Testing Mitigation of Urban Stream Hydrology and Ecology by Disconnecting Impervious Areas: A Pilot Study

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Watershed Management

Introduction

Impervious surfaces in urban and suburban areas can lead to excess runoff throughout a watershed, overwhelming the existing stormwater infrastructure, which typically results in widespread hydrologic and ecological alteration of receiving streams. Decentralized stormwater management (e.g., infiltrating runoff at sources and disconnecting stormwater pipes) may improve stream ecosystems by reducing erosional stormflows, increasing stream baseflows, and reducing delivery of pollutants to streams. We will conduct a pilot study of an economic incentive program, which encourages on-site detention of stormwater runoff by residential landowners. This study will determine whether parcel-level best management practices (BMPs), in the form of rain gardens and rain barrels, can be cost-effectively implemented throughout the headwater areas to reduce hydrologic alteration and improve stream ecosystem health.

Objectives

- Evaluate whether economic incentive-based policies can result in a least-cost approach to stormwater management
- Quantify the relationship between on-lot runoff storage capacity, stream hydrology, and stream geomorphology
- Assess changes in ecological integrity as a result of any hydrologic improvements realized from BMP implementation

Multidisciplinary Issues

By nature, stormwater management is an issue of multidisciplinary relevance. A combination of legal, socioeconomic, and ecologic/hydrologic constraints must be addressed for effective management; however, a multidisciplinary approach is complicated by competing disciplinary goals and objectives.

• *Legal Issues*: While stormwater quality is regulated in the US by the Clean Water Act (CWA, 33 U.S.C. §1342(a)), stormwater quantity is not, and few communities have instituted taxes or mitigation strategies to prevent watershed deterioration due to hydrologic changes. Without a legal limit on quantity to force compliance, the kinds of economic incentives that can be used to address stormwater quantity are limited.

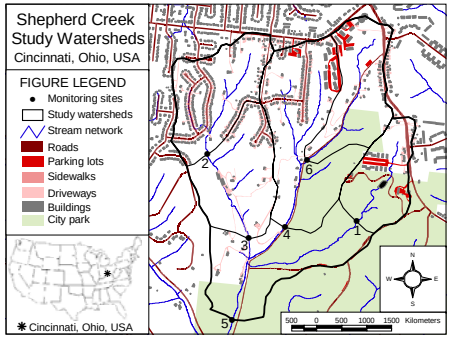

Picture taken at confluence of sites 3 and 4 during a storm.

• *Ecological/Hydrologic Issues*: Stream ecosystems are affected by impacts within the entire upstream catchment, so management and restoration must address disturbances throughout the watershed, not just those in or along streams. However, many watersheds cross jurisdictional boundaries and rely on numerous municipalities, which must work together to implement stormwater management that will successfully meet ecological requirements.

• *Economic Issues:* Used to distribute site-level BMPs, a watershed-scale market-based incentive system can lower the cost of decentralized stormwater detention when used to supplement or replace a centralized management system. However, the lack of a water quantity provision in the CWA prevents a local stormwater authority from establishing a stormwater runoff limit (or "cap") to be used in a cap-and-trade type policy instrument directed at runoff.

Study Design

The study setting is the Shepherd Creek watershed, a 20 km^2 basin in Cincinnati, OH (USA) with a 1960s-1980s era residential community occupying its headwaters. A city park, dominated by mature deciduous forest, occupies the eastern half of the watershed (see map).




Streams are instrumented with flow controls and velocity-depth sensors.

The project uses a before-after control-impact site design, where the "impact" is the installation of parcel-level BMPs. We have established six hydrologic and ecological monitoring sites in the watershed, four of which are receiving streams for the BMP installation area (sites 2-5). Sites 1 and 6 are control watersheds that will not receive BMPs.

Qualitative comparisons among stream depth time series for two spring storm events with comparable durations demonstrate "flashy" stormflow dynamics, especially in sites 3 and 4 (below).

Site No.	Rise rate log (in min^{-1})	Time to peak (min)	Peak:base depth ratio
1	0.04	70	1.41
2	0.08	85	1.50
3	0.11	35	2.50
4	0.11	50	2.02

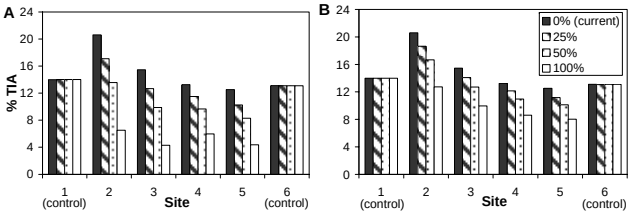
Baseline stream data from sites 1-5 in 2003 demonstrate that the Shepherd Creek watershed and its tributaries are highly impaired and could benefit from mitigation.

Site No.	NO_2+NO_3 (mg·l^{-1})	TDP (mg·l^{-1})	Chlorophyll *a* (mg·m^{-2})	% Blue-green algae	Bacteria (CFU 100 ml^{-1}) Fecal coliform	*E. coli*	Macroinvertebrates EPT richness	FBI
1	0.76	0.103	3.6	75.3	10500	1413	2.4	6.9
2	1.16	0.095	14.4	63.3	19547	4593	1.6	5.8
3	0.74	0.326	5.1	77.2	27800	5113	2.2	6.6
4	0.62	0.160	9.8	74.7	14167	4733	2.4	7.1
5	0.48	0.172	7.8	72.6	16447	1773	3.8	6.4

The table below shows total impervious area (TIA) as rooftops, driveways, sidewalks, parking lots, and roads as classified by hand from 2001 digital orthophotos.

Site No.	Impervious (% of basin area) Roof	Drive	Sidewalk	Parking	Road	Total	Impervious (% of total impervious) Roof	Drive	Sidewalk	Parking	Road
1	2.3	1.3	0.5	5.2	4.7	14.0	16.7	9.5	3.5	37.3	34.8
2	7.9	6.2	1.3	0.0	5.2	20.6	39.9	30.1	6.5	0.0	26.1
3	5.5	5.7	0.9	0.0	3.4	15.5	36.7	36.7	5.7	0.0	22.7
4	4.0	2.6	0.5	2.7	3.3	13.3	30.1	19.9	4.1	20.7	25.2
5	3.8	3.3	0.5	1.6	3.4	12.5	30.2	26.2	4.3	12.7	27.0
6	2.7	2.7	0.5	2.9	4.3	13.1	20.4	20.5	3.7	22.2	32.5

The figure below shows % TIA given various landowner acceptance rates of A) rain gardens & rain barrels, and B) rain barrels only. Projections assume BMPs will effectively eliminate TIA in rooftops and driveways for rain barrels and rain gardens, respectively.



Economic Auction

BMPs will be distributed via a voluntary economic auction, encouraging property owners to control runoff without necessitating a legal mandate. Specifications of the auction include:

- landowners bid on free BMP plus some payoff
- no penalty for not accepting BMPs
- subsidy will vary by landowner (i.e., run as discriminative price auction)
- bids will be sealed (i.e., private)

Bids will reflect landowner's willingness-to-accept BMPs based on 1) construction and maintenance costs (included), 2) opportunity cost of land taken out of other uses, and 3) non-market values residents place on positive changes in stream ecosystem health.

The figure at right shows a typical screen for auction software. The program allows parcel owners to express preference and capacity for BMP cost share.

Management Implications

Parcel-level BMPs may provide a cost effective and socially acceptable alternative to traditional centralized stormwater management projects. This site-specific pilot study will provide base levels of understanding of potential costs and benefits of decentralized stormwater management, including:

- price homeowners are willing to accept in compensation for BMPs on their property
- overall cost of BMPs per amount of stormwater mitigated (compared to centralized alternatives)
- differences in homeowner bids based on socio-economic backgrounds
- degree of stream hydrologic response for amount of runoff mitigated
- ecological responses (water quality, biotic integrity, etc.) to hydrologic improvements

Ultimately, this project will serve as a test to whether a multidisciplinary approach to retrofit stormwater management can successfully restore urban streams.