$6.49 per ft^3, at an average cost per homeowner of \$1337.

Tradeable allowances

The first hypothetical study we conducted in the Shepherd Creek area was one that envisioned the use of tradable credits for stormwater runoff, an idea first suggested by Coleman (2000). The cost effectiveness of the tradable allowance approach to pollutant reduction in airsheds is well established in the literature (Eheart 1980, Baumol and Oates, 1988, and Tietenberg 2000), and the SO_2 trading program in the United States has been operating successfully for several years. Watersheds differ from airsheds, however, in key aspects, such as confinement to a channel, non-uniform mixing and downstream accumulation, and these present new challenges for the establishment of tradable allowance systems. Watershed trading is not a new concept, but the specific application explored in this paper is new. The US EPA's *Draft Framework for Watershed-Based Trading* (1996) provides an overview of some twenty tradable allowance programs across the United States. Several of these grew out of cooperative agreements with the US EPA, the Water Environment Research Foundation, and various local stakeholder groups. These programs focus on reducing concentrations of nutrients or toxics, and most rely upon an organizational effort similar to US EPA's total maximum daily load (TMDL) process to drive stakeholder involvement.

Two necessary conditions for tradable allowance regimes to be cost reducing are that: i) transactions costs of such programs be no greater than the gains achieved and ii) there be sufficient difference in abatement cost across parcel owners so that potential cost savings can be realized through market exchange of runoff control. With these conditions satisfied, a tradable allowance system can efficiently assign runoff control to dispersed locations and may avoid the larger cost of centralized approaches.

The usefulness of inclusion of opportunity costs can hardly be overstated in this application. We use the results of our opportunity cost estimation[1] to inform a tradable allowances system much like those currently used in water quality trading programs around the country (USEPA 2003). Figure 2.3.1 compares, for the Shepherd Creek Pilot project, the per-unit runoff reduction costs faced by homeowners under assumptions of different credit prices, and inclusion or exclusion of opportunity costs. Not surprisingly when opportunity costs are ignored all costs are lower. The cost line named "18-mile tunnel" represents the costs per unit of detention in a proposed large infrastructural stormwater conveyance system that is under consideration by the Metropolitan Sewer District for the city of Cincinnati[2].

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[1] Thurston (2006) describes in detail how a Hedonic price function is estimated to approximate the opportunity cost of dedicating land to Stormwater management practices for stormwater runoff control.

[2] It should be noted that the tunnel would serve a much larger population than the Shepherd Creek Pilot project area, which is used in the other calculations.

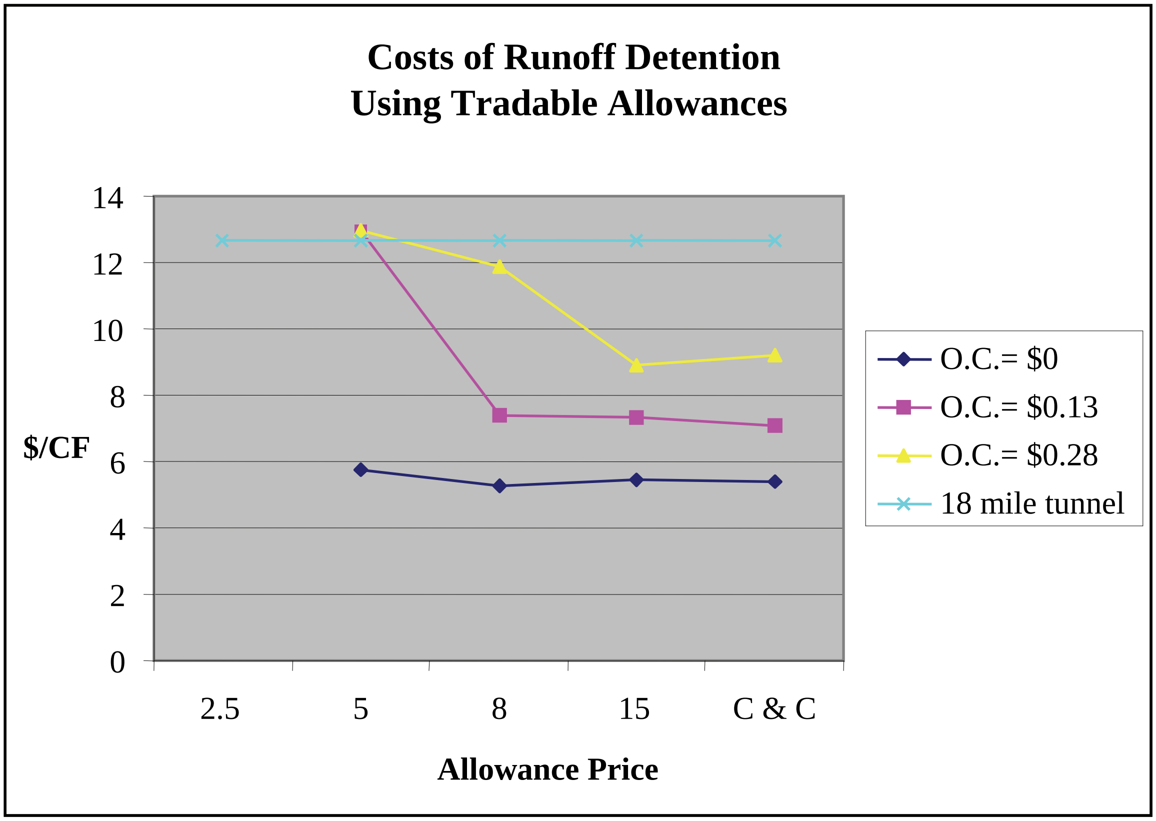

Figure 2.3.1 Costs of runoff detention with Tradable Allowances

Fee and rebate

We also considered the potential application of a fee and rebate system. An efficient tax on pollution should be a direct tax that equals the marginal external damages (Pigou 1962). But directly taxing pollution is complex, especially when monitoring is difficult (such as with a non-point source) or when there are institutional barriers to imposing differing taxes on different people in the same area. Fullerton and Wolverton (1999, 2003) note that when directly taxing the pollution is not an option, the policy maker can exploit the relationship the optimal pollution tax has with income tax and rebates on products that are related to, and relatively cleaner than the polluting good.

This type of policy is already in place in many municipalities in the United States (Doll et al 1998, Doll and Lindsey 1999), but these programs are almost exclusively for commercial properties. Where residential fees are in place they tend to be too small to either promote abating behavior or warrant a rebate. For example, monthly residential stormwater fees in Columbus, OH, St. Louis, MO, and Indianapolis, IN are about $2.70, $0.24, and $1.25 respectively. Many agree that the existing programs have not encouraged the desired behavior because the fees and rebates are simply too low (Doll and Lindsey 1999). If the fee and the rebate are high enough to make households reflect their true underlying preferences, based on our knowledge of the costs facing the residential property owner, a stormwater runoff reduction goal can be met using dispersed stormwater management practices and a two part instrument at a relatively low cost to the utility and at a low per-unit cost to the average stakeholder. We include the opportunity costs of land into the calculated the fee and rebate scenario for the Shepherd Creek watershed which makes the model more realistic. But we find that to substantially increase people's participation in stormwater infiltration practices, the fees and rebates have to be orders of magnitude larger than those that are currently in use.

Auction

There are a variety of legal barriers to implementation of most incentive mechanisms. These barriers stem mostly from language in the Clean Water Act (CWA) of 1972, and "takings" issues. The CWA provides no regulatory "stick" for policy dealing with water quantity as it is only regulated under specific circumstances. Tradable credits are simply not tested as they have just recently been recognized by the EPA as a means to control stormwater runoff. Furthermore, this recognition comes in the form of relatively weak support in the *EPA Water Quality Trading Policy* (EPA 2003). Imposition of a "cap" on a watershed's runoff, and the consequent requirement for attainment through impingement on established property rights is recognized as a takings issue. As for a fee and rebate program, although we have shown it to be economically feasible, existing fees are not tightly tied to excess runoff, and imposition of sufficient fees (much like the imposition of the cap in the trading scenario) would not be politically feasible. Thus, we turned to a wholly voluntary economic auction approach designed to encourage landholders to install stormwater management practices so as to control runoff without necessitating a legal mandate.

There are essentially four types of auctions, English, Dutch, first-price sealed bid, and Vickrey. The English auction is the type of auction most people are familiar with. An auctioneer calls out prices sequentially higher and players bid until only one remains, then that person pays the highest price called. In the Dutch auction the auctioneer calls out bids in descending order until the price reaches that which one person is willing to pay, and that person wins the item at that price. In a first price sealed bid auction bids are submitted without other bidders seeing them and the highest bidder wins. The Vickrey auction (named after William Vickrey, the first person to investigate some of the nuances of auction theory) is similar to the first price sealed bid auction, but the winning bidder pays the price that the second highest bidder bids. Using rigorous mathematical proofs these mechanisms have been proven to all be "revenue equivalent," that is that they all theoretically elicit the same winning price; although experimental and experiential evidence is mixed. Revenue equivalence and other theoretical characteristics of auction such as efficiency conditions, revenue equivalence, or pareto efficient allocation at a Bayesian Nash equilibrium are not in the scope of this paper to go into. The theoretical underpinnings of auctions have been well defined in the economics and game theory literature and are treated rigorously elsewhere. The auction we use is a variant of the first price sealed bid auction, known as a reverse or procurement auction. In this case the auctioneer is the one who wants to buy the item and there are many sellers. We describe this type of action in detail below.

Regardless of the type of auction, auctions are viewed as superior to other means of allocating public resources due to their efficiency, objectivity, transparency, and flexibility (CSIRO 2005). They are efficient because they will allocate the resource to those who are willing to pay the most and therefore are situated to make the best use of them. Objectivity is achieved because the price is not determined capriciously by a government official, rather it is market determined. The auction process is transparent because the rules for bidding and winning are known. Finally, auctions are flexible in that the mechanism can be altered to allow for various contingencies, such as changing annual budgets (CSIRO 2005).

Using market mechanisms as incentive for pollution control has increased in popularity over the years because they allow flexibility among the regulated which can decrease overall policy cost to society. Market mechanisms also act as an organizing device through which transactions costs to the policy maker or regulating agency are decreased. We have assumed that the policy maker has at his disposal several mechanisms that range, in order of increasing flexibility: command and control, tradable credits, fee and rebate and auctions. The choice of which mechanism to employ depends heavily on the situation and the legal obstacles and ecological goals of the program.

CHAPTER 3 Stream Monitoring Design

3.1 Experimental design

The project uses a before-after control-impact site design (Underwood 1994), where the "impact" is the installation of parcel-level stormwater management practices. We established six hydrologic, water quality, and ecological monitoring sites in the watershed (Table 3.1.1), four of which are receiving streams for the stormwater management practice installation area (Sub1, Sub2, Sub3, and Catch), and two which are control watersheds that will not receive stormwater management practices (Sub4 and Sub5). Stream sampling sites were monitored for a minimum of two years prior to installation of stormwater management practices (Summer 2007) and will continue to be monitored for three years following the last installation (Summer 2008). In addition to sampling locations along main tributaries of Shepherd Creek, there are 3 neighborhood sites (N1, N2, and N3) at stormwater outfalls of residential areas and that are monitored for hydrology. Sampling locations for hydrology, water quality, and/or ecology are mapped in Figure 3.1.1.

The original study design consisted of five ecological and water quality sampling sites (Sub1, Sub2, Sub3, Sub5a, and Catch). The sampling location for the control site moved from Sub5a to Sub5 in 2005 after two years of pre-implementation sampling. The site was re-located downstream because: 1) Sub5a lacked adequate baseflow for proper sampling during dry times of the year, 2) the hydrologic monitoring station was located at Sub5, and 3) the larger drainage area at Sub5 was more comparable to the other sites. Ecological and water quality data collected from both Sub5 and Sub5a in 2005 compared well, although stormwater samples were not collected at Sub5a. We also added a second control site, Sub4, in spring/summer of 2005.

Table 3.1.1 Start dates for hydrology, water quality, and ecology monitoring.

Site	Type	Hydrology	Water Quality	Ecology
Sub1	Treatment	Fall 2004	Baseflow, Spring 2004 Stormflow, Summer 2005	Spring 2003
Sub2	Treatment	Fall 2004	Baseflow, Spring 2004 Stormflow, Summer 2005	Spring 2003
Sub3	Treatment	Fall 2004	Baseflow, Spring 2004 Stormflow, Summer 2005	Spring 2003
Sub4	Control	Summer 2005	Baseflow, Spring 2005 Stormflow, Summer 2005	Spring 2005
Sub5	Control (replaced Sub5a)	Fall 2004	Baseflow, Summer 2005 Stormflow, Summer 2005	Summer 2005
Sub5a	Control (decommissioned Spring 2006)	N/A	Baseflow, Spring 2004 through Summer 2005	Spring 2003
Catch	Treatment	Fall 2004	Baseflow, Spring 2004 Stormflow, Summer 2005	Spring 2003
N1	Treatment	Spring 2006	N/A	N/A
N2	Treatment	Spring 2006	N/A	N/A
N3	Treatment	Spring 2006	N/A	N/A

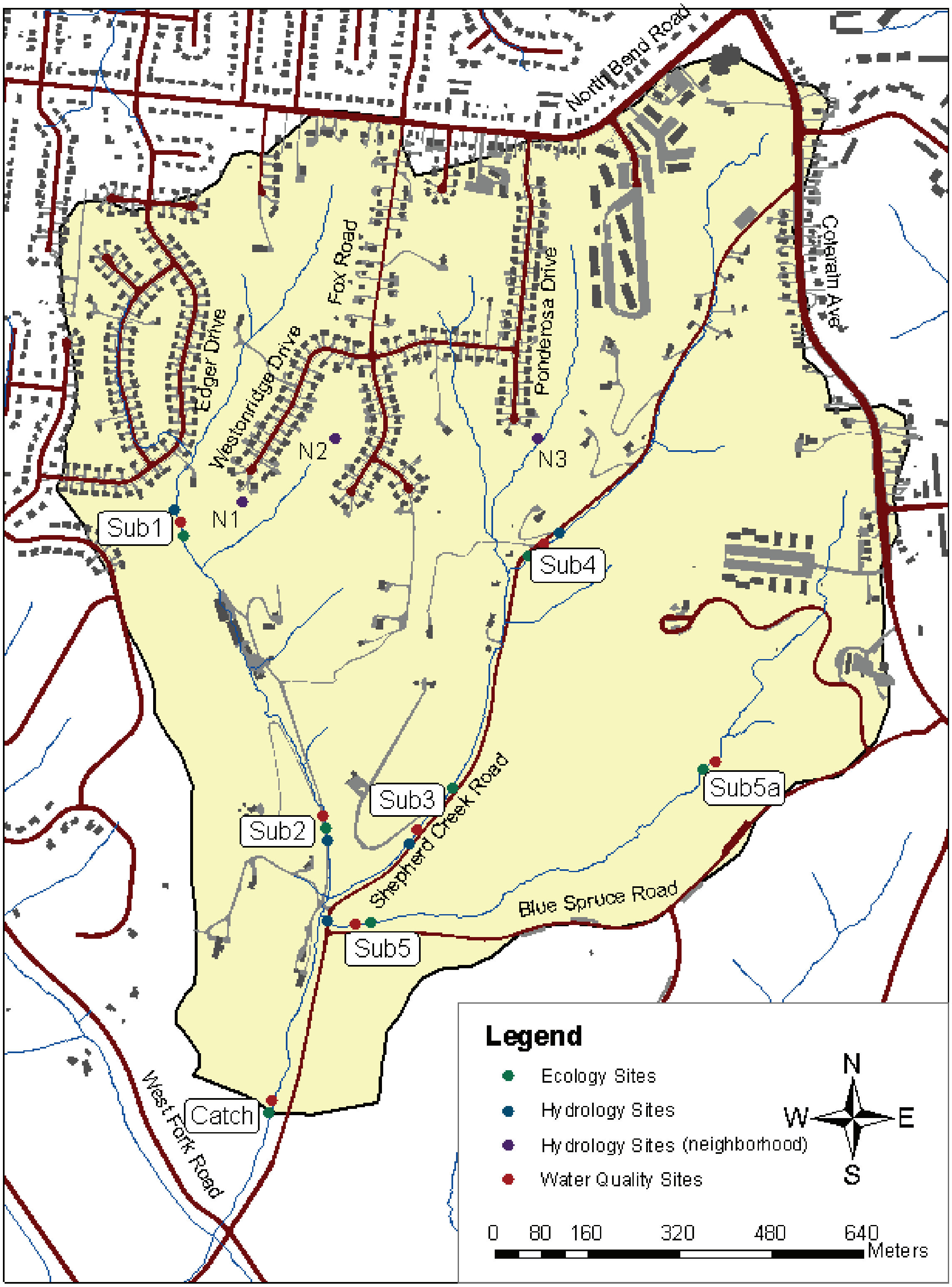

Figure 3.1.1 Location of sites for various sampling activities in the Shepherd Creek watershed.

3.2 Hydrologic monitoring

Hydrology is a "master" variable that drives dynamics in other aspects of watershed structure and function (Konrad and Booth 2005), and its characterization is key to understanding watershed dynamics and any impact that the LID retrofits might have. For this project, we set up a gaging network to measure flows at stormwater outfalls (neighborhood sites) and within streams at various locations within the watershed, thus capturing the spatial hydrology of the watershed.

Stream stage is measured at intervals of 5 minutes or less, so as to better resolve storm peaks and transient characteristics of stormflow in urbanized watersheds. Flow controls were designed for each site and implemented as either broad-crest with v-notch weirs in natural stream reaches, or as semi-elliptical plate weirs for the site with pipe culverts. Flow depth at each gage is measured with bubbler-type stage measurement devices (Design Analysis H350XL; Logan UT). Depth is converted to discharge with a site-specific stage-discharge relationship that has been determined over multiple years with episodic manual measurements made at different water depths during both baseflow and storm flows. Flows at the outlet of the watershed (Catch) are realized as mean daily flows only. The cost was prohibitive to establish a proper flow control at this large a stream cross-section, and so discharge is therefore estimated via an empirical relationship between flows explicitly measured at Sub2, Sub3, and Sub5, and accounting for the increase in drainage area and cross-sectional dimensions. We also used peak flow data derived from crest-stage gages (which passively mark and record flow depth at peak storm discharge) and converted into discharge values through modeling with USACE HEC-RAS (River Analysis System) to refine the empirical model for Catch.

Rainfall is measured at four locations around the watershed: 1) in the northeastern part of the watershed (operated by Hamilton County), 2) in the centroid of the watershed near Sub3, 3) in the eastern part of the watershed at Mt. Airy Arboretum, and 4) along the eastern edge of the watershed (near the police station). Rainfall data is gathered with tipping-bucket-type rain gages with 0.01" sampling resolution. Tip data is truncated to 5-minute intervals, and all time bases are coordinated and referenced to Greenwich Mean Time (GMT). In 2008, we also installed an integrated evapotranspiration measurement system (Campbell ET107 station; Logan UT), which we use to generate estimates of hourly evapotranspiration data.

3.3 Water quality monitoring

Urbanization causes significant changes in water chemistry that are regulated under the Clean Water Act, to the extent that these changes have the potential to harm human health and impair biological condition (Paul and Meyer 2001). Table 3.3.1 lists each of the water quality parameters sampled for the Shepherd Creek sites, and the potential sources and impairments associated with each parameter. Water quality and chemistry sampling were conducted monthly under baseflow conditions, on or near the 15^{th} day of the month throughout the year. Water quality sampling was performed in conjunction with ecological data collection when feasible, and followed baseflow protocols defined as no significant rainfall (i.e., >1 mm) in the 72 hours prior to sampling. The sampling dates and times were subject to modification due to inclement weather, or other environmental or climatic conditions deemed unsafe.

Water quality baseflow samples were collected in clean bottles (I-Chem, HDPE Environmental Sample bottles) as grab samples or field-filtered during collection using a peristaltic pump (Geopump Series II, Geotech Environmental Equipment), Teflon sample tubing and in-line filter holders (47mm; with 0.45 µm Millipore Durapore membranes) for dissolved constituents. Samples were preserved by acidification (as needed, depending on the type of analysis) and shipped on ice, overnight, to U.S. EPA's Central Regional Laboratory for most analyses. Alkalinity was determined using EPA Method 310.1; organic carbon analysis via EPA Method 415.1 (high temperature combustion); anions were determined by ion chromatography; nutrients by automated colorimetric methods (EPA Methods 353.2, 350.1, 351.2 and 365.4); and metals and cations by ICP-AES (EPA Method 200.7 and 200.2). Suspended sediment concentration was determined in-house following ASTM Method D 3977-97. For each baseflow sample, in-situ water quality parameters (temperature, dissolved oxygen, etc. as indicated in Table 3.1.1) were measured using a YSI 6600 Water Quality sonde.

In addition to monthly baseflow sampling, periodic stormflow samples were collected at a frequency of 6–8 storms per year, with a goal of sampling 2 storm events per season. Stormflow samples can be used to estimate pollutant loads from nonpoint source runoff and provide water quality data at high flow conditions. For each storm event, 4–6 samples per site were collected using automated samplers (Teledyne-ISCO Model 6712; timed or triggered from changes in depth or turbidity signals from YSI 6600 Water Quality sondes). Stormflow samples were analyzed using the same methods described above for baseflow samples, except that filtration was performed in the laboratory. Samples were split for analysis as needed using a Dekaport Teflon Cone Sample Splitter (Geotech Environmental Equipment).

Table 3.3.1 Summary of water quality monitoring parameters and associated impairments.

Water Quality Category	**Constituents to be Monitored**	**Potential Sources in the Watershed**	**Potential Impairments**
In-situ water quality monitoring (YSI 6600)	Temperature, Specific Conductance, Dissolved Oxygen, pH, ORP, Turbidity	General condition assessment used to support specific parameter analyses	pH critical for determining metal speciation; Conductivity is a surrogate for chloride; Turbidity is a surrogate for suspended sediment
Sediment	Suspended Sediment Concentration (SSC); Turbidity; Particle Size Distribution	Erosion, both hillslope and channel; Runoff from impervious surfaces	Changes to sediment regime may degrade the physical habitat in streams; Sediment-associated contaminants may impair biological condition
Nutrients	Dissolved Inorganic Nitrogen (DIN; NO_3-N+NO_2-N); Ammonia (NH_4-N); Total Kjeldahl Nitrogen (TKN); Total and Total Dissolved Phosphorus (TP and TDP)	Lawn and garden fertilizers; Human and animal waste	Excess nutrients may cause localized eutrophication; Export of nutrients to more sensitive waterbodies may promote eutrophication

Organic Carbon	Total and Dissolved Organic Carbon (TOC and DOC)	Runoff from lawns and gardens and inputs from riparian vegetation; In-stream primary production; Wastewater	Degradation of excess OC may cause localized hypoxia or anoxia
Ions and Alkalinity	Anions: Cl^-, Br^-, F^-, SO_4^{2-}, NO_3^-, PO_4^{3-}; Cations: Na^+, Mg^{2+}, K^+, Ca^{2+}; Alkalinity (mostly HCO_3^-)	Natural weathering; Fertilizers; Road salt; Wastewater	Changes in ionic strength may alter contaminant speciation; Decreased alkalinity limits capacity to buffer inputs of acidic wastewater; Cl^- can be a chronic or acute stressor
Metals	Total and Dissolved Fe, Mn, Al, Cu, Zn	Roadway and rooftop runoff; Wastewater	Excess may cause impairment of biological condition (chronic/acute toxicity)
Microbiology	Enterococci, Fecal Coliforms, E.Coli	Human and animal waste	Bacteria may impair human health and present a contact hazard

3.4 Ecological monitoring

We designated 61 m (200 ft) reaches at each site for sampling periphyton, benthic macroinvertebrates, and physical habitat. Pre-treatment sampling began in 2003 and sampling will continue for three years following the installation of stormwater management practices. Sites were sampled for all parameters five times per year, approximately 6 weeks from April through October. An additional, quantitative bucket method for sampling benthic macroinvertebrates occurred 3 times per year associated with the spring, mid-summer, and fall sampling events. An overview of the types of samples collected is provided in Table 3.4.1, and sampling methods are described below in more detail.

Table 3.4.1 Summary of samples collected and sampling resolution.

Sample Type	**Data collected**	**Data resolution**	**Output/Indices**	**Reference**
Periphyton (50 mL)	Biomass	5 times per year (every 6 weeks Apr.-Oct.)	dry mass, ash-free dry mass	Barbour et al. (1999)
Periphyton (~400 mL)	Taxonomic ID and abundance (cell and natural units)	5 times per year (every 6 weeks Apr.-Oct.)	richness, diversity, composition, tolerance, multimetric indices, etc.	Barbour et al. (1999)
Periphyton (2 glass fiber filters)	Chlorophyll *a*	5 times per year (every 6 weeks Apr.-Oct.)	chlorophyll *a* concentration	Barbour et al. (1999)

Benthic macroinvertebrates (triangular dip net)	Taxonomic ID, abundance, and length	5 times per year (every 6 weeks Apr.-Oct.)	richness, diversity, composition, tolerance, multimetric indices, etc.	Barbour et al. (1999)
Benthic macroinvertebrates (bucket sampler)	Taxonomic ID, abundance, and length	3 times per year (April, July, October)	richness, diversity, density, biomass, composition, tolerance, multimetric indices, etc.	Fritz et al. (2006)
Physical characterization and habitat assessment data sheets	Ranking of physical attributes of sampling sites	5 times per year (every 6 weeks Apr.-Oct.)	Qualitative Habitat Evaluation Index (QHEI), separate habitat metrics	Barbour et al. (1999)

Periphyton

Periphyton samples were collected from ~12 cobbles selected randomly from pool and riffle habitats throughout the reach. Cobbles were removed from the stream and a designated 11.4-cm^2 ring (PVC circle) on each rock was brushed with a toothbrush for ~2 min. Rocks and brushes were then rinsed with stream water into a 500-mL bottle. Periphyton from all rocks within a reach were composited into a single bottle and placed in the dark on ice. In the lab, samples were split for three analyses: chlorophyll a, algal biomass, and periphyton identification. First, the total volume of the sample was measured and recorded. The sample was shaken and homogenized prior to every 10 mL of sample removed. A minimum of 30 mL was filtered onto each of two glass fiber filters and frozen for analysis of chlorophyll a using a multi-wavelength spectrophotometer (Arar 1997). Both the biomass sample and the remaining sample for periphyton identification were preserved with a 1% solution of gluteraldehyde. For biomass analysis, 50 mL of sample was filtered onto a pre-ashed glass fiber filter (47 mm, PALL Type A/E, 1-µm pore size). Filters were dried for 24 hours at 105ºC to a constant weighted and then ashed in a muffle furnace for 1.5 hours at 500ºC to obtain ash-free dry weight. Periphyton cells (300 ±10%) were identified to genus level and densities were reported as both cells and natural units per cm^2.

Macroinvertebrates

Benthic macroinvertebrates were collected using two methods: qualitative kick samples and quantitative bucket samples. The kick sample method was adapted from EPA's Rapid Bioassessment Methods and designed to capture the diversity of macroinvertebrates by sampling habitat types according to their dominance in the stream reach (Barbour et al. 1999). Qualitative kick samples were collected by kicking or otherwise disturbing the substrate over the entire reach and collecting invertebrates and debris in a triangular net (0.5-mm mesh). The quantitative bucket sampler (Fritz et al. 2006) was designed to sample a fixed area and does not require flow for adequate performance. Samples were taken from three haphazardly-selected locations within riffle habitats (rocky pools if riffles are dry). A five-gallon bucket (0.053 m^2) with the bottom removed was driven into the stream bed 3-5 cm deep. Using a trowel, the bed sediment was disturbed to 10 cm for 10 seconds, and a dip net (0.5-mm mesh) was used to remove the suspended material. Material was placed into a wash basin and the procedure was repeated two more times. For both the qualitative and quantitative samples, organic material was elutriated in a bucket to remove inorganic material, sieved, and preserved in 70% ethanol. Bucket samples were kept separate for identification of macroinvertebrates. Three hundred individuals (± 10%) per sample were counted, measured, and identified to genus level.

Physical habitat

General morphometric, geomorphic, and water quality parameters were measured within the 61-m sample reach during ecological sampling. Physical attributes measured included visual estimates of: % riffle, % pool, % run, average width, average depth, wetted area, surface velocity, large wood density, % small wood, % large wood, % detritus, bed texture (% bedrock, cobble, gravel, sand, silt), and % canopy cover. Water quality measurements were taken with a YSI multi-probe, and included: water temperature, conductivity, dissolved oxygen, pH, oxidation-reduction potential, and turbidity. Finally, we calculated two visual assessment habitat evaluation scores: EPA's Rapid Bioassessment Protocols Quantitative Habitat Assessment (QHEI), and the Primary Headwater Habitat Evaluation Form (HHEI) that is specifically designed for streams with water depths <40 cm (Barbour et al. 1999). Visual assessments included ten parameters: substrate, pool depth, bankfull width, riparian zone width, vegetative protection, bank stability, flow regime, sinuosity, bed stability, embeddedness, and channel alteration.

An additional geomorphic assessment was conducted once during the pre-treatment phase (Fall 2004) and will be repeated in 2010 (post-treatment). Cross-section profiles were taken at several locations along the stream reach using an electronic total station (Trimble 5600 Direct Reflex, Dayton, OH). The number of cross-section surveys made was dependent upon the number of breaks between reach areas with contrasting or changing geomorphic properties. The total station was also used to generate bankfull and water surface longitudinal surveys. Bank soil was collected at locations where cross sectional surveys had been made. Soil samples were dried and analyzed in the laboratory for particle size distribution. Finally, a pebble count (Harrelson et al. 1994) was conducted at 100 random locations along the thalweg to determine particle size distribution and median particle size (D50) for the reach.

CHAPTER 4 Auction Design

4.1 Background

Within the treatment areas of the Shepherd Creek watershed, rain barrels and rain gardens were distributed to homeowners using an auction mechanism. There are approximately 350 parcels, each of which was offered the opportunity to receive stormwater management practices free of charge. Apartment buildings (11 within 2 apartment complexes) were also eligible to receive stormwater management practice free of charge; however, apartment owners were approached separately and were not included in the auction.

We conducted the procurement auction design which is consistent with the types of auctions currently being used by federal, state, and local agencies for the purposes of land conservation. We determined a base amount of money to be used for the auction, and stormwater management practices were allocated based on that limit. All homeowners within the pilot area were provided fair and equal opportunity to participate in the auction.

We use a sealed bid, first price, discriminative price auction, where bids are further tempered by the environmental weighting index, and are accepted up to the cumulative reservation price of the agency. A non-uniform price auction is employed because of its theoretical “truth-revelation” properties, which should induce an optimal bidding strategy and will reflect the actual opportunity cost of stormwater management practice adoption. All eligible participants received background information (described below) and those wishing to adopt stormwater management practices submitted bids. The goal was to pay those landowners who adopt the most effective best management practices at the lowest price. The auction was run in the spring 2007and repeated in spring 2008, and resulting in actual payouts and installations of rain gardens and rain barrels. The auction, installations, and maintenance were contracted to TetraTech, Inc.; however, we assessed the auction bids and performed all monitoring.

4.2 Information to homeowners

Potential participants received two direct mailings detailing the function and uses of the rain gardens and rain barrels, and the auction process. The first mailing included a cover letter and informational brochure (Figure 4.2.1), which was intended to notify the landowners in the watershed of the opportunity to participate in the Shepherd Creek project. The second mailing was sent out two weeks after the first and contained a cover letter, a copy of the informational brochure, an auction bid form (Figure 4.2.2), a self-addressed, stamped envelope. All recipients also received nominal financial compensation ($5) to encourage bidding and compensate homeowners for their time. In 2007, due to the novelty of the project, we used door hangers to inform homeowners of the forthcoming mailing. We also extended the auction for 2-3 weeks and sent an additional letter with another copy of the bid form. Homeowners were directed to the project website (www.mtairyraincatchers.org) or a contact phone number for additional information.

Saving the Best News for Last

U.S. EPA is offering Mt. Airy homeowners a free rain garden and rain barrel!

U.S. EPA is sponsoring a limited number of rain gardens and rain barrels in the Mt. Airy neighborhood. Interested households must bid in an auction to receive them. Houses will be chosen based on **lowest bids** coupled with some environmental factors.

EPA's contractors will work with you on siting the rain garden in your yard, and will install the rain garden and rain barrel... FREE

Bid forms will be coming in the mail next week. Send in bid-forms early! **Bid low, to increase your chances of receiving a free rain garden and/or rain barrel.** Winning households will receive their bid amount as a one-time payment after the installation is complete.

U.S. EPA's contractor Tetra Tech, Inc., and its partner Horticultural Management, Inc., will **install** and **maintain** the gardens and barrels for three years.

This unique opportunity is a one-time offer only for Mt. Airy homeowners in the spring of 2007. During this summer and for the next three summers, U.S. EPA will monitor local streams for changes in runoff quantity and water quality resulting from the combined effects of individual rain gardens and rain barrels.

Visit the model rain garden planted at the bottom of the hill on the road to Mt. Airy Arboretum. Also see a rain barrel in action, installed at the Arborteum building. Both were installed by U.S. EPA's contractors.

Ohio native flowers such as purple coneflower (above) and cardinal flower add color and beauty to landscaping features such as rain gardens. Rain gardens are more than just pretty—they help protect water quality in urban areas.

More information on the Web:

Rain Gardens of West Michigan:
www.raingardens.org

Rain Garden Network:
www.raingardennetwork.com

Mid-America Regional Council Rain Garden and Rain Barrel Brochures:
www.marc.org/Environment/Water/publications.htm

Rain Barrel Guide:
http://rainbarrelguide.com

U.S. EPA Homeowner's GreenScapes:
www.epa.gov/epaoswer/non-hw/green/owners.htm

Ohio's Summer Wildflowers:
www.ohiodnr.com/dnap/summer/default.htm

Brought to you by:
U.S. Environmental Protection Agency
Tetra Tech, Inc. (contractor)

Questions? Mike Valerius (Tetra Tech, Inc.) can be reached by phone: (513) 241-0149 or by email: mike.valerius@ttemi.com

This summer,

Don't Get Caught High and Dry

Get a Free Rain Garden and Rain Barrel Instead!

Rain gardens are just what they sound like—gardens that soak up rainwater, mainly from your roof, but also from your driveway and lawn.

A rain garden is shaped like a depression to catch a few inches of rain, or stormwater runoff. It allows the water to slowly filter into the ground, rather than running off into nearby streams and lakes.

A rain garden is like a "raised bed in reverse." A shallow bowl-shaped area, planted with native plants, captures rainfall runoff and allows it to seep slowly into the ground.

This landscaped area is planted with wildflowers, native plants, and shrubs. As the rain garden matures, you will enjoy a beautiful patch of flowers and plants that require less maintenance, watering, and chemical inputs than a lawn.

Native plants like Black-eyed Susans have deep roots that help the soil absorb more rainfall. These root systems are also hardier than those of non-native species, which help natives survive different climatic conditions.

Why Catch Rainfall?

Pollutants such as fertilizers and pesticides can wash off your yard into storm drains and enter local streams and lakes without receiving any treatment. Holding back stormwater runoff helps prevent water pollution. By reducing the total amount of water that enters local storm systems, rain gardens can also help to reduce the chances for local flooding. Allowing more water to soak into the ground helps replenish our ground water supplies—an investment in our future.

Rain gardens can help make our water cleaner— one yard, and one landscape, at a time.

People in many parts of the country are starting to plant rain gardens in their yards and other locations, such as neighborhood parks.

A newly planted backyard rain garden.

A mature rain garden adds a unique feature to your yard, attracting birds and butterflies as regular visitors. Rain gardens are often described as a "beautiful solution to pollution."

Water should stand in a rain garden no longer than a day or two after the rain stops. Mosquitoes cannot complete their breeding cycle in this length of time, so a rain garden should not increase mosquito populations.

Rain water can be collected from your driveway or lawn by locating a rain garden in a low spot where the water naturally drains.

Minimum of one percent slope to rain garden.

The middle of the rain garden will hold water during a heavy downpour, so that runoff can gradually soak into the ground.

Storm drain and street

Place a rain barrel beneath the downspout on your gutters to collect rainwater from your roof.

Rain water is naturally acidic and doesn't contain chlorine like tap water from municipal water. It's also free from dissolved salts like lime and calcium.

Today's rain barrels are fitted with hoses so you can use the free water to:

- Help your houseplants, like ferns and orchids, thrive
- Water your gardens and planter beds (and your rain garden too!)
- Rinse off gardening tools and outdoor furniture
- Wash cars
- Clean windows
- Keep your compost moist
- Reduce your demand for municipal tap water and save money on your water bill

A rain barrel is generally a 55-gallon drum fitted with PVC couplings and a screen grate to keep debris and insects out.

Only a tenth of an inch of rainfall runoff from the average roof will completely fill the typical barrel. Whether the rain water is collected for use or just emptied after it rains, it decreases the amount of stormwater runoff that leaves your property. Using a rain barrel is one way to decrease your household's impact on local waterways and to become a good steward of the local watershed.

Figure 4.2.1 Brochure sent to eligible homeowners.

REVERSE AUCTION FORM - MT. AIRY RAIN CATCHERS

FUNDED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY WITH ASSISTANCE FROM CONTRACTOR TETRA TECH EM, INC.

A few weeks ago, we sent a form to bid on a rain barrel and/or rain garden to Mt. Airy residents. We have received many bids, but have also heard that some residents had questions about the process, so we have extended the deadline on bidding.

If you did not respond last time because you are not interested, we understand and thank you for your time: please disregard this second mailing. But, if you didn't respond because you had a question or thought your property wouldn't be eligible (all properties in the area will be considered and would provide environmental benefits) we are glad to give you this second opportunity.

To bid, please complete this form and send it back to us in the enclosed envelope by May 9th. If you have any questions at all, please contact Mike at 241-0149 or Michael.valerius@ttemi.com. There is more information at www.mtairyraincatchers.org.

EPA and Tetra Tech will select winners of the auction based on the amount of the bid (lower bids are more likely to be accepted) and the potential environmental benefits based on where you live. If you are selected, you will receive the rain catcher(s) for free plus a one-time payment equal to your bid amount.

Bid amount for rain garden (amount you will receive if selected):

- ☐ $0
- ☐ $50
- ☐ $100
- ☐ $150
- ☐ $250
- ☐ other amount ____________

Bid amount for rain barrels (amount you will receive if selected):

- ☐ $0
- ☐ $50
- ☐ $100
- ☐ $150
- ☐ $250
- ☐ other amount ____________

Number of barrels requested ☐

Name: ____

Address: ____

____

Phone: Email:

Preferred contact method (email, regular mail, phone):______________________________

Please send us your comments on this process, even if you do not bid:

____

____

Figure 4.2.2 Auction bid form included in second mailing.

The back of the form had map of the parcel, house, driveway, etc. and asked the homeowner to indicate their preferred rain garden location.

In addition to the information mailed to homeowners, a demonstration rain barrel and two rain gardens were installed in Fall 2006 at the Mt. Airy Arboretum, a public park area within the Shepherd Creek watershed. The rain gardens had signage explaining the project and the stormwater management practices (Figure 4.2.3).

A.

C.

B.

Figure 4.2.3 Pictures of demonstration rain barrel (A), rain garden (B), and signage (C).

4.3 Methods for assessing auction bids

To rank auction bids for stormwater management practices, we considered each eligible parcel's total impervious area, rooftop connectivity to sewer pipes, the predominant soil type, and distance from a stream based on GIS data. Our scoring procedure weighted bids from a procurement auction with the above-listed environmental criteria to systematically place rain gardens and rain barrels in the watershed. Individual auction bids were assessed for their relative acceptability based on the cost of installation (C), the bid price (B), and the environmental benefit index (EBI). Bids for rain gardens and rain barrels were evaluated and ranked separately. For the purposes of ranking bids, C was assumed to be uniform across properties, and was estimated to be $1500 for each rain garden and $250 for each rain barrel, such that:

$$\text{(i)} \qquad C_{garden} = \$1500$$

$$\text{(ii)} \qquad C_{barrel} = \$250 \times \#\ \text{barrels}$$

The overall rank (R) for rain gardens and rain barrels is designed to give weight to the bid price, in order to appropriately reward lower bids, which is reflected in B/EBI. Equally important is the actual cost of installing the rain gardens and rain barrels, and this is reflected in C/EBI. Importantly, the potential environmental benefits are included in both portions. In order to give equal weight to the two calculations, they are normalized by the maximum value across all bids, and further scaled from 1-100. The equation for ranking, which is to be calculated separately for rain gardens and rain barrels, is as follows:

$$R = (((B \div EBI) \div \text{Max}(B \div EBI)) + ((C \div EBI) \div \text{Max}(C \div EBI))) \times 50 \qquad \text{(iii)}$$

Environmental valuation provides a basis for assessing the potential environmental benefits resulting from stormwater management practice installation. The variable set was developed based on the potential beneficial environmental impact on the receiving stream. In addition, all variables can be evaluated using Geographic Information System (GIS) software and do not require individual site visits, which would constitute a major undertaking. The environmental values were determined from sum of likewise weighted and property-specific characteristics, which are detailed below for rain gardens and rain barrels.

Beyond these objective criteria, there was also potential for bid refusal based on the location of the stormwater management practice on the property. Because the goal of the project is to mitigate stormwater runoff *within* the Shepherd Creek watershed, any barrel or garden that would be located such that it benefits areas outside of Shepherd Creek was not accepted. This was the case for the few bids from households on the watershed's border. For the rain barrels, this can largely be determined on GIS (i.e., if the rooftop is outside of the watershed, the bid will be refused). However, if there are roof downspouts inside and outside the watershed, then bids were only be accepted if the homeowner agreed to put the barrel on a downspout inside the watershed (determined during field visits). For the rain gardens, the homeowners indicated their preferred location on the bid form; however, the precise location was based on field evaluations and discussions with the homeowner. If the field crew determined that the garden would have no benefit or minimal benefit for the watershed, for example if the house's back yard sloped into the adjacent watershed, the bid was refused.

Environmental Benefits Index (EBI)

The scoring process was designed to be a simple, informative, and repeatable technique for quantifying the potential environmental value of placing stormwater management practices on the property. This allows for objective comparison of landowner bids based on the potential environmental benefits and utilizes available GIS information. Variables were scored for each property, with high numbers indicating a preferred condition. The rationale and scoring for each variable is detailed below.

Rain Gardens

The environmental value of rain gardens was based on the amount of stormwater runoff potentially infiltrated and the proximity of property to a stream channel. Potential infiltration of runoff was determined using percent total impervious area (TIA) on the parcel and soil drainage characteristics. Environmental value for rain garden installation will be maximized where: there is high % TIA on the parcel, soils have comparatively low capacity for drainage, and the property is in close proximity to stream channels. Scoring criteria for each variable are detailed in the next section. The following formula was used to create a linear combination of variable scores for the environmental weighting. TIA is expected to be twice as important for influencing runoff quantity (and hence, environmental valuation) compared to the other two variables, and is likewise reflected in the coefficient.

$$EBI_{garden} = 2(\text{TIA score}) + (\text{Soil score}) + (\text{Proximity score}) \qquad \text{(iv)}$$

Calculation of scores:

1) Percent total impervious area

Total impervious area (TIA) is the area of land that is covered by rooftops, driveways, sidewalks, pools, or other surfaces that do not allow for water to infiltrate into the ground. Parcels with a high percent of total area as TIA received higher scores because these areas presently have the least opportunity for infiltration, and would therefore benefit the most from rain gardens. Parcel-level TIA was available as GIS layers of rooftops, driveways, and sidewalks which were digitized from 2001 aerial photography (specifically, ortho-rectified images), and updated with recent site-specific surveys (*ca.* 50% of the properties).

Variable Description: TIA	**Score**
>30% parcel area as TIA	4
15-30% parcel area as TIA	3
5-15% parcel area as TIA	2
<5% parcel area as TIA	1

2) Soil drainage characteristics

Soil series differ in terms of capacity to infiltrate precipitation and surface runoff. Therefore, the dominant soil series on the parcel was used to estimate the existing capacity for drainage for a given parcel. For parcels in this watershed the dominant soil types are Switzerland silt loam, which has moderate drainage characteristics; and Eden silty clay loam, which has relatively poor drainage characteristics. Where the soils have been modified due to urban disturbance (UELC = urban Eden land complex; USLC = urban Switzerland land complex), they are assumed to have slightly less infiltrative capacity compared to the undisturbed soils, and are scored accordingly. Parcels where the dominant soils have poorer drainage characteristics were given preference for receiving a rain garden because these properties are likely to generate a greater amount of surface runoff, and would likely benefit the most from having a rain garden. A detailed soil survey map created by the Natural Resource Conservation Service was used to determine the dominant soil series for a given parcel. Scoring was as follows:

Variable Description: Soils	**Score**
Dominant soil type has low infiltration capacity (UELC)	4
Dominant soil type has med-low infiltration capacity (Eden)	3
Dominant soil type has med-high infiltration capacity (USLC)	2
Dominant soil type has high infiltration capacity (Switzerland)	1

3) Proximity to stream channel

The proximity of a parcel to a stream channel is inversely proportional to the area of land available to act as a buffer for upstream developed land. The closer the parcel is to the stream channel, the fewer opportunities for infiltration of runoff, and therefore an increased potential for runoff contributing to peak flows in the stream channel. Properties that are closer to the stream would be expected to benefit the most from a rain garden acting to intercept and infiltrate surface runoff. The stream network determined from 2 ft. Digital elevation maps (DEMs) was used to calculate the distance between the centroid of the parcel and the stream channel following the flow path. Scoring proximity was as follows:

Variable Description: Proximity	**Score**
Centroid of parcel <50 m from stream channel	4
Centroid of parcel 50-100 m from stream channel	3
Centroid of parcel 100-150 m from stream channel	2
Centroid of parcel >150 m stream channel	1

Rain Barrels

The environmental value of rain barrels was based on the potential amount of water that would otherwise be lost to direct connection or conveyance to storm sewers. Environmental value will be maximized where 1) higher numbers of barrels were requested, and 2) the roof gutter downspouts were wholly or in-part connected to storm sewers. The environmental weighting of rain barrels are therefore calculated accordingly:

$$EBI_{barrel} = \# \text{ barrels} \times \text{Rooftop connectivity score} \qquad \text{(v)}$$

The proportion of rooftop area that is directly connected to storm sewer pipes reflects the potential for precipitation to be stored in rain barrels rather than contributing directly to peak flows in streams. Thus, properties with higher connectivity of rooftops to storm sewers received higher scores, because runoff from these areas are currently routed directly into streams and could benefit the most from storage in rain barrels. Rooftop connectivity was determined using a combination of local storm sewer pipe information, a rooftop data layer digitized from 2001 ortho-rectified aerial photography, and site-specific surveys of roof gutter downspouts (*ca.* 50% of properties surveyed and 50% estimated from neighboring lots). Rooftop connectivity was scored as follows:

Variable Description: Rooftop connectivity	**Score**
75-100% connectivity of rooftops to storm sewers	4
50-75% connectivity of rooftops to storm sewers	3
25-50% connectivity of rooftops to storm sewers	2
0-25% connectivity of rooftops to storm sewers	1

CHAPTER 5 Auction Results

5.1 Phase 1, Year 2007

Of the ~350 eligible homeowners, we received 57 bids for rain gardens and 61 bids for a total of 121 rain barrels (Table 5.1.1). Most homeowners bid for both rain gardens and rain barrels (47), although there were some bids for just gardens (10) and some for just barrels (16; Figure 5.1.1). Bids ranged from $0 to $500, with a mean bid of $50.27 for a rain garden and $32.06 for a rain barrel. Interestingly, a majority of bids were $0, indicating the willingness of homeowners to receive stormwater management practices for free without any additional compensation (Table 5.1.1).

Table 5.1.1 Summary of bids for rain gardens and rain barrels in 2007 and 2008

	2007	2008	Total	% Change
Rain gardens				
Number of bids	57	37	94	-21.3
Minimum bid	$0.00	$0.00	$0.00	0.0
Maximum bid	$500.00	$1,000.00	$1,000.00	50.0
Mean bid	$58.16	$88.54	$70.12	43.3
Mean bid excluding max	$50.27	$63.22	$60.12	21.5
Number of $0 bids	30	16	46	-30.4
Percent $0 bids	52.6	43.2	48.9	-19.2
Rain barrels				
Number of bids	63	45	106	-17.0
Average number of barrels per bid	1.9	1.7	1.8	-11.5
Minimum bid (per barrel)	$0.00	$0.00	$0.00	0.0
Maximum bid (per barrel)	$500.00	$250.00	$500.00	-50.0
Mean bid (per barrel)	$32.06	$44.30	$36.44	33.6
Mean bid excluding max (per barrel)	$24.51	$34.74	$32.03	31.9
Number of $0 bids	38	20	58	-31.0
Percent $0 bids	60.3	44.4	54.7	-29.0

Because the sum of all bids did not exceed the amount of money allocated for subsidies and installations, we accepted nearly all of the bids. Two barrel bids were refused because the roofs were located outside the Shepherd Creek watershed, and one barrel bid was refused due to the high bid amount ($500 for 1 barrel) relative to other bidders and the cost of installation. All but one rain garden bid were initially accepted, again excluding the extremely high bid ($500) relative to other bids. Bidders were relatively evenly distributed throughout the treatment area (Figure 5.1.1).

Table 5.1.2 Rain barrel rankings, 2007

Rank	Barrel Bid ($)	# Barrels	Weighted Score	Accept?	Rank	Barrel Bid ($)	# Barrels	Weighted Score	Accept?
1	0	4	3	yes	33	0	1	13	yes
2	100	4	4	yes	34	0	1	13	yes
3	0	3	4	yes	35	0	1	13	yes
4	0	4	4	yes	36	0	1	13	yes
5	0	3	4	yes	37	0	1	13	yes
6	0	3	4	yes	38	0	1	13	yes
7	0	4	4	yes	39	0	1	13	yes
8	50	3	5	yes	40	5	1	13	yes
9	0	3	6	yes	41	27	1	13	yes
10	0	2	6	yes	42	50	1	14	yes
11	0	2	6	yes	43	50	1	14	yes
12	0	2	6	yes	44	50	1	14	yes
13	0	2	6	yes	45	100	1	15	yes
14	0	4	6	yes	46	100	1	15	yes
15	0	2	6	yes	47	0	1	17	yes
16	0	2	6	yes	48	0	3	17	yes
17	0	2	6	yes	49	0	1	17	yes
18	0	2	6	yes	50	50	1	18	yes
19	0	2	6	yes	51	250	4	19	yes
20	0	2	6	yes	52	100	3	20	yes
21	0	2	6	yes	53	0	2	25	yes
22	50	2	7	yes	54	0	2	25	yes
23	100	2	8	yes	55	0	2	25	yes
24	100	2	8	yes	56	0	2	25	yes
25	100	2	8	yes	57	100	2	30	yes
26	100	2	8	yes	58	150	2	33	yes
27	150	2	8	yes	59	0	1	50	yes
28	0	2	8	yes	60	0	1	50	yes
29	250	2	9	yes	n/a	500	1	100	no
30	500	2	13	yes	n/a	100	1	n/a	no
31	0	1	13	yes	n/a	50	1	n/a	no
32	0	1	13	yes					
Number of barrel bids accepted				60					
Total number of barrels				118					
Total cost (bid amount)				$2,532					

Table 5.1.3 Rain garden rankings, 2007

Rank	Garden Bid ($)	Weighted Score	Accept?	Rank	Garden Bid ($)	Weighted Score	Accept?
1	0	25	yes	30	0	36	yes
2	0	25	yes	31	0	36	yes
3	0	25	yes	32	0	36	yes
4	5	25	yes	33	5	37	yes
5	0	27	yes	34	50	38	yes
6	25	28	yes	35	100	39	yes
7	0	29	yes	36	100	39	yes
8	0	29	yes	37	0	40	yes
9	0	29	yes	38	0	40	yes
10	0	29	yes	39	0	40	yes
11	0	29	yes	40	0	40	yes
12	50	30	yes	41	150	42	yes
13	30	31	yes	42	50	45	yes
14	0	31	yes	43	100	46	yes
15	0	31	yes	44	250	46	yes
16	0	31	yes	45	250	46	yes
17	0	31	yes	46	250	46	yes
18	0	31	yes	47	250	46	yes
19	50	32	yes	48	100	50	yes
20	100	33	yes	49	100	50	yes
21	0	33	yes	50	50	50	yes
22	0	33	yes	51	50	50	yes
23	0	33	yes	52	0	50	yes
24	0	33	yes	53	0	50	yes
25	50	35	yes	54	100	56	yes
26	50	35	yes	55	250	59	yes
27	0	36	yes	56	250	59	yes
28	0	36	yes	n/a	500	90	no
29	0	36	yes				
Number of garden bids accepted				56			
Total cost (bid amount)				$2,815			

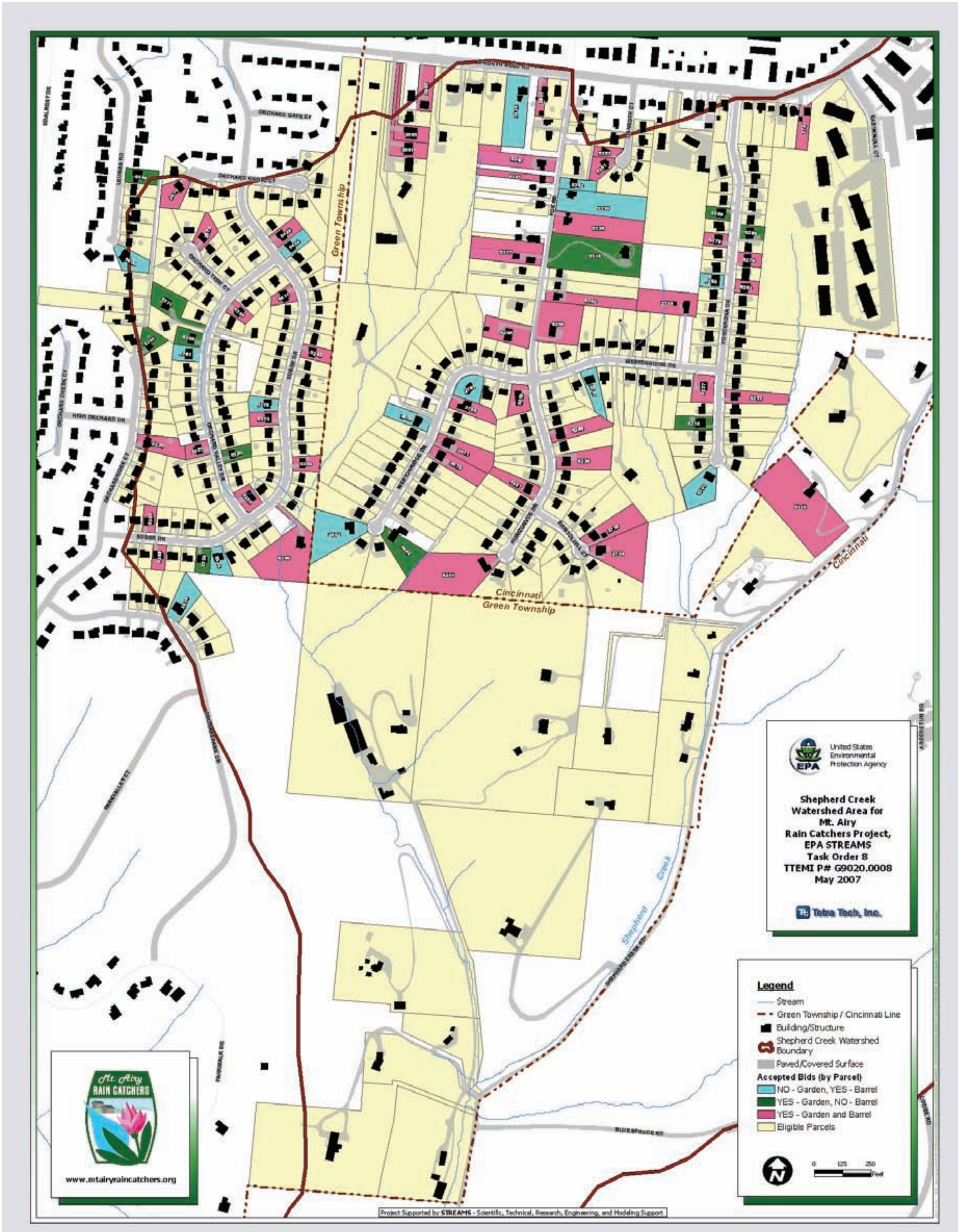

Figure 5.1.1 Location of rain barrel and rain garden bids in Phase 1, 2007

5.2 Phase 2, Year 2008

When the auction was repeated in spring 2008, there were 37 bids for rain gardens averaging $88.54, 43% higher than in 2007 (Table 5.1.1). The high bid was $1000 and the percent $0 bids dropped to 43.2%. For barrels, there were 45 bids for 76 barrels, averaging $44.30 per barrel, a 33% increase from 2007 bids. Thirteen homeowners who bid in 2007 also bid in 2008, reflecting their pleasure with the stormwater management practices received the previous year and/or their continued interest in this project. Two garden bids and one barrel bid were refused due to their high weighted score relative to other bidders, reflecting the high bid price and/or low environmental benefit of the stormwater management practice on that property (Table 5.2.1, 5.2.2). Again, bidders were located throughout the treatment portion of the watershed, although there were clusters of bidders that may reflect influences from neighbors (Figure 5.2.1).

Table 5.2.1 Rain garden rankings, 2008

Rank	Garden Bid ($)	Weighted Score	Accept?	Rank	Garden Bid ($)	Weighted Score	Accept?
1	0	19	yes	20	100	29	yes
2	0	20	yes	21	0	30	yes
3	0	20	yes	22	0	30	yes
4	0	20	yes	23	0	30	yes
5	50	20	yes	24	0	30	yes
6	0	21	yes	25	250	30	yes
7	50	22	yes	26	150	31	yes
8	25	22	yes	27	100	32	yes
9	0	23	yes	28	50	33	yes
10	0	23	yes	29	250	33	yes
11	0	23	yes	30	100	35	yes
12	0	23	yes	31	150	38	yes
13	100	23	yes	32	1	38	yes
14	150	23	yes	33	50	41	yes
15	50	25	yes	34	50	41	yes
16	0	25	yes	35	100	44	yes
17	0	25	yes	n/a	250	71	no
18	250	27	yes	n/a	1000	80	no
19	0	27	yes				
Number of garden bids accepted			35				
Total cost (bid amount)			$2,026				

Table 5.2.2 Rain barrel rankings, 2008

Rank	Barrel Bid ($)	# Barrels	Weighted Score	Accept?	Rank	Barrel Bid ($)	# Barrels	Weighted Score	Accept?
1	0	4	13	yes	24	50	1	17	yes
2	0	4	13	yes	25	0	1	17	yes
3	0	3	13	yes	26	0	1	17	yes
4	0	3	13	yes	27	150	2	19	yes
5	0	2	13	yes	28	50	2	19	yes
6	0	2	13	yes	29	25	1	20	yes
7	0	2	13	yes	30	100	1	21	yes
8	0	2	13	yes	31	150	1	25	yes
9	0	2	13	yes	32	150	1	25	yes
10	0	2	13	yes	33	150	1	25	yes
11	0	1	13	yes	34	0	2	25	yes
12	0	1	13	yes	35	1	1	25	yes
13	0	1	13	yes	36	200	1	29	yes
14	0	1	13	yes	37	250	1	33	yes
15	50	3	14	yes	38	250	1	33	yes
16	50	2	15	yes	39	0	4	50	yes
17	50	2	15	yes	40	0	2	50	yes
18	50	2	15	yes	41	0	1	50	yes
19	25	1	15	yes	42	1	1	51	yes
20	50	1	17	yes	43	100	2	67	yes
21	50	1	17	yes	44	100	2	67	yes
22	50	1	17	yes	n/a	300	2	100	no
23	50	1	17	yes					
Number of barrel bids accepted				44					
Total number of barrels				74					
Total cost (bid amount)				$2,152					

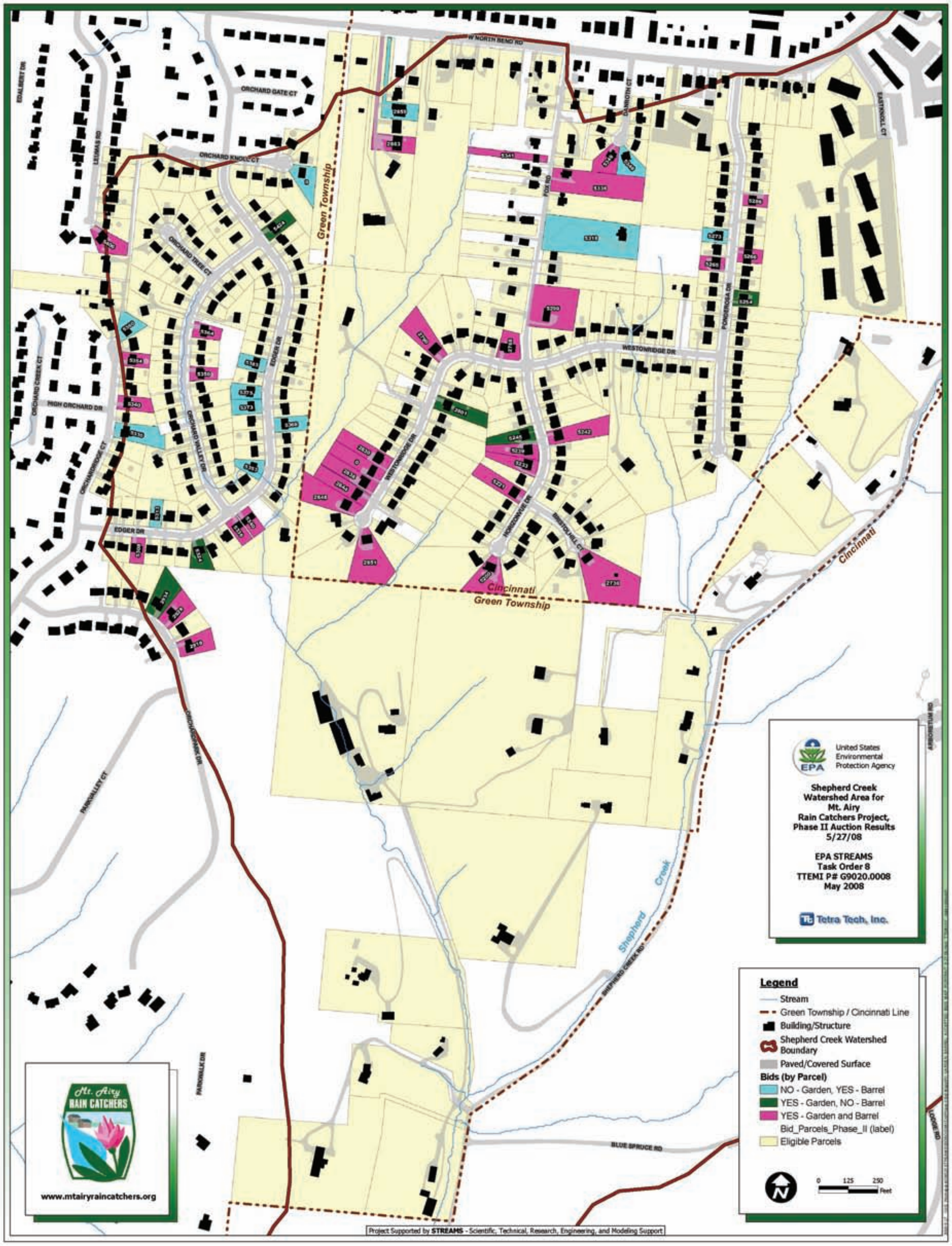

Figure 5.2.1 Location of rain barrel and rain garden bids in Phase 2, 2008

CHAPTER 6 Stormwater Management Practice Installations

6.1 Overview

We installed rain barrels and rain gardens on those properties identified through the auction and granted subsequent permission by the homeowner. Soon after the bidding process we contacted the homeowners by mail and informed them they had been selected to participate, and scheduled a site visit. Upon visiting the site for the first time the homeowner was asked to sign an access agreement that gave consent to the "Mt. Airy Rain Catchers Project Team" to access their yard to install and maintain the rain barrels and rain gardens. The agreement specified the term of three years for the maintenance period. Both the property owner and a representative of the Project Team signed the agreement. Also in the first site visit the homeowner was handed a check in the amount of his or her bid. In 2007, we installed 50 gardens and 100 barrels. The lower number of installations relative to accepted bids was due to not finding an acceptable location for the stormwater management practice on the property (e.g., preferred garden location above utility or lacked hydrologic benefit) and homeowners changing their mind upon consultation (e.g., did not want their gutter downspouts cut). In 2008, we installed 25 gardens and 50 barrels. An explanation of the installation guidelines and maintenance protocol for rain gardens and rain barrels follows.

6.2 Rain gardens

Installation protocol

We worked with individual homeowners to determine location and design (i.e., shape) of the rain garden stormwater management practice. Rain gardens were approximately 150 sq. ft., although the final shape depended on the landscape and property features of each individual parcel. Using our index of ecological effectiveness we worked with individual homeowners to determine an optimal location and design for the rain garden, to maximize hydrological benefit while being suitable for the homeowner. If the homeowner indicated a location on the auction bid form, we flagged the location of the garden on the lawn and work with the homeowner to determine shape and design. If the homeowner indicated that they were flexible, we worked with the homeowner to determine the best location. We maintained the qualification that if we and the homeowner could not reach agreement about placement of the rain garden, either party could terminate the process of installing the rain garden.

Rain gardens were installed between June and September. First, the sod was removed and a Dingo excavator was used to excavate a trench for installing a perforated underdrain pipe at the bottom of the trench. Most rain gardens were fitted with underdrains and outlets to allow for free-drainage of water to prevent the incidence of standing water for any extended period of time (Appendix A, Garden A). If landscape slope was insufficient to place an underdrain, the rain garden was instead made slightly larger (160 ± 10% sq. ft.) and 6" deeper (Appendix A, Garden B). In 2007, a majority of the rain gardens (34 of 50) were fitted with underdrains. Rain gardens were developed from native soils, but amended with coarse peat moss and sand and supplemented with organic fertilizer. In 2008, we amended the soils with peat moss and native compost (aged 3 years), since we felt that the proportion of sand was so low that they were unlikely to increase infiltration. Exposed soil on the berm was seeded and covered in straw held in place with netting.

Due to drought conditions that persisted into September 2007, the gardens were planted in the fall that year so as to maximize plant survival. The planting area was covered with mulch to retain moisture and reduce weeds. Plants were primarily native species and cultivars that are adapted to periodic wet conditions expected in the rain gardens (Figure 6.1.1). Homeowners were given some choice in plants, and were asked to water the gardens periodically in the 1-2 weeks following planting. In spring 2008 we conducted a plant inventory to determine plant success. In the second year, we used larger plant starts (8-10" pots) and planted species that were most successful in 2008. Additional species that were expected to be more resistant to deer browsing were also used. Figure 6.2.1 overviews the numbers of species planted while figure 6.2.2 presents a typical raingarden in the study area.

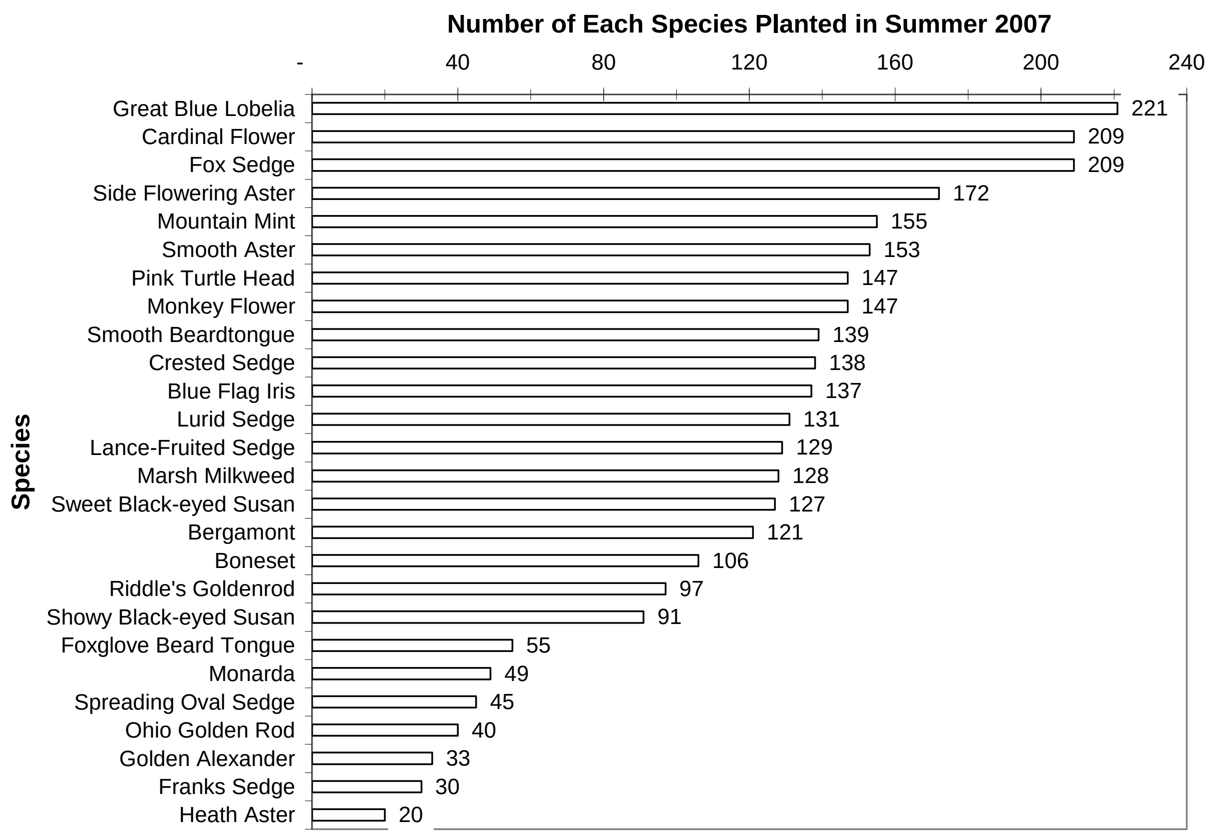

Figure 6.2.1 Species in plant communities planted in rain gardens, 2007.

Figure 6.2.2 Typical rain garden installation

Maintenance protocol

We took on responsibility for maintenance of rain gardens over the research project period of three years from the date of construction. Regular maintenance was implemented into the project plan so as to sustain good performance and improve consistency in rain garden condition over the course of the research project. This includes assuring that the rain gardens are draining properly and plants remain in good conditions for the duration of the pilot study. Maintenance involves mulching and re-planting (as necessary) in the spring, weeding in the summer, and mulching and pruning in the fall. Homeowners also received a manual that explained our maintenance plan and asked homeowners not to add plants, fertilize, or otherwise disturb the garden.

6.3 Rain barrels

Protocol for installation

The location of rain barrel(s) was determined by the amount of rooftop draining into a gutter downspout, the current drainage location of the gutter, and preferences of the homeowner. Ideally, rain barrels were located where a large portion of the roof runoff will be collected, and where runoff currently drains to stormwater conveyances. However, rain barrels connected to any downspout were deemed to be acceptable.

We used green, 75-gallon rain barrels which were fitted with a spigot and hose located near the bottom of the barrel that allowed the barrels to be emptied in accordance with procedures set out in the owners manual. The barrels also have an internal overflow tube that is routed to another external opening at the bottom of the barrel. A screened cap was placed on top of the barrel to prevent debris from entering the barrel and prevent insects from breeding in the barrel. Roof gutter downspouts were cut and fitted with a flexible pipe to route the water to the barrel. Barrels were placed on cinder blocks and overflow tubes were routed into storm drains or landscape areas away from the house. Up to four barrels could be linked together on a single downspout to allow for increased detention capacity. Although the standard-issue rain barrel in the Mt. Airy project was 75 gallons, 23% of barrels issued to homeowners in 2007 were 55 gallons due to shortfall in supplier inventory. See Appendix B for schematic representations of the rain barrels and their typical setting for installation.

Maintenance protocol

As a part of the licensing agreement, the homeowner agreed to take responsibility for maintenance of the rain barrels (e.g., emptying the barrel after a rainfall event). Homeowners were instructed on how to empty their barrels and given a manual that explained recommended maintenance. If a homeowner did not plan to use the water in their barrel, we recommended that the overflow and spigot hoses empty into the rain garden (if applicable) or other landscape feature that is designed to infiltrate water (e.g., a swale). Homeowners were advised to empty their barrels in the winter to prevent freezing and cracking of the barrels.

CHAPTER 7 Rain Garden and Rain Barrel Monitoring

7.1 Overview

In cooperation with individual homeowners, we identified a subset of rain gardens to monitor for a period of three years from the date of construction. This monitoring will be conducted for a period of three years, and includes hydrology, soil, and water quality measurements. Five rain gardens are being monitored from the 2007 installations and an additional 5 gardens will be selected in 2008 to represent a range in soil types, landscape settings and drainage types (garden types A and B). Rain barrels are also monitored for water level and water quality.

7.2 Hydrology and soils

At each location, we are monitoring rain gardens for infiltration and water redistribution. We are measuring soil water content by averaging measurements taken every 30 seconds and recorded as a datum point every 10 minutes and at 10-cm intervals to 50-cm (Sentek EasyAG; Campbell Scientific; Logan UT), and this data is stored using an automatic logging system (Campbell CR800). Underdrains are evaluated qualitatively for evidence of flow (trickle flow after storms, build up of algae at outlet, erosion around outlet). Rain barrels are monitored continuously for water level using level loggers (In-Situ; Fort Collins CO) in order to determine patterns in the times and rates of water use by residents and number of overflow events. The level loggers are removed each winter (November-March) as rain barrels will be left open and freezing would damage the level logger pressure sensors.

7.3 Water quality

Monitoring for water quality will consist of episodic, storm-event based sampling of surface runoff to rain gardens, soil water sampling using suction lysimeters installed at a depth of 12 to 18 inches in rain gardens, and underdrain flow sampling (where applicable; one rain garden site does not have an underdrain). Stainless steel suction lysimeters (SW-071 single chamber; Soil Measurement Systems, LLC) were installed in finished rain gardens during the months of April and May 2008 according to ASTM standard specifications (ASTM International 1992). Water quality sampling will also include periodic sampling of water collected in rain barrels at the chosen site locations.

For rain garden and rain barrel performance monitoring, the results from sampling will be aggregated for data analysis purposes in order to determine: 1) the chemical composition of roof runoff as captured in rain barrels; 2) the chemical composition of lawn runoff to rain gardens on a seasonal basis; and 3) the treatment provided by rain gardens with respect to changes in nutrient concentrations (nitrogen and phosphorus), organic carbon, alkalinity, ions and metals. Lawn runoff samples also will be analyzed for suspended sediment concentration. Treatment will be determined by comparing soil water (lysimeter) and underdrain concentrations directly with lawn runoff and rain barrel samples using paired sample analysis of variance methods

(Dietz and Clausen 2006, Davis 2007). Sampling frequency will consist of 2 storm events per season for a total of 8 events per year. The minimum acceptable number is 6 storm events, given the element of chance and practical problems associated with storm sampling. For purposes of replication, the goal will be to collect 3 samples of each type (lawn runoff, soil water from lysimeters, and underdrain discharge) at each site for each storm event. This yields a minimum of 18 samples of each type per site each year, where applicable. Only a single sample will be collected from the rain barrel at the end of the storm event, for a total of 6 to 8 samples per year. In the event that the replicate samples for a given storm exhibit temporal trends, they will be treated as independent samples.

CHAPTER 8 Conclusions

This study is a part of an ongoing effort to fully describe a realistic market-based mechanism to alleviate the water quality and ecological problems caused by the typically large volumes of excess stormwater runoff in urban and urbanizing areas. As impervious surface grows relative to natural landscapes the problem will increase, and municipal authorities will look for ways to deal with it that are both practical from a political standpoint and ecologically effective. We hypothesized that deployment of stormwater management practices in a watershed via market incentives would reduce stormwater runoff substantially, thus improving stream water quality and biotic integrity. To test this hypothesis, we examined four market mechanisms: command and control, cap and trade, fee and rebate, and auction. We modeled each policy using realistic cost functions, including the estimated opportunity cost of residential land dedicated to particular stormwater control practices, and we employed sound hydrologic models. In most cases we showed the incentive schemes to be economically efficient. When considering actual application of the market mechanism to a small Midwestern watershed, there were several legal and regulatory obstacles to the imposition of a cap on stormwater runoff (for a tradable credit mechanism) and the appropriately high stormwater fee (to allow for a fee and rebate policy). Thus, we opted for a wholly voluntary approach using a reverse auction.

We are now testing our hypothesis that deployment of enough distributed, low-tech stormwater management practices in a watershed will reduce stormwater runoff sufficiently to effect positive hydrologic, water quality, and ecological change. We are doing this with actual installation of stormwater management practices in the Shepherd Creek watershed. We employed a before-after-control-impact experimental design, wherein we monitor streams for three years before installing the stormwater management practices in the treatment watersheds, and then continue monitoring for an additional three years. We employed a reverse auction to determine where to install the management practices in a cost effective way. The reverse, or procurement, auction is often used when there are many potential sellers of an item (in this case, homeowners selling the limited use of their property) and a single buyer (in this case, a government agency trying to buy as much stormwater retention capacity as economically feasible). To try to improve the subscription rate among homeowners and to test our hypotheses about iterative auctions, we conducted the auction and installation two years in a row. In 2007, we installed 50 rain gardens and 100 rain barrels at 68 properties for a total bid payout of $5,347. In 2008, we received acceptable bids for 35 rain gardens and 74 rain barrels on 49 properties, including 12 properties that received some stormwater management practice(s) in 2007. After two years of running the auction, we will have installed stormwater management practices on about 30% of the eligible properties in the treatment watershed. Future research includes the ongoing monitoring effort wherein we will quantify the hydrologic and ecological effectiveness of the installed storm water management practices. Overall, this methodology will provide defensible results about the efficiency, both economic and ecologic, of deploying rain gardens and rain barrels in a suburban watershed in order to reduce the effects of stormwater runoff.

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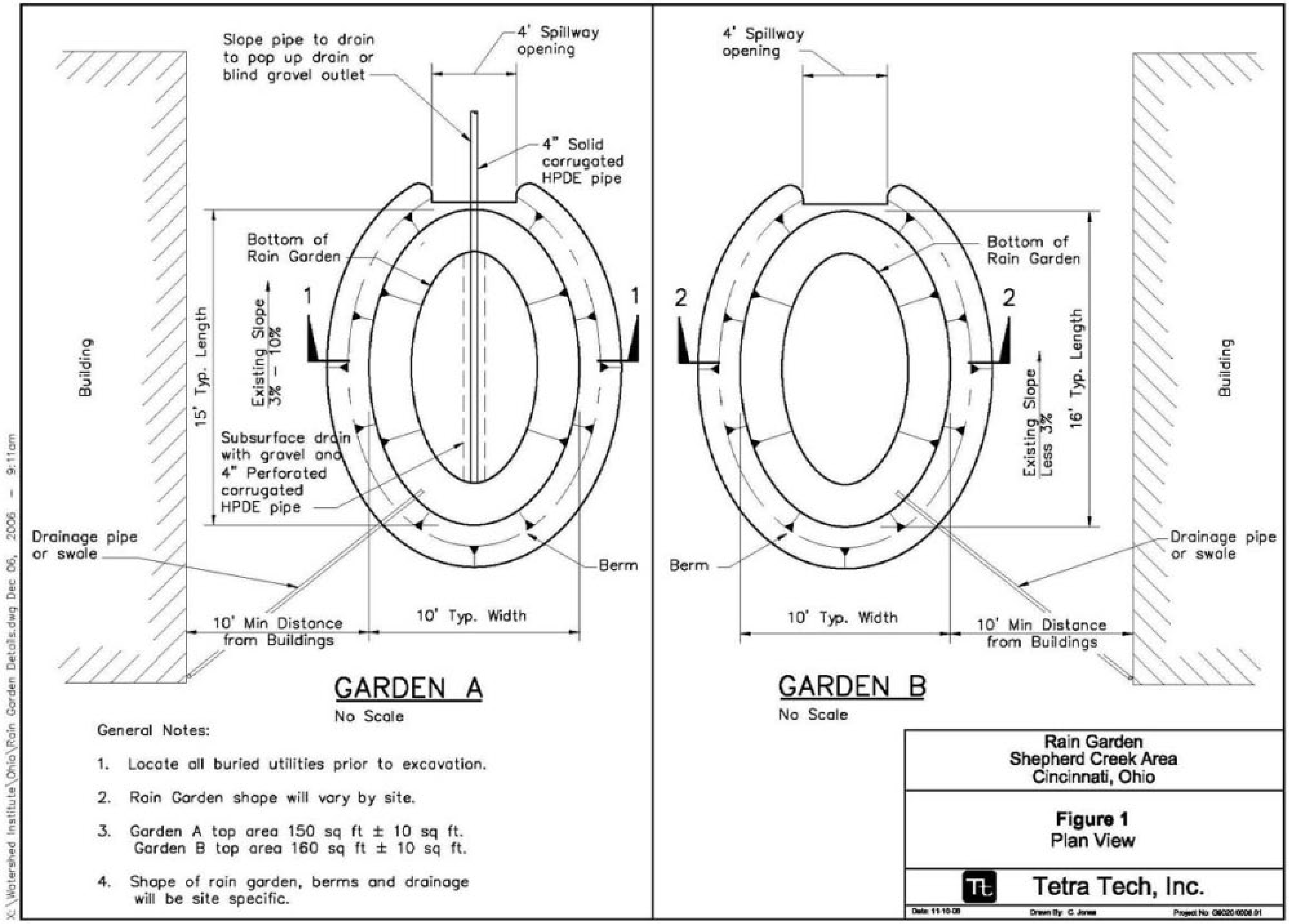
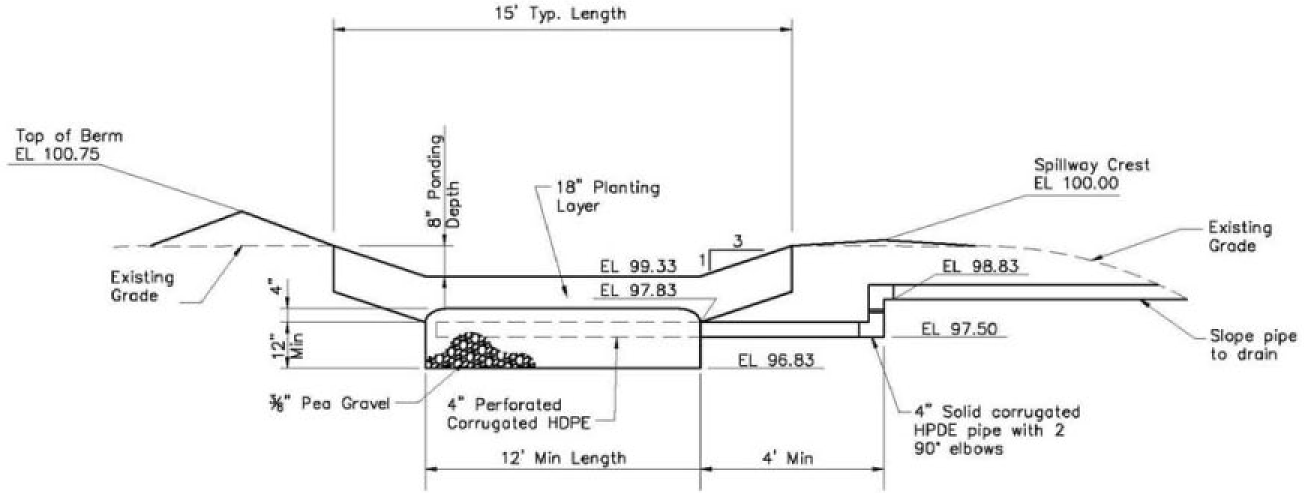
APPENDIX A: Rain Garden Schematics


X:\Watershed Institute\Ohio\Rain Garden Details.dwg Dec 06, 2006 - 9:11am
Slope pipe to drain to pop up drain or blind gravel outlet
4' Spillway opening
4" Solid corrugated HPDE pipe
Bottom of Rain Garden
Existing Slope 3% - 10%
15' Typ. Length
1
1
Building
Subsurface drain with gravel and 4" Perforated corrugated HPDE pipe
Drainage pipe or swale
Berm
10' Min Distance from Buildings
10' Typ. Width
GARDEN A
No Scale
4' Spillway opening
Bottom of Rain Garden
2
2
Existing Slope Less 3%
16' Typ. Length
Building
Drainage pipe or swale
Berm
10' Typ. Width
10' Min Distance from Buildings
GARDEN B
No Scale
General Notes:
1. Locate all buried utilities prior to excavation.
2. Rain Garden shape will vary by site.
3. Garden A top area 150 sq ft ± 10 sq ft. Garden B top area 160 sq ft ± 10 sq ft.
4. Shape of rain garden, berms and drainage will be site specific.
Rain Garden
Shepherd Creek Area
Cincinnati, Ohio
Figure 1
Plan View
Tetra Tech, Inc.



Note:
Elevations shown are not actual elevations, but show relative location only.

GARDEN A PROFILE

No Scale

Rain Garden
Shepherd Creek Area
Cincinnati, Ohio

Figure 4
Profile

Tetra Tech, Inc.

Date: 11/09/06 Drawn By: C. Jones Project No: G0020.0008.001

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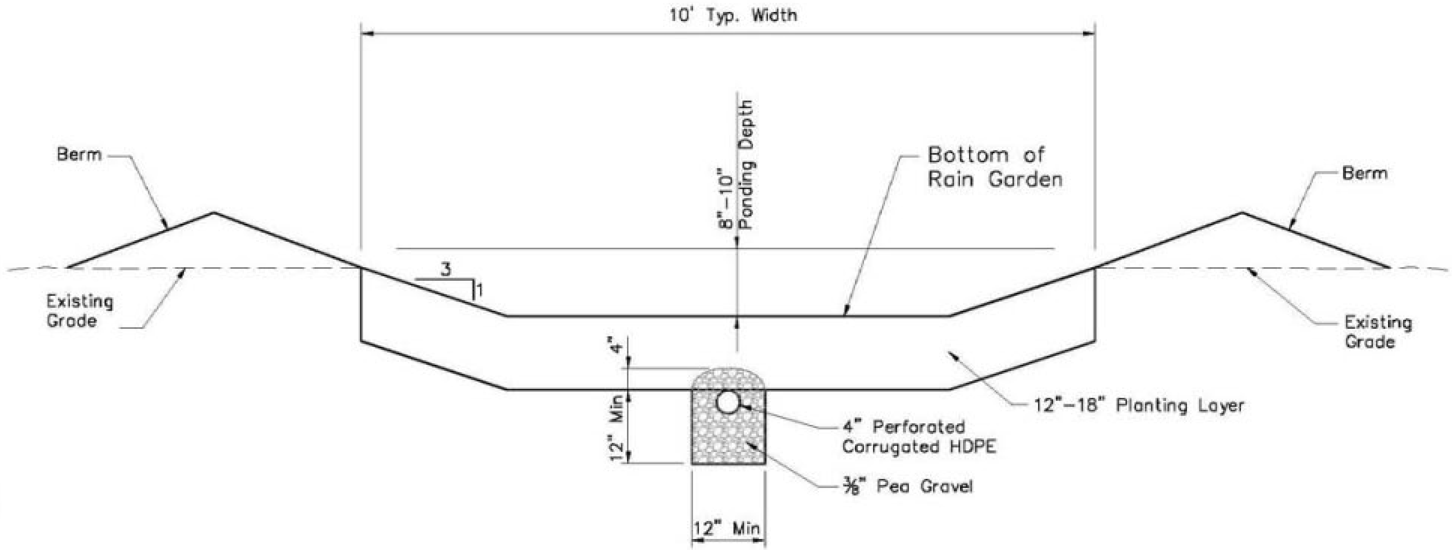

GARDEN A CROSS SECTION 1–1

No Scale

Note:

1. Planting layer to be mechanically tilled.
2. Planting layer may incorporate sand, compost and other amendments to improve permeabilty.
3. Do not compact berm soil material.
4. Existing sod can be removed, stored and replaced on berm area.
5. Use excavated material to construct berm.

Rain Garden
Shepherd Creek Area
Cincinnati, Ohio

Figure 2
Cross Section

Tetra Tech, Inc.

Date: [illegible] Drawn By: C. Jones Project No: [illegible]

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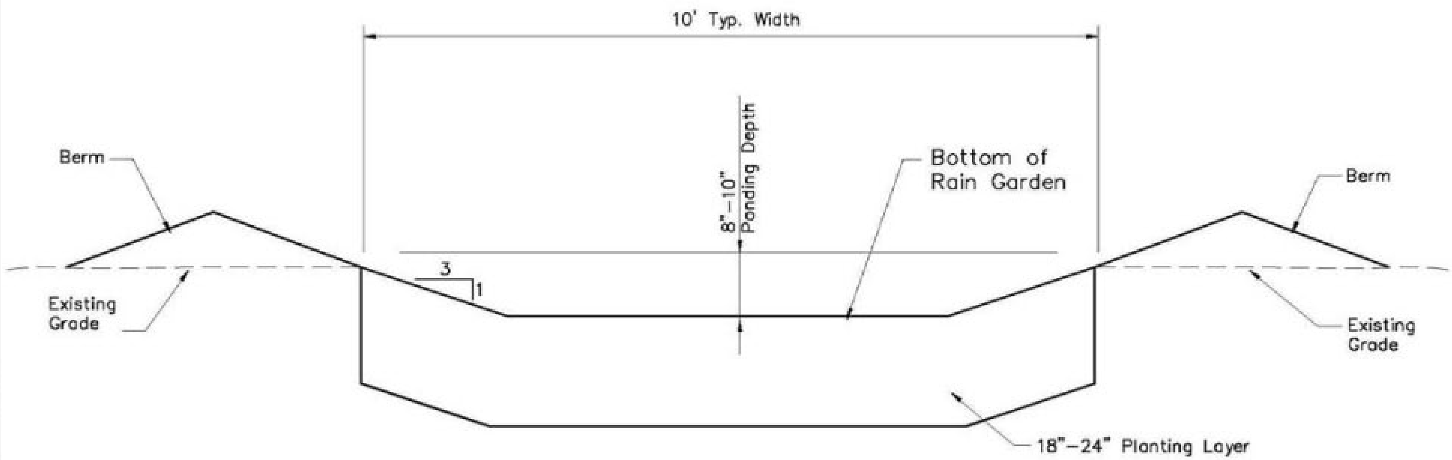

GARDEN B CROSS SECTION 2–2

No Scale

Note:

1. Planting layer to be mechanically tilled.
2. Planting layer may incorporate sand, compost and other amendments to improve permeabilty.
3. Do not compact berm soil material.
4. Existing sod can be removed, stored and replaced on berm area.
5. Use excavated material to construct berm.

Rain Garden
Shepherd Creek Area
Cincinnati, Ohio

Figure 3
Cross Section

Tetra Tech, Inc.

Date: 11/08/06 Drawn By: C. Jones Project No: [illegible]

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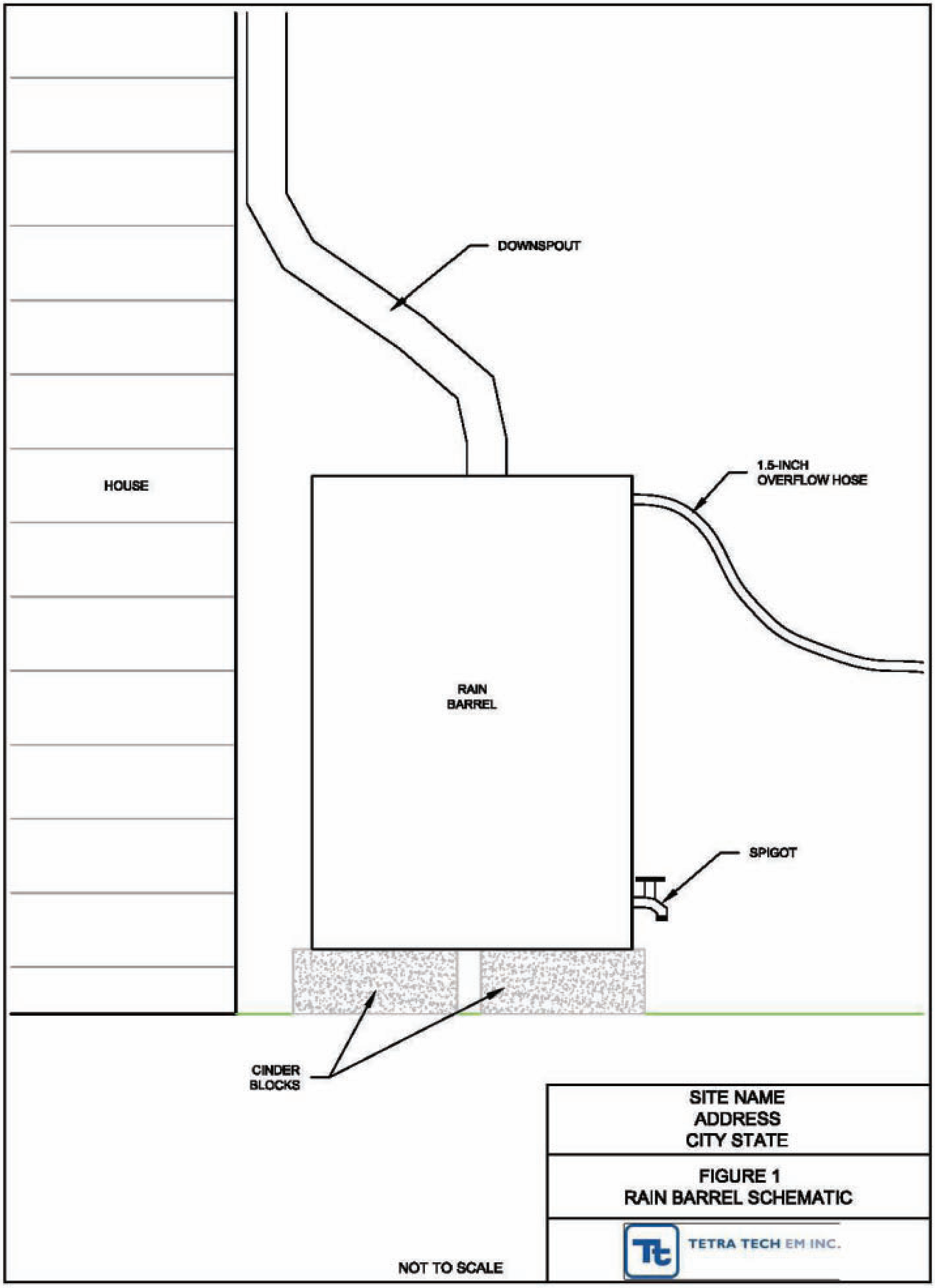
APPENDIX B: Rain Barrel Schematic



APPENDIX C: Quality Management Program

1.0 Purpose

The intent of this appendix is to better illustrate the sampling processes for hydrologic, ecological, and water quality monitoring efforts, and describe important changes that have been implemented since the project's inception. This document will be updated periodically to document, amend, and otherwise record changes and progress in this monitoring effort.

2.0 Problem definition/Background

Successful ecosystem management of watersheds requires the integration of the ecological, economic, and social influences that collectively determine the sustainability of human communities. Additional impervious surface as a consequence of urbanization has altered the partitioning of stormwater into runoff, infiltration, interflow, stream flow, and groundwater recharge. These urbanized conditions increase the risk of downstream flooding, stream channel degradation, and damage to both aquatic and terrestrial ecosystems.

Although off-site detention and retention are used to mitigate the hydrologic impacts of urbanization, the large areas needed for these best management practices (BMPs) are considered by many to be impractical. BMPs based solely on economic decisions typically lead to inadequate BMP capacity; while BMPs may improve the stormwater retention and water quality on the site in which they are located, there are no data to suggest that BMPs effectively improve the ecological integrity of either the streams directly downstream, nor the integrity of the overall watershed.

An alternate approach to stormwater runoff management addresses runoff production at smaller scales, and involves reduction of impervious surface and increased temporary storage of runoff at the parcel level, or on-lot measures. The idea of limiting excess runoff at the parcel level is relatively new, and capitalizes on converting impervious surfaces to at least partially pervious surface, as well as capturing modest runoff volumes in economical parcel-level facilities. The implementation of this approach to storm water management has not been tested, nor has a path to implementation been outlined. There is a critical need to determine whether the type and storage capacity of typical on-lot BMPs, as chosen using economic constraints, are adequate to restore or protect ecosystems.

3.0 Project organization

The Shepherd Creek Monitoring Project is primarily supported by the Office of Research and Development, National Risk Management Laboratory, Sustainable Technology Division, Sustainable Environments Branch with Dr. William Shuster serving as the primary point person for the monitoring. Ongoing monitoring includes hydrology, water quality, and ecology, with Dr. William Shuster, Dr. Matthew Morrison, and Dr. Allison Roy as the primary leads associated with each portion, respectively. Other divisions within NRMRL, contractors, and inter-agency agreements (IAG) with other federal organizations also support this project. The impervious survey was a one-time survey to further characterize directly connected impervious areas in the Shepherd Creek watershed and assist in predicting stream responses to BMPs.

4.0 Project description

4.1 Overview

The purpose of this study is to investigate the potential for stakeholder participation in an on-lot stormwater management program. Field monitoring is used to determine whether such a program is effective insofar as the improvement of hydrologic (including sediment dynamics), ecologic, and water quality conditions of downstream subcatchments. In this project, the effectiveness of BMPs under realistic field conditions will be measured.

4.3 Experimental design

This study has a before/after and control/impact (BACI) experimental design. This approach is popular in watershed work, as it attempts to control for the high levels of variance that are common to experiments conducted at large-scales. Due to this experimental approach, we will be unable to avoid a certain level of pseudoreplication, as errors will not be independent between the before and after treatment time periods (since consequences that lead to fluctuations accumulate over time). We will be collecting at 6 different sites (3 of which should be relatively independent as they are disconnected hydrologically from each other) for at least one year before and two years after BMP implementation (Table 4.1). Two of the sampling sites will not have BMPs installed within their respective sub-watersheds, and therefore serve as controls. Because this project will not be replicated in other watersheds, interpretation of our results will be somewhat restricted to the results and conclusions drawn from the Shepherd Creek and similar environmental settings.

Table 4.1. Sample sites, type (control/treatment), and initiation of monitoring by category.

Site	Type	Hydrology	Water Quality	Ecology
REF1	Control	Fall 2004	Baseflow, Spring 2004	Spring 2003
PWR2	Treatment	Fall 2004	Baseflow, Spring 2004 Stormflow, Summer 2005	Spring 2003
DRI3	Treatment	Fall 2004	Baseflow, Spring 2004 Stormflow, Summer 2005	Spring 2003
ROA4	Treatment	Fall 2004	Baseflow, Spring 2004 Stormflow, Summer 2005	Spring 2003
CON5	Treatment	Fall 2004	Baseflow, Spring 2004 Stormflow, Summer 2005	Spring 2003
URB6	Control	Summer 2005	Baseflow, Spring 2005 Stormflow, Summer 2005	Spring 2005
REF7	Control (to replace REF1)	Fall 2004	Baseflow, Summer 2005 Stormflow, Summer 2005	Summer 2005
N1	Treatment	Spring 2006	N/A	N/A
N2	Treatment	Spring 2006	N/A	N/A
N3	Treatment	Spring 2006	N/A	N/A

4.4 Sampling procedure

Details regarding the sampling approach for hydrology, water quality, and ecology can be found in the respective supporting QAPPs and SOPs. Briefly, hydrology is sampled continuously (5 min. intervals) for stage and discharge, and one rain gauge (at ROA4) services the entire watershed. Channel cross sections, bed sediment, and bank soils will be assessed at one time before and 3 years after BMP implementation. Water quality is sampled monthly during baseflow conditions (grab sample), and opportunistically during stormflow conditions (automated ISCO sampler). Periphyton and macroinvertebrates are sampled 5 times per year (every 4-6 weeks from April to October) during baseflow conditions. Macroinvertebrates are also sampled seasonally using a quantitative, bucket sampler. During all ecological sampling periods, physical characteristics, water quality parameters (YSI), and habitat characteristics (visual assessment) are measured. A summary of the sampling is in Table 4.2.

Table 4.2. Summary of sampling approach, type, and sampling resolution.

Instrument/Sample	**Data collected**	**Data resolution**	**Output/Indices**
Hydrology			
Stream stage and discharge via control structures (i.e., weir or culvert)	Stream stage and discharge	5 minute	Rating curve, stream discharge record, event hydrographs
Tipping-bucket raingauge located at ROA site	Rainfall intensity, cumulative amount	Continuous logging, truncated to 5minute intervals	Rainfall intensity, duration, and amount
Geomorphic assessment	Cross-section surveys, bankfull and water surface longitudinal survey, bank soil collection, Wolman pebble count	Baseline survey done Fall 2004, repeat post-BMP implementation in 2009 or 2010	D50 (pebble count), particle size distribution
Water Quality			
YSI 6600 data sonde	Temperature, ORP, conductivity, pH, dissolved oxygen, turbidity	Monthly baseflow sampling, opportunistic stormflow sampling, and with ecology sampling	Water quality parameters
Grab (baseflow) and automated ISCO (stormflow) water quality samples	Nutrients, anions, metals	Monthly baseflow sampling, opportunistic stormflow sampling	Chemical concentrations
Sediment	suspended and bed-load sediment	Monthly baseflow sampling, opportunistic stormflow sampling	Sediment flux, weight and particle size distribution
Ecology			
Periphyton (2 50ml jars)	1 jar: taxonomic ID 1 jar: biomass	5 times per year (every 4-6 weeks April-October)	Multimetric indices, % orders, ordination

Periphyton (1 glass fiber filter)	Chlorophyll α	5 times per year (every 4-6 weeks April-October)	Multimetric indices, % orders, ordination
Benthic macroinvertebrates (1 L jar)	Taxonomic ID, abundance and richness	5 times per year (every 4-6 weeks April-October); seasonal bucket samples	Multimetric indices, tolerance indices, ordination
Physical characterization and habitat visual assessment	Ranking of physical attributes of sampling sites	5 times per year (every 4-6 weeks April-October); seasonally with macroinvertebrates	Qualitative Habitat Evaluation Index (QHEI)

5.0 Project changes and additions

Since the inception of the Shepherd Creek monitoring project in 2003, various aspects of the monitoring have changed. Below is a chronological listing of the major changes and additions to the project, including the creation of supporting documents:

1. *September 2005.* The baseline monitoring period was extended until spring 2007 (originally spring 2006), after which BMPs will be implemented.
2. *January 2005.* An additional control site (URB6) was established; the weir for hydrological monitoring was installed in May 2005.
3. *May 2005.* Water quality assessment expanded to include monthly baseflow and opportunistic stormwater samplings (previously only during ecological sampling), and additional analytes (e.g., metals).
4. *May 2005.* An additional reach downstream of REF1 site was established (called REF7) due to dry upstream conditions at REF1. Because REF7 is the location of hydrologic monitoring, all stormflow water quality sampling will take place at REF7.
5. *June 2005.* A survey of directly-connected impervious areas (DCIA) in the Shepherd Creek watershed was initiated in conjunction with USEPA summer interns.
6. *January 2006.* A Health and Safety Plan for field and laboratory was created for work conducted under this QMP.
7. *April 2006.* Implementation of three additional hydrologic monitoring sites at neighborhood stormwater outfalls to increase the spatial resolution of runoff and drainage monitoring.
8. *November 2007.* Install equipment in 5 rain gardens to monitor soil water content and soil water quality (suction lysimetry).

6.0 Quality objectives and criteria for measurement data

The investigators followed appropriate, established protocols so that data conforms to commonly accepted and reasonable standards of accuracy and resolution. The standards are detailed in the family of supporting QAPP and SOPs related to this project.

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