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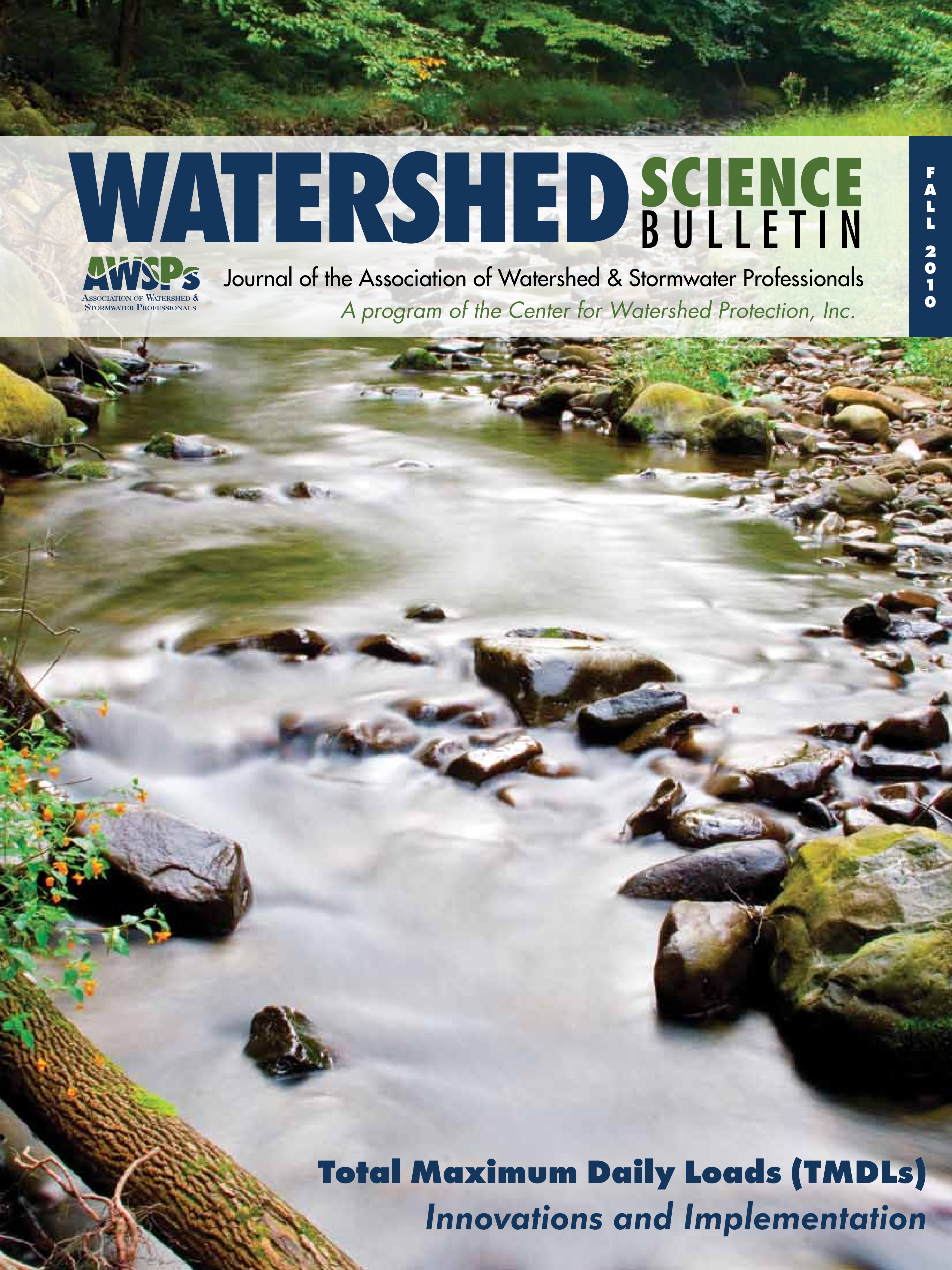
WATERSHED SCIENCE BULLETIN

AWSPs
Association of Watershed & Stormwater Professionals

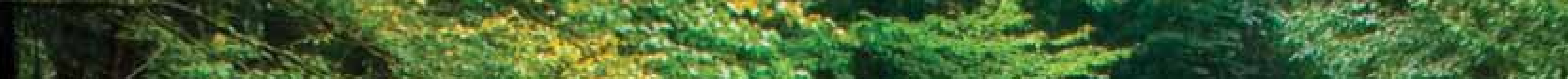
Journal of the Association of Watershed & Stormwater Professionals

A program of the Center for Watershed Protection, Inc.



Total Maximum Daily Loads (TMDLs)

Innovations and Implementation



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This photo was taken along Pocono Creek in Monroe County, PA, near Camelback Mountain. Like many streams in Pennsylvania, it is dominated by a forested watershed and provides critical habitat for trout populations. Some tributaries in the Pocono Creek watershed qualify for the highest level of water quality protection under Pennsylvania regulations. Population growth and the resulting urbanization and hydrologic changes are a threat to the health of the watershed.

Responding to the First Impervious Cover–based TMDL in the Nation

Chester L. Arnold,[a] Christopher J. Bellucci,[b] Kelly Collins,[c] and Rich Claytor[d]*

Abstract

In 2007, the Connecticut Department of Environmental Protection promulgated the first total maximum daily load (TMDL) in the country based on impervious cover. This TMDL, developed as a way to deal with streams impaired by poorly understood urbanization-related impacts, is for Eagleville Brook, a small watershed that drains much of the University of Connecticut campus. What is an *impervious cover TMDL*? This article reviews the status and findings of an ongoing project designed to devise an effective and pragmatic response to this new approach. Using the language in the TMDL itself as a starting point, the project team focused on impervious cover disconnection and the related goal of reducing stormwater runoff volume. However, the "bottom line" of improving biota-based indicators of stream health will also require approaches beyond what would result from a strict focus on impervious cover. Based on geospatial data analysis followed by extensive field work, the project team has identified 51 retrofit opportunities, including a "Top Ten" list that attempts to maximize both the environmental and social or educational impacts of the response. Although the watershed plan has not yet been written, considerable progress has been made on campus, including the replacement of conventional parking lots with pervious materials and changes to plans for upcoming construction. The team's preliminary conclusion is that combining the simple framework of impervious cover with the force and accounting rigor of a TMDL can be an effective way to catalyze communities to plan and implement actions to remediate stormwater problems.

Introduction

Watershed professionals have long recognized that impervious cover is a useful indicator of the impact of watershed land use on the health of the receiving water body (Schueler 2003; Brabec et al. 2002). This relationship integrates a complex web of impacts resulting from urbanization. As an indicator, impervious cover has the potential to be widely applied to various land use planning and design scenarios (Arnold and Gibbons 1996)—an approach that has earned both praise and criticism for its simplicity. The total maximum daily load (TMDL) program mandated by the Clean Water Act, on the other hand, can be said to take quite the opposite approach. It is very site-specific and can be implemented with confidence only when scientific understanding of a particular water body and the fate and transport of specific pollutants within that system is sufficiently comprehensive. This approach, too, has both fans and detractors.

Can these two approaches be wedded successfully? The ongoing Eagleville Brook Impervious Cover TMDL Project, a partnership of the Connecticut Department of Environmental Protection (CTDEP), the University of Connecticut, and the Town of Mansfield, aims to answer this question. This article summarizes the project's progress to date, focusing on project approach and methods rather than technical results.

The Genesis of the Impervious Cover TMDL

Connecticut is an urbanizing state. During the 21-year period from 1985 to 2006, the state added approximately 616 km^2 of land comprising the *development footprint*, as determined by remote sensing land cover data. This represents almost 5% of the entire area of the state (Center for Land Use Education and Research [CLEAR], University of Connecticut n.d.). As might be expected, urbanization is a major cause of water quality impairment in the state. Of the 105 impaired stream segments listed by CTDEP in 2006 as *not meeting water quality standards*, CTDEP attributed this status to urbanization for at least 58%; for another 40%, the agency attributed it to unknown causes (Bellucci 2007).

Under Section 303(d) of the federal Clean Water Act, Connecticut is required to develop TMDLs for these 105 stream segments. But as a practical matter, how does one apply the data-intensive TMDL program to so many water bodies, most of which are suffering from what has been called *urban stream syndrome*, a complex and synergistic combination of hydrologic alteration and multiple pollutant stressors (Walsh et al. 2005)? As Bellucci (2007) notes:

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Developing TMDLs for "urbanization" presents an enormous challenge for Connecticut because of the number of impairments and the complicated nature of urban stream syndrome … Often, there is insufficient information that indicates any specific pollutant is causing or contributing to an exceedance of a particular water quality criterion. Rather, given the variability in types and concentrations of pollutants associated with stormwater, and the range in magnitude of storm events, a surrogate approach that aggregates the effects of multiple stressor syndrome is perhaps a more appropriate measure of impact.

To investigate this hypothesis, in 2005–2006, CTDEP conducted statewide research comparing stream health, as indicated by metrics for benthic macroinvertebrate populations, to watershed impervious cover estimates provided by CLEAR models based on 30-m remotely sensed data (Chabaeva et al. 2007). A total of 125 stream segments were studied, and the results were compelling, if widely in keeping with the literature on the impacts of impervious cover: no stream with over 12% impervious cover in its immediate upstream catchment area met the state's aquatic life criteria for a healthy stream (Bellucci 2007; Figure 1).

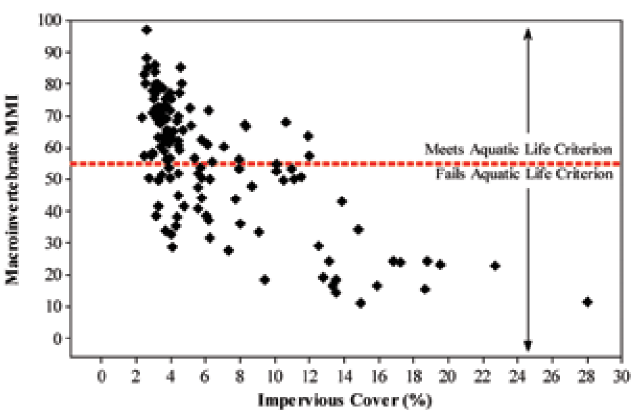

Figure 1. Scatter plot of the percentage of total impervious cover and macroinvertebrate multimetric index (MMI) for 125 stream monitoring locations in Connecticut. The MMI score is the average score of seven metrics and ranges from 0 to 100, with higher values representing the least stressed sites. Sites that plot above the horizontal line meet Connecticut's water quality criterion to support aquatic life.

Based on this result, and the need for a pragmatic regulatory response to urban stream syndrome in the face of insufficient local data, CTDEP developed the nation's first impervious cover TMDL for the Eagleville Brook watershed in Mansfield, Connecticut. The US Environmental Protection Agency approved this TMDL in 2007.

Eagleville Brook is typical of urban stream syndrome—it is included on the 2006 list of Connecticut waterbodies not meeting water quality standards (CTDEP, 2006) based on very low aquatic life use support scores, the causes of which are cited as "unknown." The brook has a 6.2-km^2 drainage area and is tributary to an impoundment of the Willimantic River, a tributary of the Thames River basin, which encompasses much of the eastern third of the state (Figure 2). The Eagleville watershed drains a large portion of the University of Connecticut (hereafter, "the University"), and for long stretches in the upper part of the watershed the brook is piped underground beneath the campus. The watershed surficial material is predominantly glacial till. Rainfall in the region is typical of the state, which has a long-term average of about 114 cm per year, distributed fairly evenly throughout the year (Miller et al. 2002).

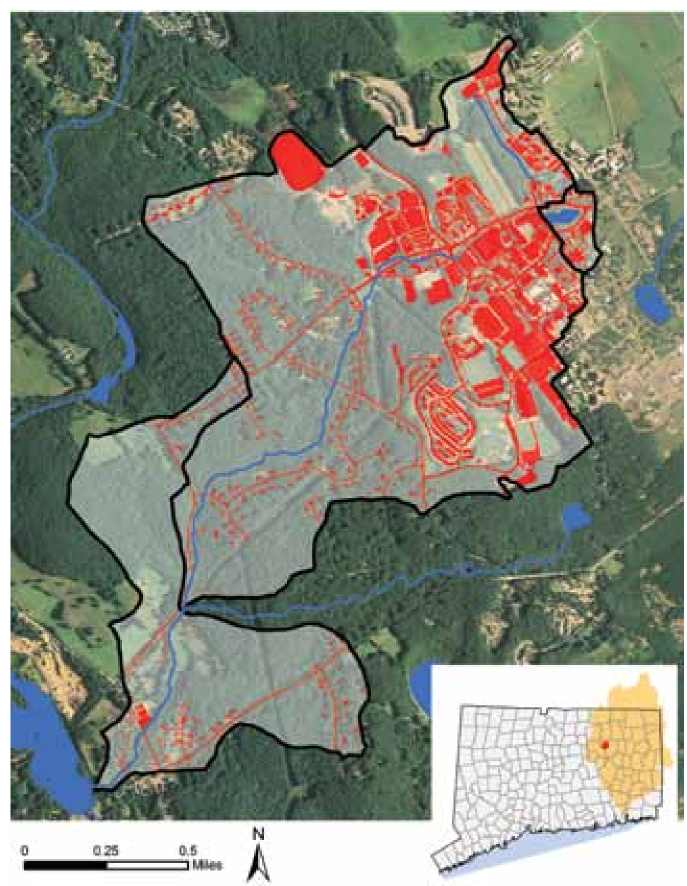

Figure 2. The Eagleville Brook watershed and its location (inset) within the state and within the Thames River major basin. Black lines depict the boundaries of the watershed and subwatersheds, blue lines represent water, and red areas depict impervious cover digitized from 2008 high-resolution imagery, that comprises the map background. The University of Connecticut campus can be seen as the concentration of impervious cover in the upper watershed.

Based on the statewide research, CTDEP set the TMDL target at 12% impervious cover (CTDEP, 2007). Applying a margin of safety factor—and noting that, for this analysis, "it is not feasible to draw a clear distinction between stormwater originating from [National Pollutant Discharge Elimination System (NPDES)]-regulated point sources and non-NPDES regulated sources (point and nonpoint)"—CTDEP (2007, 8) set both the wasteload allocation and the load allocation for this TMDL at 11% impervious cover for the entire basin. Based on the statewide modeling estimates, the three subbasins of the brook varied in impervious coverage from 5% in the lower watershed to 27% in the upper (campus) area (CTDEP 2007).

Interpreting the Impervious Cover TMDL's Bottom Line

Does the impervious cover TMDL constitute a mandate to get out the jackhammers? Not necessarily. The TMDL specifically states that the goal is to have the watershed ecosystem look and act *as if* the watershed were no more than 11% impervious, and it takes pains to remind the regulated community that the bottom line is ultimately not land cover, but stream biology:

> *…[impervious cover] is being used in this TMDL as a surrogate for the impacts that pollutants and other stressors from stormwater have on aquatic life in streams. The goal of the TMDL is to reduce impacts from stormwater on the aquatic life in Eagleville Brook. In the absence of actual [impervious cover] reduction, stormwater management techniques that offset the negative effect of [impervious cover] should be implemented in the Eagleville Brook watershed. Meeting the TMDL will be assessed by measuring the aquatic life directly. Tracking the [impervious cover] elimination/disconnection or equivalent [impervious cover] reduction in the watershed during BMP implementation may be used as an interim measure to assess progress. (CTDEP 2007)*

Thus, the language of the TMDL itself makes clear that this is not a strict acre-by-acre accounting exercise. In fact, we would argue that it lends itself to flexible solutions more readily than does a conventional TMDL. In addition, this approach is in keeping with several strong and emergent themes in watershed management. First, it recognizes the growing consensus that it is *effective* or *connected* impervious cover that should be the focus of remediation efforts, rather than total impervious cover (Booth and Jackson 1997; Brabec 2002). Although the research providing the technical basis for the impervious cover TMDL uses estimates of total impervious cover—the only feasible method given that it was a statewide study—implementation must focus on impervious cover disconnection, and for that, detailed site-level work is necessary. In a recent watershed study, Roy and Shuster (2009) conclude that on-site assessments are necessary to accurately tease apart total impervious cover from directly connected impervious cover, and that parcel-scale field work is needed for the management of suburban and urban watersheds. Our project team's experience corroborates this (see next section).

Second, the impervious cover TMDL can also be seen as taking a *runoff reduction* approach (Hirschman et al. 2008), which places a high degree of emphasis on volume-based hydrologic mitigation as a major method of watershed management (Reese 2009). In Connecticut, the importance of runoff reduction was a key lesson of the Jordan Cove project, a long-term nonpoint source monitoring project comparing runoff quantity and quality before, during, and after construction in paired low-impact development (LID) and conventional watersheds. Notably, that project concluded that the lower pollutant load in the LID watershed, versus that in the conventional watershed, was mainly due to the dramatically lower runoff volume in the LID watershed (Dietz and Clausen 2008).

The Project

Subsequent to the issuance of this unique TMDL, a partnership was formed to determine the overall framework and specific elements of a response. The objectives of this project are twofold: (1) develop a plan for the University and the town to respond to the TMDL and (2) in the process, evaluate the feasibility of the impervious cover TMDL concept and document a general methodology by which others can implement a similar program.

Key elements of the project include: (1) geospatial data gathering and mapping; (2) field work to further refine the mapped information and to identify stormwater retrofit opportunities; and (3) educational and technical assistance to the Town of Mansfield, as well as more general educational efforts intended to help other communities navigate the impervious cover TMDL process. The project team includes the University of Connecticut's CLEAR Nonpoint Education for Municipal Officials Program, the Center for Watershed Protection (CWP), and the Horsley Witten Group.

Data and Mapping

During the winter of 2008–2009, the project team collected all potentially relevant geospatial data. Both the Town of Mansfield and the University have fairly detailed data sets on drainage, roads, and other infrastructure. CLEAR used 2008 high-resolution color imagery to update and correct previously digitized information on impervious cover and its component parts (e.g., roads, rooftops, parking lots, and walkways) on campus, and to digitize impervious cover for the noncampus portion of the watershed (Figure 2). Since the original TMDL estimate was based on a model using 30-m resolution data from 2002,it is not surprising that updated data show an increase in the amount of impervious cover in the watershed (Table 1). In addition, the team used the imagery to update and correct the location of storm drains on campus. The project team used these data not only to refine the original CTDEP estimates of impervious cover, but to formulate preliminary ideas on retrofit opportunities and to help plan the field analysis. All data were placed on an internet geographic information system mapping site, using ArcGISServer® software, to make them easily accessible to the team and, eventually, to the public.

Field Verification and Analysis

In July 2009, the project team conducted a four-day field analysis of the watershed. Field work identified important features that could not be determined from the mapping exercise alone. First, the team identified discrepancies in the original watershed boundary as contained in the state hydrography data layer; the revised watershed boundary was about 0.11 km^2 (26 acres) less than the original. Second, the team estimated that about 0.21 km^2 (51 acres) of the impervious cover in the watershed were effectively disconnected via sheet flow to a large forested area, undetected diversion to another watershed, or through treatment by a recently constructed stormwater practice (Table 1). In addition, although the drain locations had been updated, the data on the location of the pipes themselves were not always up-to-date. In many cases, drainage patterns had been altered multiple times and did not necessarily follow what might be assumed from topography and drain locations.

Table 1. Existing conditions in Eagleville Brook. The original estimates were based on modeling using 2002 land cover data with 30-m resolution.

Eagleville Brook Watershed	Existing Conditions		
	TMDL Estimated	Adjusted and Updated with Imagery[a]	Field-Adjusted[b]
Watershed drainage area, km2 (acres)	4.96 (1,225)	4.96 (1,225)	4.85 (1,199)
Watershed impervious cover, km2 (acres)	0.59 (145)	0.87 (216)	0.67 (165)
Watershed impervious cover , %	11.8	17.6	13.8
11% impervious cover TMDL target, km2 (acres)	0.55 (135)	0.55 (135)	0.53 (132)
Impervious cover to disconnect/manage to reach target, km2 (acres)	0.04 (10)	0.33 (81)	0.13 (33)

[a] The middle column shows additional impervious cover resulting from updates and improvements using 2008 high-resolution satellite imagery. [b] The far right column includes field adjustments that decreased the watershed area by 0.11 km^2, and "removed" 0.21 km^2 of disconnected impervious cover.

Retrofit Opportunities

The project team assessed potential stormwater retrofit opportunities at 51 project sites in the Eagleville Brook watershed, using methods identified by Schueler et al. (2007). Sites were almost entirely located on the University campus, where the dominant fraction of the watershed's impervious cover is found. The Town of Mansfield portion of the watershed is largely rural residential, representing a small amount of the total impervious cover and composed mostly of relatively narrow secondary roads and private rooftops and driveways (see Figure 2). For the town section of the watershed, the focus will be on future development rather than retrofits, emphasizing proactive LID approaches and changes to road standards and maintenance.

The 51 retrofit opportunities include a variety of stormwater management practices, including rain gardens, bioretention, downspout disconnection, green roofs, swale enhancement, soil amendments, dry swales, porous pavement, cisterns, sand filters, constructed wetlands, floodplain reconnection, impervious cover removal, tree plantings, pervious area restoration, and stormwater planters. CWP and Horsley Witten evaluated each of these opportunities using professional judgment and the following technical factors: impervious area treated, pollutant removal capability, runoff reduction estimates, cost, and maintenance requirements.

The project team as a whole then reviewed the 51 sites with respect to nontechnical factors such as feasibility, educational or demonstration potential, and opportunity (e.g., upcoming plans to repave a parking lot). Out of these discussions came a "Top Ten" list of priority retrofits based on both technical and nontechnical factors (the number ten was determined not by analysis but by the limitations of the work plan). The list does not necessarily reflect the ten retrofits that would remove or disconnect the maximum amount of impervious cover, but rather the projects that, as a package, would have a large impact while creating the greatest momentum on campus for further change. Thus, the list includes a range of retrofit types, geographically spread about campus and applied to different types of land use and impervious cover patterns (e.g., dormitories, academic buildings, and parking lots). As per the project plan, the team created *25% design* conceptual drawings for the Top Ten. We do not necessarily assume that these practices will be built exactly as designed; rather, as construction, renovation, and landscaping take place on a project-by-project basis in the future, they will provide ideas and guidance that will foster creative TMDL implementation.

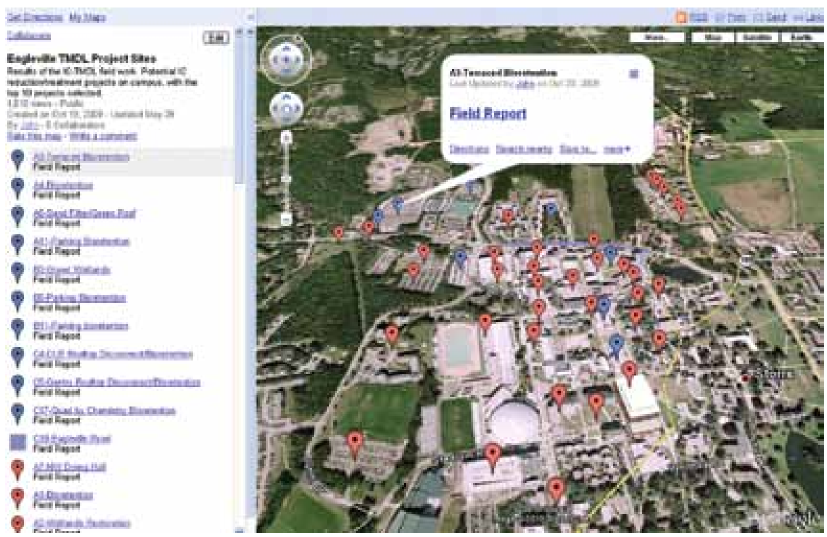

Figure 3. A Google Earth "mashup" from the project website, showing most of the University campus and a portion of the 51 retrofit locations; Top Ten sites are in blue. The markers can be linked to maps, drawings, documents, photos, or other content and will be populated as the project proceeds. IC, impervious cover.

Project Status and Implementation

At the time of this writing, the project is in transition from the technical phase of the work to the plan writing, outreach, and implementation phase. The retrofit technical report is complete. Work with the Town of Mansfield on land use regulation review and changes will begin during fall 2010 and will be ongoing. The project team will develop educational materials in late 2010, using the project website as a repository for all project information. For instance, Figure 3, taken from the project website, shows a Google Earth–based display of a portion of the 51 retrofit sites, each of which is linked to technical documents, photos, and other information.

At this early stage, much remains to be worked out in terms of implementation strategies. However, three simple but important concepts have emerged. First, implementation will take place during the course of ongoing University and Town of Mansfield activities, as opportunities occur during the design process at the site level. Second, there is general agreement that the impervious cover TMDL approach will extend beyond the boundaries of the Eagleville watershed to other portions of the town and campus. Finally, University and town officials increasingly recognize the enormous role that the maintenance of these practices will play in the ultimate success of the effort. The University has already contracted to develop maintenance manuals for pervious pavements and has purchased new vacuum equipment. Similar manuals for the operation and maintenance of other LID practices will be developed as these practices are put into place.

... the growing consensus that it is effective or connected impervious cover that should be the focus of remediation efforts, rather than total impervious cover

Implementation will be ongoing for the foreseeable future and has, in fact, already begun even before the issuance of the project's final report or the formal TMDL response. In summer 2009, the University repaved two parking lots—one with permeable concrete, and one with permeable asphalt (believed to be the first permeable asphalt parking lot in the state). Plans for extensive remodeling to upgrade the safety sprinkler system of an off-campus graduate housing unit now include plans for pervious parking stalls and rain gardens receiving both road and rooftop runoff. Plans for the construction of a new building in the heart of campus will include a green roof, bioswales, and pervious paving. Although these projects were conceived prior to the determination of the Top Ten, they can be directly attributed to the University's desire to respond to the TMDL.

The consonance of the impervious cover TMDL practices with separate but parallel efforts on campus offers enormous potential. Promising coordination has taken place between the TMDL team and the team developing a landscape master plan for the campus; these plans have many areas of agreement on the use of vegetation, specifically trees, as both aesthetic and stormwater amenities. And in 2007, the University established a sustainable design and construction policy that requires that all new construction and renovation projects costing over $5 million attain a Leadership in Energy and Environmental Design "silver" rating as a minimum standard (US Green Building Council n.d.).

Tracking Progress

One thing yet to be worked out in detail is the project accounting process. Ultimately, the ability to measure progress is a major factor that separates the impervious cover TMDL approach from a simple urban retrofit analysis. Based on the guidance contained in the TMDL language itself and the project team's experience to date, the team envisions that progress will be measured in three tiers:

The amount of impervious cover removed or disconnected. This seems relatively straightforward, and our current estimates show that the 11% goal is more than achievable (Table 2). However, complexities still must be worked out. As one might expect on a large college campus, the results of soil compaction tests performed on many of the pervious areas, particularly large quads and greens, were closer to those of concrete than turf. While the project implementation plan is expected to address this issue (in concert with a campus landscape master plan), to date these areas have not been accounted for in any quantitative tracking system. In addition, no provision yet exists in Connecticut for assigning certain retrofit practices (e.g., pervious paver areas) with partial credit toward disconnection, as has been done in several states (North Carolina Division of Water Quality 2007). Finally, the 11% target was set for the entire watershed, while most of the impervious cover (about 75% of the total acreage) is in one subwatershed containing the campus. Discussions are under way about means of tracking progress at both the watershed and subwatershed levels; this would serve to focus even more attention on the University portion of the watershed.

Improvements in reestablishing a more natural hydrologic regime in Eagleville Brook. The project team has renovated and reactivated an abandoned research weir located on the brook just downstream of the campus portion of the upper watershed, for the purpose of conducting long-term monitoring of streamflow as the TMDL is implemented. In addition, the University has provided funds for monitoring of the runoff from, and flow through, the two new pervious parking lots. Project partners are discussing the value of modeling the runoff reduction effects of the recommended LID practices, both as a predictive tool and to compare to the weir data.

The health of the stream, as indicated by the macroinvertebrate and fish sampling conducted by CTDEP. This ultimate objective is a reminder that, while volume reduction is the primary concern, it should not be the sole focus of the impervious cover TMDL. Thus, the final report and management plan also will include (1) source reduction strategies for likely

Table 2. Estimated progress toward the TMDL target of 11% impervious cover if the recommended retrofits were implemented.

Estimated Result of Retrofit Implementation						
Sites	Drainage Area Treated, km2 (acres)	Impervious Area Treated, km2 (acres)	Watershed IC after Implementation km2 (acres)	Target IC (11% of watershed), km2 (acres)	Watershed IC after Implementation (%)	Estimated Cost ($)
Top Ten Retrofit Sites	0.30 (74)	0.13 (32)	0.54 (133)	0.53 (132)	11.1%	$1,350,000
All 51 Retrofit Sites	0.47 (115)	0.25 (61)	0.42 (104)	0.53 (132)	8.7%	$5,800,000

Notes: The Top Ten retrofits bring the watershed to 11.1% impervious cover, essentially in compliance with the target; implementing all 51 retrofits would far exceed the target, reducing impervious cover to just over 3%. These estimates do not factor in new impervious cover added with additional building or renovations. IC, impervious cover.

"hot spot" areas, like the motor pool; (2) innovative water quality practices, like a gravel wetland; and (3) projects focused on wetlands and/or riparian restoration.

Is It Working?

Based on our experience to date, we believe that the impervious cover TMDL is on its way to success. In the minds of project team members, the acid test is this: *does the impervious cover TMDL make it easier, or more difficult, for a regulated community to develop and implement a response to a TMDL that is likely to improve the health of the water body in question?*

We believe that the impervious cover TMDL makes a response easier, primarily because impervious cover provides a framework that communities can use to assess the problem and make decisions (Arnold and Gibbons 1996). Coupling the impervious cover framework with the regulatory driver of a TMDL provides an approach well-suited to catalyze local action. Certainly, a town manager asked to reduce the effective amount of impervious cover may more easily develop next steps than one who is asked to reduce bacterial concentrations from *a* to *b* and zinc concentrations from *x* to *y*. Although not yet quantifiable, the progress made to date in Eagleville Brook supports this view.

Conclusion

An impervious cover TMDL does require detailed, and often painstakingly acquired, information as its basis. However, one could argue that digitizing parking lots, evaluating storm drains, and conducting soil testing (for example) are more easily understood and achieved than modeling and monitoring a suite of pollutants. So, for those who can marshal the wherewithal to do the field work required, an impervious cover TMDL seems like a viable alternative for urban or urbanizing watersheds. Urban stream syndrome is widespread, and the resources needed to take the traditional, data-intensive, pollutant-by-pollutant TMDL approach are limited. Based on our experience in Eagleville Brook, combining an integrative indicator like impervious cover with an accounting system like a TMDL provides a promising approach for helping communities move in positive directions regarding land use planning and design that is protective of water resources.

More information is available at the project website:

http://clear.uconn.edu/eagleville/Eagleville_TMDL/Home.html

Acknowledgments

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