STORMWATER AND AQUATIC LIFE: MAKING THE CONNECTION BETWEEN IMPERVIOUS COVER AND AQUATIC LIFE IMPAIRMENTS FOR TMDL DEVELOPMENT IN CONNECTICUT STREAMS

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ABSTRACT

Stormwater can be a significant source of stressors to aquatic stream biota in many urban areas. The *2006 List of Connecticut Waterbodies Not Meeting Water Quality Standards* has a total of 105 stream segments that do not meet aquatic life goals established in Connecticut's Water Quality Standards. At least 58% of these waterbodies have stressors related to urbanization as the suspected cause of the impairment (e.g. stormwater, habitat modifications, erosion, sedimentation etc.).

Modeling stormwater impacts can be challenging due to their episodic nature. In many instances, surrogate measures of stormwater impacts may provide useful benchmarks when data are unavailable to support more complex stormwater models. The State of Connecticut, Department of Environmental Protection (DEP), has developed an Impervious Cover (IC) model applicable in situations where the most probable cause of the aquatic life support impairment is stormwater. An IC target of 12% was established for developing Total Maximum Daily Loads (TMDLs) based on correlating the percent IC upstream of macroinvertebrate monitoring locations with a final assessment of passing or failing Connecticut's aquatic life standards. Connecticut DEP has used the IC Model to develop a TMDL for a small stream in Eastern Connecticut and has engaged stakeholders to focus stormwater management efforts to restore aquatic life in the brook.

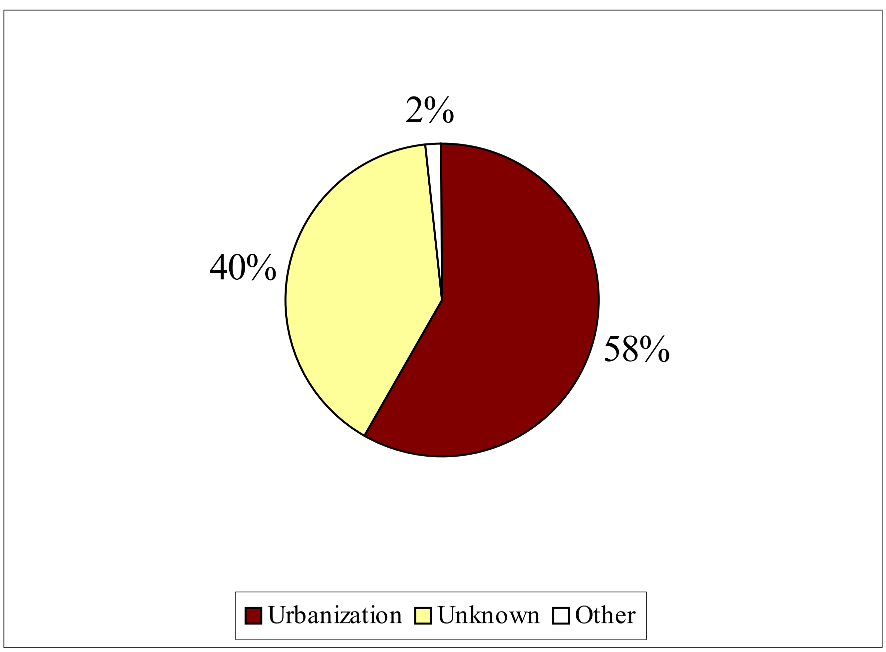
KEYWORDS
Aquatic Life, Impervious Cover, Multiple Stressor Syndrome, Stormwater, Urbanization, TMDL

INTRODUCTION

It is well documented that changes in land use impact the ecological characteristics of streams, including the distribution and abundance of biota (Allan, 2004; Arnold and Gibbons, 1996; Chadwick et al., 2006; Coles et al., 2004; Gergel et al., 2002; Schueler, 1994). In particular, measures of urban land use have negative impacts on biotic integrity (Bilkovic et al., 2006; Miltner et al., 2003; Morse et al., 2003; Ourso and Frenzel, 2003; Stanfield and Kilgour, 2006; Wang et al., 2001; Wang and Kanehl, 2003). In effect, urbanization and stormwater runoff result in "urban stream syndrome" (Meyer et al., 2005; Walsh et al., 2005) in many of our nations waterways. That is, as watersheds become more urbanized, stormwater runoff results in a flashier hydrograph, elevated concentrations of pollutants transported from impervious surfaces to streams, altered channel morphology, and reduced biotic integrity with a dominance of more tolerant species.

Stormwater runoff from urban land development with impervious surfaces is currently the largest contributor to the impairment of water quality in New England, as well as in many other parts of the country (ENSR 2006). In Connecticut, the *2006 List of Connecticut Waterbodies Not Meeting Water Quality Standards* (CTDEP, 2006a) has listed a total of 105 stream segments that do not meet aquatic life goals established in Connecticut's Water Quality Standards (CTDEP, 2002). At least 58% of these waterbodies have stressors related to urbanization (e.g. stormwater, habitat modifications, erosion, sedimentation) as the suspected cause of the impairment (Figure 1). Under Section 303 (d) of the Federal Clean Water Act, Connecticut is required to develop Total Maximum Daily Loads (TMDLs) for these 105 stream segments.

Figure 1 - Potential causes of the 105 stream segments listed in the 2006 List for not meeting Connecticut's aquatic life use support designated use.



Developing TMDLs for "urbanization" presents an enormous challenge for Connecticut because of the number of impairments and the complicated nature of urban stream syndrome. Simply stated, urban stream syndrome is generally a result of what I will call "multiple stressor syndrome," the fact that many complex and interactive impacts are associated with this phenomenon (Figure 2). These characteristics of "multiple stressor syndrome" make it difficult to identify which pollutant is the most suitable for TMDL analyses. 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 storm water, 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.

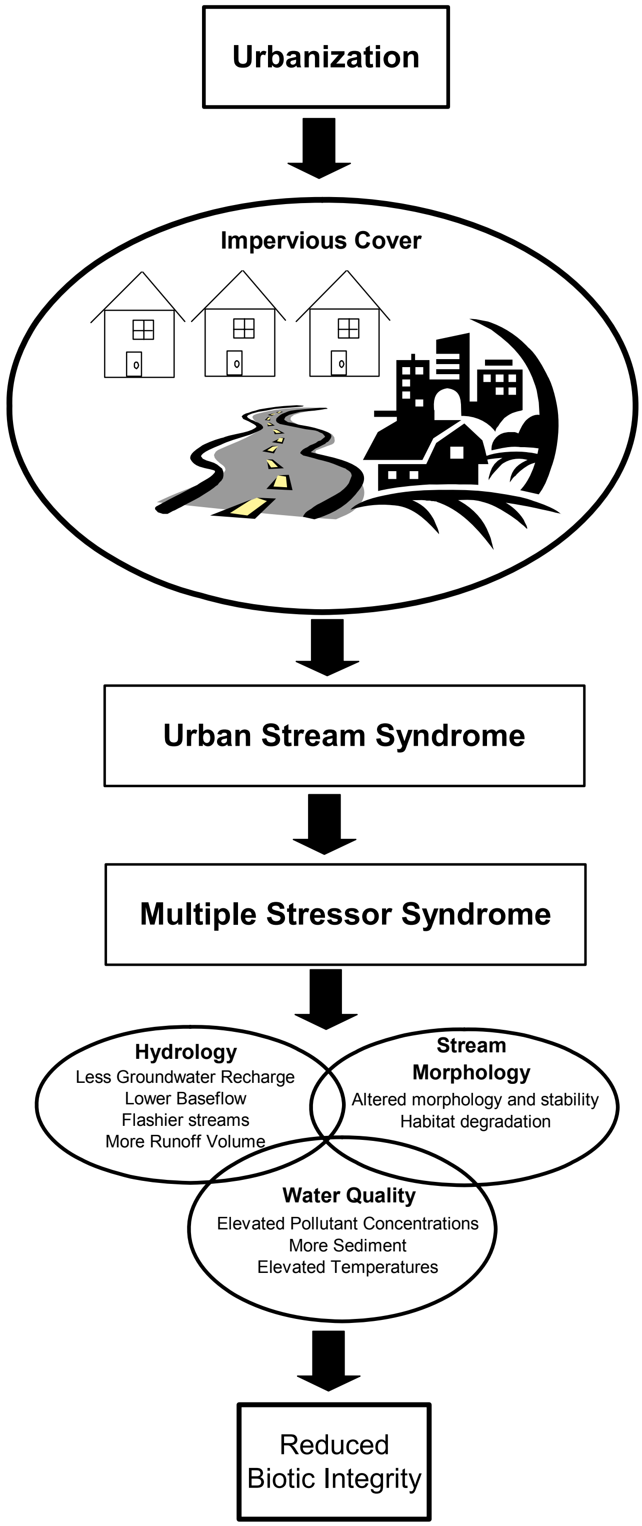
The Connecticut Department of Environmental Protection (CTDEP) has developed a TMDL approach for situations where aquatic life goals are not met and it has been identified that stormwater is the most probable cause of the impairment. The approach uses a surrogate measure, impervious land cover (IC), to develop TMDL targets, wasteload allocations, load allocations, and margin of safety using a percent reduction approach. IC in the watershed was chosen as a good surrogate measure of stormwater because it aggregates pollutant loads, storm water flows, and has a direct relationship with benthic macroinvertebrate assessments, the primary measure of aquatic life goals in Connecticut. A target of 12% IC in the contributing watershed was chosen based on an analysis of 125 stream monitoring locations and IC estimated using GIS. The 12% IC threshold represents a level of imperviousness in the upstream watershed that, if exceeded, is not likely to support a macroinvertebrate community that would meet aquatic life use goals established in Connecticut’s Water Quality Standards.

METHODOLOGY

Estimates of Impervious Cover

Estimates of the percent impervious cover of the total land cover (% IC) for 1985, 1990, 1995, and 2002 by basin were obtained from the Center for Land Use Education and Research at the University of Connecticut (E. Wilson, Personal Communication). The % IC values were derived from land cover data using an ArcView® Impervious Surface Analysis Tool (ISAT). ISAT multiplies IC coefficients by each land cover class to obtain an estimate of total impervious cover by area (such as a local drainage basin). These IC coefficients were developed using nine Connecticut towns that have accurately measured IC (Prisloe et al., 2002). Actual IC measurements from these nine towns were used to "truth" the computer interpretation of IC and provide more accurate IC coefficients for use statewide. Further information on ISAT can be found at http://nemo.uconn.edu/tools/impervious_surfaces/measure/isat.htm and http://www.csc.noaa.gov/crs/cwq/isat.html.

Figure 2 – Conceptual model of multiple stream syndrome which provides linkages between urbanization, impervious cover and biotic integrity. The term Urban Stream Syndrome was initially referenced in Meyer et al. (2005).



Applicable Streams

Monitoring locations (Figure 3, Appendix 1) included in this analysis represent benthic monitoring sites that were sampled by CTDEP as part of a rotating basin approach from 1996 to 2001 and more recently a group of sites selected based on a probabilistic sampling design (CTDEP, 1999). Sites were limited to only those in which Rapid Bioassessment Protocol (RBP III) level of effort were completed (Plafkin et al., 1989). In Connecticut, the RBP III level of effort consists of a two square meter kick net sample collected from erosional riffle habitat, 200 organism sub sample, and organism identification to the lowest taxon possible (generally species level).

The ISAT estimates of IC were estimated as the % IC of the total land cover upstream of the monitoring location. For monitoring locations in smaller streams (e.g. local basins), IC measurements were delineated to the upstream extent of the local basin boundary. Similarly, for monitoring locations contained in subregional basins, IC measurements were delineated to the upstream extent of the subregional basin boundary. Since the influence of IC is greater at smaller scales, the analysis was limited to monitoring locations with upstream drainage areas of < 50 square miles. Watersheds > 50 square miles were excluded because IC clusters located far upstream of the monitoring location may not affect the macroinvertebrates at the monitoring location.

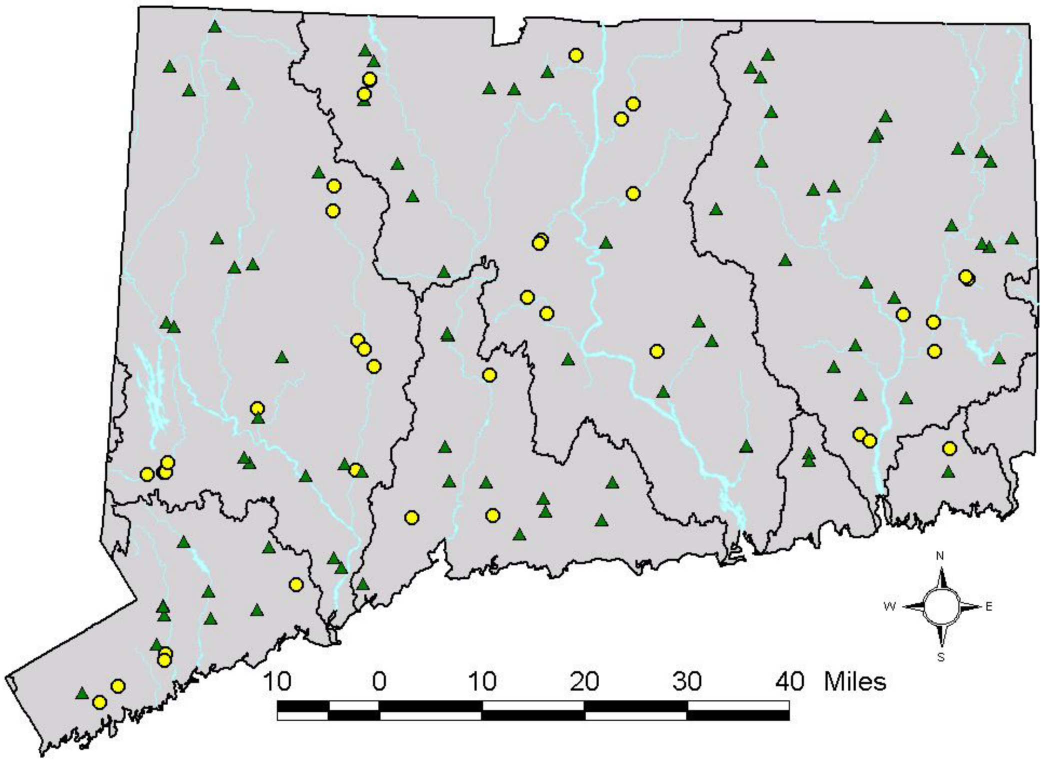
In addition to excluding monitoring locations with large watersheds upstream, monitoring locations within one mile downstream of a sewage treatment plant discharge were also excluded from the analysis. Also, monitoring sites on streams that have a portion of the upstream basin in states bordering Connecticut were excluded because IC estimates were not readily available for other states.

As a result of the qualifiers mentioned above, the Applicable Streams effectively are those with monitoring locations with RPB III level of effort on streams with < 50 square miles drainage upstream, beyond 1 mile of a sewage treatment plant discharge, and no portion of the drainage in another state. Care should be taken when making inferences to monitoring sites in streams that may exhibit different characteristics.

Linking Impervious Cover with Benthic Macroinvertebrates Data to Develop TMDL Targets

The % IC in the contributing watershed and benthic macroinvertebrates data from Applicable Streams were analyzed graphically using scatterplots and box and whisker plots to determine potential TMDL targets. Since IC estimates were available for four years - 1985, 1990, 1995, and 2002 – and the macroinvertebrate sampling years were variable, the IC dataset from the closest year preceding the monitoring date was used in all cases.

Figure 3 - Applicable streams: benthic monitoring sites considered for this analysis. Thick black lines show major drainage basin divides. Green triangles are sites that met Connecticut's aquatic life criteria (n=86) and yellow circles are sites that did not meet Connecticut's aquatic life criteria (n= 39).



The % IC was plotted against final benthic metric scores as a percent of the reference community. The final percent of reference score integrates seven metrics: taxa richness, modified Hilsenhoff Biotic Index, ratio of scraper and filtering collector functional feeding groups, ratio of EPT (taxa in the orders Ephemeroptera, Plecoptera, and Trichoptera) and Chironomidae abundance, percent contribution of dominant taxa, EPT index, and community loss (Plafkin et al., 1989).

Connecticut currently has a pass/fail methodology of assessing attainment of aquatic life use goals based primarily on the benthic macroinvertebrate community in a stream. Benthic macroinvertebrates integrate the effects of pollutants and other conditions over time, and therefore are felt to have the best and most direct measure of aquatic life use support goals. In general, monitoring locations that score >54% of reference community pass aquatic life standards, while those that score < 54% of reference community fail aquatic life standards. Other factors such as species composition and age class distribution of the fish community, evaluation of chemical criteria, and water diversions factor into aquatic life assessments for streams as decribed in Connecticut's Consolidated Assessment and Listing Methodology (CTDEP 2006b), but for the majority of cases, the macroinvertebrate scores are the primary measure of aquatic life goals. Therefore, for this analysis, the pass/fail demarcation of 54% of reference condition was used as a measure to assess TMDL targets since aquatic life assessments in Connecticut are strongly influenced by this result.

RESULTS

A total of 125 sites met the criteria as outlined in Applicable Streams above and were considered in this analysis. The median drainage area upstream of these 125 sites was 14.8 square miles (range 5.3 - 46.4 square miles) and the percentage of impervious cover ranged from 2.3-28.0 % with a median value of 4.4% (Figure 4). Scatter plots from the Applicable Streams in Connecticut showed that taxa richness and EPT taxa generally decreased with increasing IC (Figure 5). As a group, EPT taxa can be characterized as sensitive taxa and often occur in decreased abundance in response to environmental stress (Lenat and Penrose, 1996).

Applicable Streams were further separated in two groups - 1) those that met Connecticut's aquatic life criteria as assessed using RBP III % of reference score and 2) those that did not meet Connecticut's aquatic life criteria. The general trend observed in these data was that the % IC was lower for streams that met Connecticut's aquatic life criteria than sites that did not meet Connecticut's aquatic life criteria, although there was some overlap in the upper quartile of the "meet" group with the lower quartile of the "do not meet" group (Figure 6).

Figure 7 demonstrates a "threshold" effect in that as the % IC in the contributing watershed increases to approximately 12%, no Applicable Streams met Connecticut's aquatic life criteria (i.e. >54% reference community).

Figure 4 -Box and whisker plot of upstream drainage area (left) and percent impervious cover (IC) in the upstream watershed(right) for 125 sites that were included as Applicable Streams in this study. The notched box shows the median and lower and upper quartiles. The dotted line extending from the quartile boxes shows the nearest observations within 1.5 interquartile ranges (IQR). Crosses indicate observations exceeding 1.5 IQRs and circles indicate observations exceeding 3.0 IQRs

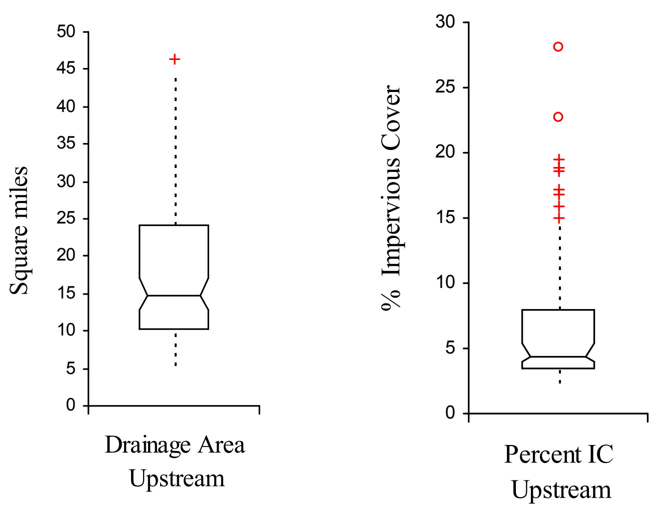


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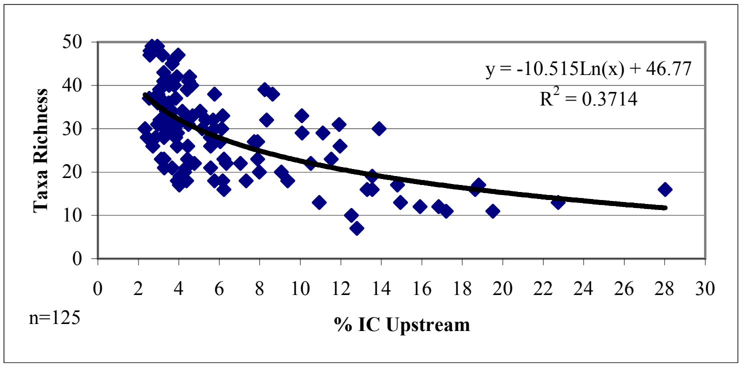
Figure 5 – Scatter plots of taxa richness (upper) and EPT taxa (lower) and percent impervious cover upstream of macroinvertebrate monitoring locations from Applicable Streams in Connecticut.



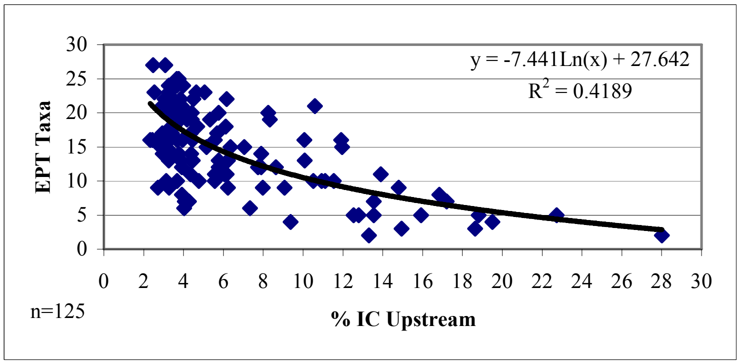


Figure 6. Box and whisker plot of sites that meet Connecticut's Water Quality Criteria (WQC) for aquatic life (n=86) and sites that do not meet Connecticut's aquatic life criteria (n=39). The notched box shows the median and lower and upper quartiles. The dotted line extending from the quartile boxes shows the nearest observations within 1.5 interquartile ranges (IQR). Crosses indicate observations exceeding 1.5 IQRs.

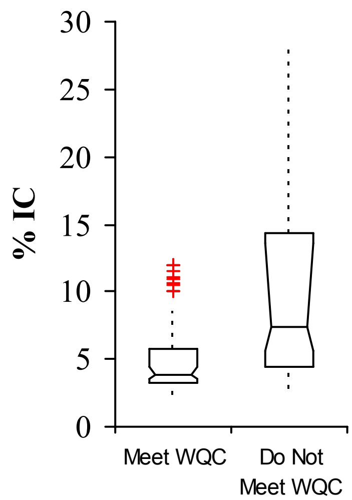
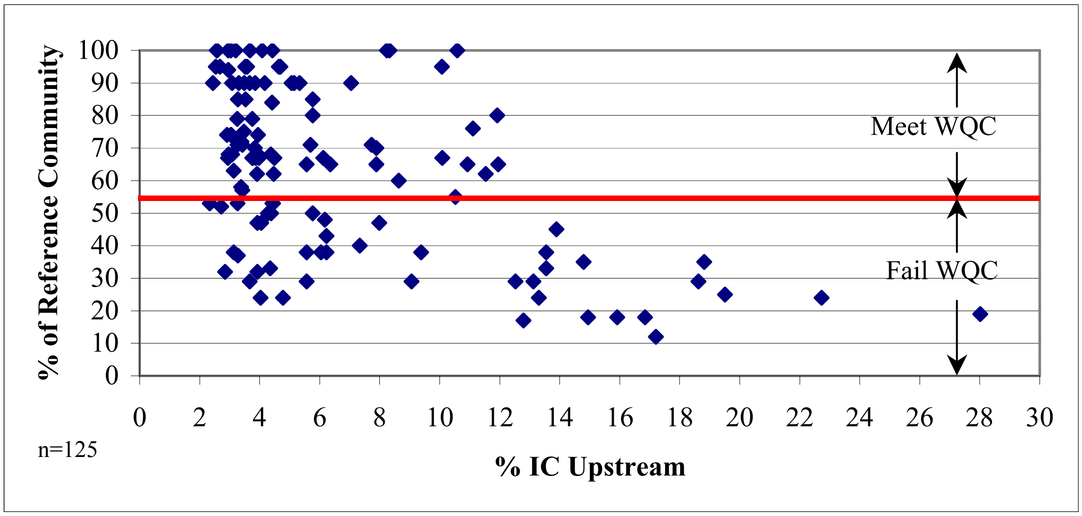


Figure 7. Scatter plot of percent impervious cover (IC) upstream of monitoring locations and % of reference macroinvertebrate community as assessed using Connecticut's Consolidated Assessment and Listing Methodology. Points that plot above the horizontal red line meet Connecticut's water quality criteria (WQC) to support aquatic life. Points that plot below the horizontal red line do not meet Connecticut's water quality criteria to support aquatic life.



Impervious Cover Target for TMDLs in Connecticut

Based on the results of this analysis, CTDEP believes that 12% IC is a reasonable TMDL target for aquatic life impairments in Applicable Streams where stormwater has been identified as the most probable cause of the impairment. It is recognized these correlations do not demonstrate causation, but given the known effects of urbanization and impervious cover on biotic integrity due to multiple stressor syndrome, this approach seems reasonable. The 12 % IC target value has been used as the surrogate TMDL target, and to further define a surrogate Wasteload Allocation (WLA) and Load Allocation (LA) target for stormwater caused aquatic life impairments in Connecticut.

DISCUSSION

This 12% IC target observed for Applicable Streams in Connecticut represents a level of imperviousness in the upstream watershed that, if exceeded, is not likely to support a macroinvertebrate community that would meet aquatic life use goals. The 12% IC threshold is within the range of % IC values causing impacts to aquatic life generally reported in the literature (Schueler, 1994; Center for Watershed Protection, 2003), and is within the range of % IC values from other New England States. For example, the State of Maine recently proposed IC targets that ranged from 6-15 % to support their tiered aquatic life use categories based on an analysis of macroinvertebrate and IC data (Maine Department of Environmental Protection, 2005).

CTDEP has developed a TMDL approach using the 12% IC target that is recommended for use in situations where there is a clear linkage between measured aquatic life impacts and stormwater discharging from areas dominated by IC (e.g. urbanized areas). Protocols such as EPA's Stressor Identification Guidance (US EPA 2000) can provide support to establish linkages between aquatic life in streams and stormwater. The IC target has been used to develop a TMDL using IC as a surrogate for stormwater impacts to a small brook in eastern Connecticut (CTDEP 2007). This TMDL is available for review at the Department's website http://www.ct.gov/dep.

This approach to stormwater TMDLs has several benefits. First, the IC TMDL was a useful tool to describe the connection between urbanization, impervious cover, stormwater, and biotic integrity to stakeholders during the public participation process of TMDL development. The concepts were well understood by stakeholders and provided a link between stormwater impacts and poor aquatic life in their local waterbody. In this sense, the TMDL provides a template to educate local decision makers and can assist local officials to obtain funding to reduce stormwater impacts among strongly competitive local budgets. Second, using a quantifiable surrogate measure such as impervious cover allows for calculations of TMDLs anywhere in the state, since IC data are already available statewide (and can be updated when land cover data are updated). This allows for TMDL calculation in any situation where stormwater and its complex and interactive impacts cause degradation to aquatic life in Connecticut's streams (i.e. urban stream syndrome caused by multiple stressor syndrome). Third, many more TMDLs for "urbanization" will be required in the future since there are 105 stream segments on the *2006 Connecticut List of Waterbodies Not Meeting Water Quality Standards*, of which at least 58 % have potential causes linked to urbanization. This methodology provides a template for those TMDLs.

Given the concept is easily understood by the public, statewide availability of IC data, and number of potential TMDL's for stormwater related impacts to aquatic life in Connecticut, a streamlined approach such as the one described here will advance the process to the TMDL implementation phase sooner than would happen if each stream required more complex stormwater modeling. For example, in a pilot study using the IC TMDL methodology (CTDEP 2007), stakeholder involvement with implementation of stormwater controls has been initiated even prior to formal approval of the TMDL. Thus using this surrogate approach for a complex issue such as characterizing stormwater impairments will bring us closer to the ultimate goal - achievement of water quality standards.

ACKNOWLEDGMENTS

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APPENDIX 1. Benthic monitoring sites selected for analysis (Applicable Streams).

Sample Date	Stream Name	Drainage Area Upstream (square miles)	Percent IC upstream of site	Percent of Reference [1]
10/17/2002	Ekonk Brook	5.3	2.9	67
10/28/1998	Pocotopaug Creek	5.4	3.7	29
10/13/1998	Stony Brook	5.7	2.7	52
11/2/2000	Hewitt Brook (Poquetanuck Brook)	5.8	3.4	72
10/30/2002	Lake Waramaug Brook	5.8	3.3	90
10/15/2002	Latimer Brook	5.9	3.8	67
11/13/1997	Pequonnock River	5.9	8.6	60
10/20/1998	Burlington Brook	5.9	4.5	62
10/26/1999	Tenmile River	6.0	3.5	95
10/6/1999	Myron Kinney Brook	6.1	2.3	53
10/19/2000	Seth Williams Brook	6.2	4.3	50
10/16/2000	Farm River	6.3	4.1	47
10/9/2002	Pond Meadow Brook	6.4	3.5	85
11/5/1996	Naugatuck River	6.7	7.3	40
11/5/1997	Norwalk River	6.8	7.9	65
10/29/1997	Norwalk River	6.8	7.9	70
10/3/2002	Norwalk River	6.8	8.0	47
10/4/2000	Transylvania Brook	6.9	4.3	33
10/23/1997	West River	7.2	3.0	94
10/21/1997	West River	7.2	3.0	100
10/17/2000	Sympaug Brook	7.2	13.1	29
10/2/1997	Salmon Creek	7.4	3.6	95
11/9/1999	Factory Brook	7.5	3.9	67
10/14/1997	Mill River	7.7	8.2	100
10/17/1997	Branford River	8.3	5.7	71
11/13/1997	Mill River	8.4	7.0	90
10/24/2000	Still River	8.5	9.4	38
10/23/1998	Salmon Brook	8.8	10.1	67
10/6/2000	Willow Brook	9.2	18.6	29
11/3/2000	Oxoboxo Brook	10.2	5.6	29
11/2/2000	Oxoboxo Brook	10.2	5.6	38
11/2/2000	Trading Cove Brook	10.2	4.6	95
10/22/1999	Whetstone Brook	10.3	3.4	58
10/20/2000	Gardner Brook	10.5	3.4	71
10/20/1998	Nepaug River	10.7	3.7	90
10/16/2000	Bladdens River	10.7	6.2	48
10/31/1996	Bladdens River	10.7	6.2	105

[1] Percent of Reference is calculated as described in Plafkin et al., (1989) . In general, sites > 54 % of reference community meet Connecticut's narrative aquatic life use in wadeable streams, although others factors are involved in the assessment.

Sample Date	Stream Name	Drainage Area Upstream (square miles)	Percent IC upstream of site	Percent of Reference
10/13/1999	Middle River	10.9	4.4	68
10/10/2000	Noroton River	11.0	19.5	25
10/13/1998	Muddy Brook	11.1	4.0	24
10/25/1999	Mill Brook	11.2	3.9	32
10/27/1998	Jeremy River	11.4	4.0	67
10/13/1999	Furnace Brook	11.6	3.3	53
10/4/2000	Shepaug River	11.8	2.4	90
10/6/1999	Pachaug River	11.9	3.3	37
10/3/2000	Middle River	12.0	4.4	53
11/4/1997	Harbor Brook	12.1	18.8	35
10/28/1998	Pine Brook	12.3	3.8	67
10/31/2000	Latimer Brook	12.4	4.2	90
10/24/2002	Whitford Brook	12.5	4.1	100
10/25/1999	Quanduck Brook	12.9	3.0	68
10/7/1999	Merrick Brook	13.0	3.0	74
10/17/2003	Eightmile River	13.1	10.6	100
10/12/1999	Eightmile River	13.1	10.1	95
10/14/1999	Willimantic River	13.5	3.8	79
10/20/1997	Mianus River	13.6	10.5	55
11/9/2000	Silvermine River	13.8	10.9	65
10/19/1999	Bungee Brook	14.2	2.9	74
10/21/1998	Still River	14.5	6.2	43
10/5/2000	Still River	14.5	6.2	38
11/14/1996	Farmill River	14.7	12.0	65
10/14/2003	Saugatuck River	14.8	4.4	100
10/6/1998	Trout Brook	15.1	22.7	24
11/7/1996	Farmill River	15.1	11.9	80
10/6/1999	Broad Brook	15.2	2.9	32
10/29/1998	East Branch Eightmile River	15.3	3.3	71
10/20/2000	Susquetonscut Brook	15.3	3.5	90
11/1/1996	Little River	15.5	5.1	90
10/22/1998	Broad Brook	15.8	4.8	24
10/28/1999	Moosup River	15.8	4.4	84
10/19/1999	Still River	16.0	3.0	74
10/6/1998	Piper Brook	16.3	28.0	19
10/12/2000	Steele Brook	17.0	13.5	38
10/12/2000	Steele Brook	17.0	13.5	33
10/1/1998	Coppermine Brook	17.4	11.5	62
11/7/1996	Eightmile Brook	17.4	4.5	105
11/6/1996	Hollenbeck River	17.6	2.5	105
10/14/1997	Mill River	18.4	8.3	100
11/13/1996	East Aspetuck River	18.7	4.7	95
11/4/1998	Pootatuck River	18.9	5.3	90

Sample Date	Stream Name	Drainage Area Upstream (square miles)	Percent IC upstream of site	Percent of Reference
10/10/2000	Rippowam River	19.1	17.2	12
10/16/1997	Muddy River	19.3	7.7	71
10/30/1996	West Aspetuck River	19.6	3.3	85
11/6/1997	Wepawaug River	19.9	11.1	76
11/4/1998	Pootatuck River	20.8	5.8	80
11/4/1998	Pootatuck River	20.8	5.8	85
11/13/1996	Nonewaug River	21.3	3.8	90
10/2/2003	Roaring Brook	22.0	3.0	100
11/19/1997	Aspetuck River	23.1	5.1	90
10/22/1999	Blackwell Brook	23.4	3.3	79
10/27/1998	Blackledge River	23.8	4.5	67
10/8/2002	Sandy Brook	24.2	2.6	100
11/14/1996	Mad River	24.3	15.9	18
10/29/1998	Eightmile River	24.4	2.7	95
10/30/1997	Norwalk River	25.2	14.8	35
10/19/1999	Bigelow Brook	25.2	2.5	95
10/24/2000	Still River	26.3	12.5	29
10/21/1997	Hammonasset River	26.4	3.7	106
10/19/1998	West Branch Salmon Brook	26.6	3.1	90
11/12/2003	Sandy Brook	26.8	2.6	100
11/6/1996	Blackberry River	26.9	3.5	75
10/14/1999	Fenton River	27.3	3.9	68
10/21/1998	Mad River	27.6	3.4	57
10/10/2000	Pequonnock River	27.9	16.8	18
10/26/1999	Mount Hope River	28.1	3.1	68
10/2/1998	Coginchaug River	28.3	6.1	67
10/22/2002	Mashamoquet Brook	28.5	3.2	100
11/5/1996	West Branch Naugatuck River	28.8	3.8	70
11/1/1999	Skungamaug River	30.7	3.9	74
10/17/1997	West River	31.7	14.9	18
10/22/1998	Scantic River	32.0	6.0	38
10/19/1998	Salmon Brook	34.5	3.9	62
11/19/1997	Saugatuck River	34.7	5.6	65
10/7/1999	Little River	36.7	3.1	63
10/16/1996	Mattabesset River	36.9	13.3	24
10/28/1999	Fivemile River	38.2	4.4	53
10/9/1997	Bantam River	38.7	3.7	100
10/24/2000	Still River	39.5	12.8	17
10/26/1998	Hockanum River	41.7	9.1	29
10/5/2000	Still River	41.7	4.4	50
11/1/2000	Little River	41.9	3.1	38
11/5/1996	East Branch Naugatuck River	43.8	5.8	50
10/29/1997	Norwalk River	46.4	13.9	45