THE UNIVERSITY OF MAINE

Senator George J. Mitchell Center for Environmental and Watershed Research

MEASURING THE IMPACT OF DEVELOPMENT ON MAINE SURFACE WATERS

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Sucker Brook in Hampden is one of Maine's streams under urban pressure.

SUMMARY

Maine is unique in its bounty of natural wonders, from the majestic western mountains, the rocky Atlantic coast, the dense northern forests, to the clear blue lakes, streams, and rivers. Maine shares one thing in common with the rest of the country, however, and that is the rapid expansion of its urban and suburban areas.

Urban expansion is a particularly harsh threat to lakes and streams. Urbanization alters the landscape and changes ecological characteristics, resulting in degraded streams. A recent study from the University of Maine (Morse, 2001) in cooperation with the *Maine Department of Environmental Protection (DEP)* and the *Senator George J. Mitchell Center for Environmental and Watershed Research at the University of Maine*, provides an important perspective on the influences of development on the physical condition, water quality, and biological communities of streams.

This study identified a land disturbance threshold phenomenon above which ecological damage increases rapidly. Studies from many places in the U.S. have identified a threshold for development at about 10% of the watershed area, above which surface waters become degraded. Morse (2001) determined that this threshold applies in Maine as well; the water quality of Maine's streams, and their ability to support fish and other aquatic life, becomes degraded when the level of watershed imperviousness exceeds 6%-10% of the watershed area. The impact of the threshold is dependent on both the nature of the imperviousness and the geographic distribution of that imperviousness within the watershed. Watershed imperviousness (caused by pavement, gravel roads, sidewalks, driveways, and roofs which prevent water from soaking into the soil) was found to be a good predictor of the level of degradation of the overall stream condition.

As a reference point, a typical house, garage, and driveway on a one-acre lot would have 5% - 12% impervious area. However, we are not recommending that one-acre residential development is the appropriate approach for development. For protection of aquatic resources, the important factor is not that each *acre* should have less than 6%-10% impervious area, but rather that each *watershed* should have less than a target of 6%-10% impervious area, unless otherwise mitigated. *The bottom-line: landscape alterations should be designed to slow the runoff of water, maximize infiltration of water, and prevent erosion of soils.*

This research provides a simple tool for protection of aquatic resources and for prediction of future environmental impacts. Citizens, legislators, municipal officials, land-use decision makers, and developers can apply the index of watershed imperviousness as a planning guide to manage the impacts of development and protect streams for future generations.

LAND DEVELOPMENT

Development is a process of landscape change. We are all familiar with the picturesque qualities of Maine's natural landscape. Urban development replaces forests and fields with buildings, roads, and sidewalks. Some development is inevitable; therefore the goal of this document is to describe an index that predicts the impact of development so that any negative effects can be reduced through smart planning.

Development comes in many forms, including residential housing, commercial shopping and businesses, and industrial facilities. The amount of area developed, both nationally and in Maine, is rapidly growing. Poorly planned development represents 'sprawl', which is widely recognized to be a cause of environmental degradation and loss of habitat. Urban areas are estimated to occupy roughly 64 million acres nationwide and this number has been increasing for decades. According to the Maine State Planning Office, over the last 30 years, the fastest growing towns in Maine have been "new suburbs," 10 to 25 miles distant from metropolitan areas (The Cost of Sprawl, May 1997). This "suburban sprawl" increases the amount of area under development. In general, development that is initially residential produces an increase in commercial development as stores and businesses move to the area, and it is at that point that newly-developing watersheds usually approach or exceed the 6% to 10% imperviousness threshold.

Urbanization and development change the physical landscape (watersheds) and thus impact Maine's water bodies. The impacts include:

- disturbance and compaction of soil that reduces water infiltration and increases erosion;
- removal of vegetation that normally would intercept rainfall and slow runoff;
- grading to detrimentally increase water runoff;
- clearing of riparian zones along lakes and streams that increases erosion, decreases shade, and impairs habitat;
- increased impervious surfaces that prevent water from infiltrating the soil.

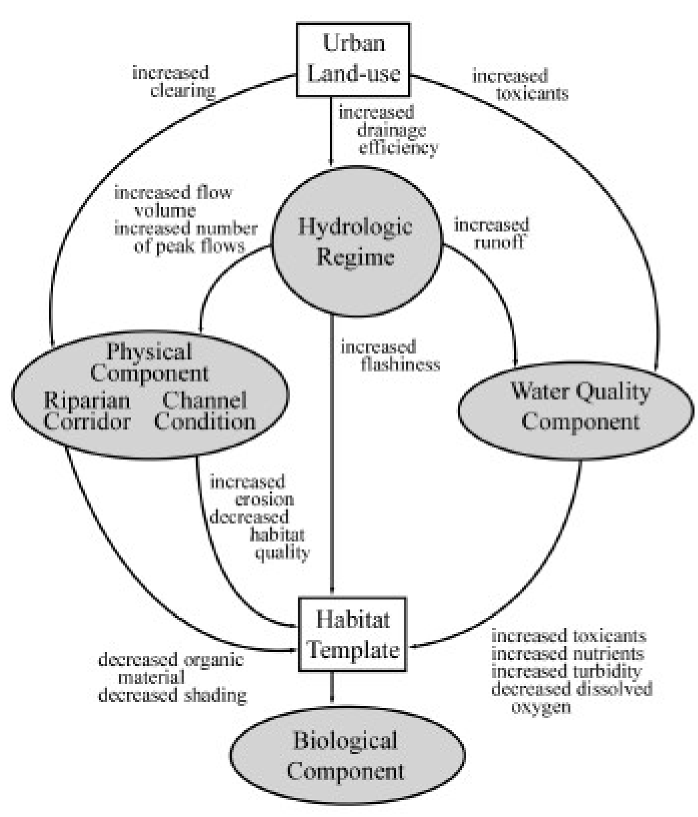

Figure 2. The interrelated set of influences that urban development puts into motion and how they affect streams.

Such alterations to the condition of Maine's watersheds result in changes to the streams that drain them, and these changes are seldom positive.

STREAM DEGRADATION

Stream ecosystems can be divided into four basic components:

· the *hydrologic regime,* or the patterns of rainfall and stream runoff within the watershed;

· the *physical condition* of the stream channel and adjacent riparian forest;

· the *quality of the water* flowing in the channel;

· the *condition of the biological communities*.

The process of urban development puts into motion a complex and interrelated set of influences illustrated in Figure 2 that leads to changes to all of the components of stream systems.

Hydrologic Influences

The most important environmental influences are those that alter the watershed hydrologic regime. In an undisturbed forest less than 10% of rainfall and melting snow will typically run over the land surface *directly* into lakes and streams. A shift in the landscape from rural to developed alters the infiltration and runoff patterns of rainfall and the amount of evapotranspiration (the water used by plants). In heavily urbanized areas, up to 90% of rainfall results in runoff which enters the stream or lake directly or is diverted to storm sewers which eventually drain to water bodies. This rapid runoff causes erosion and carries pollutants from developed areas into the water. Flooding becomes more common and more serious as the percentage of developed land increases.

Table I. Impervious Thresholds of Degradation

Researchers	State	PTIA Threshold
C. May (1997)	Washington	5-10%
R.D. Klein (1979)	Maryland	10%
E.J. Shaver, G.C. Maxted, & D. Carter (1995)	Delaware	8-15%
T.R. Schueler & A. Gali (1992)	Maryland	15%
G.C. Maxted (1996)	Delaware	10-15%
R.C. Jones & C.C. Clark	Virginia	15-25%

From: Schueler, T.R. 1994. The importance of imperviousness. Watershed Protection Techniques 1 (3): 100-111.

The increase of rapid runoff and stormflow also means that infiltration has not recharged groundwater and soilwater. As a result, summer baseflow will decrease and the impacts of drought will be greater. Habitat will be more limited, and biota will suffer.

Alterations to the hydrologic regime may have large consequences for the physical, chemical, and biological stream components. As a simple goal, alterations of the landscape, such as development and forest harvesting, should strive to retain the original infiltration capacity of the soil. The vegetated buffer strips along water bodies should also be retained. This simple plan will prevent many future water quality and flooding problems.

Physical Effects

When stormwater flows through stream channels faster, more often, and with more force, the result is erosion, stream channel widening, and streambed scouring. All of these processes result in an unstable stream ecosystem that impacts habitat. The clearing of the riparian zone and the loss of roots that help strengthen the stream bank make erosion worse. The loss of stream bank vegetation also removes the source of leaves, branches and limbs that provide refuge and food for organisms.

Changes in Water Quality

Land development creates an increase in sources of pollutants, including fertilizers, pesticides, gasoline, and heavy metals. Runoff washes these pollutants into streams and lakes, along with sediment from erosion. The effects include burial of habitat from sedimentation, increased algae or macrophytes from excess nutrients that can suffocate other biota, and toxicity to aquatic organisms from metals or pesticides. Development often alters the thermal regime of streams. Loss of shade leads to increases in temperature, and increasing the rate of runoff may increase the variability of the temperature of receiving water bodies by reducing the moderating effect of groundwater and adding stormwater warmed by hot pavement and storage in detention ponds.

Biological Impacts

Alterations to the hydrologic regime, the physical condition of the stream, and water quality, all combine to degrade the overall habitat, leading to a loss of diversity in the biological community. As the amount of impervious area increases, fish and invertebrate communities exhibit a loss of biodiversity and a shift in the community composition away from sensitive species.

IMPERVIOUSNESS AND THE DEVELOPMENT 'THRESHOLD'

In response to increasing pressures from development, new tools for preservation and management of aquatic resources are emerging. The percentage of the total impervious area (PTIA), or the amount of the watershed covered by surfaces preventing water infiltration, has been found to be predictive of the amount of stress and degradation to the stream. The level of imperviousness is not *itself* responsible for stream degradation, but rather imperviousness is the *cumulative indicator* of the changes to the hydrology of the natural watershed.

Nationally, many researchers have identified a threshold phenomenon for the percent of impervious area (Table 1). Below the threshold, there is little discernable impact on the stream biota. As development exceeds the threshold for imperviousness, stream water quality and habitat are increasingly degraded (Figure 3). There is a high degree of variability for the reported *threshold* PTIA levels, ranging from 5% to 15% imperviousness. Variation should be expected due to the differing ecological characteristics from region to region, and the starting point for accessing the condition of 'unimpaired'. The question addressed in this digest is, *"Can we identify a threshold for watershed development suitable for guiding future development and conservation efforts?"*

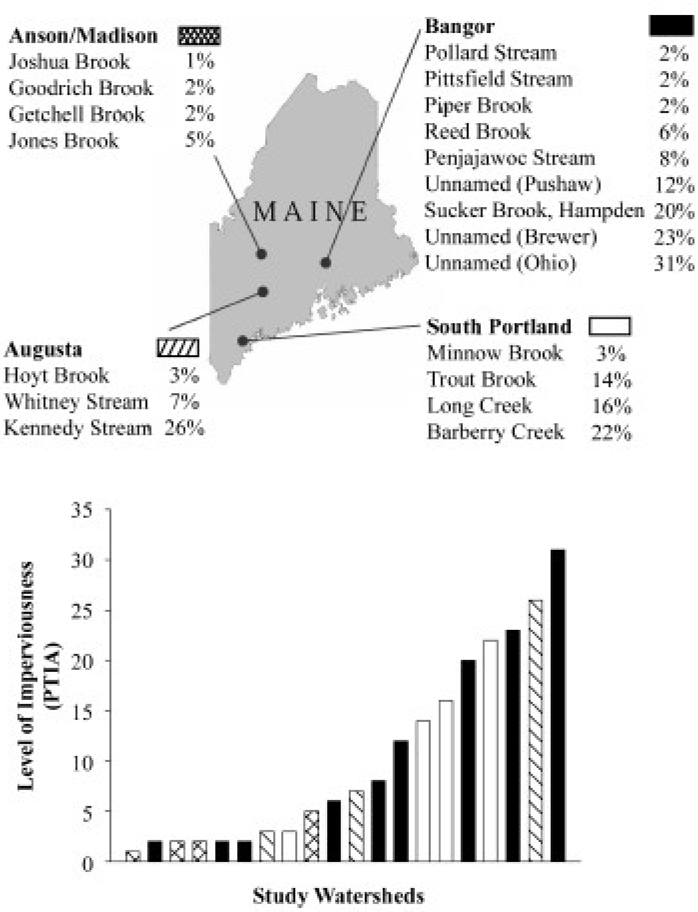

Figure 3. The names and locations of the watersheds with the levels of watershed imperviousness (PTIA) as well as a graphical representation of the urbanization gradient within the watershed.

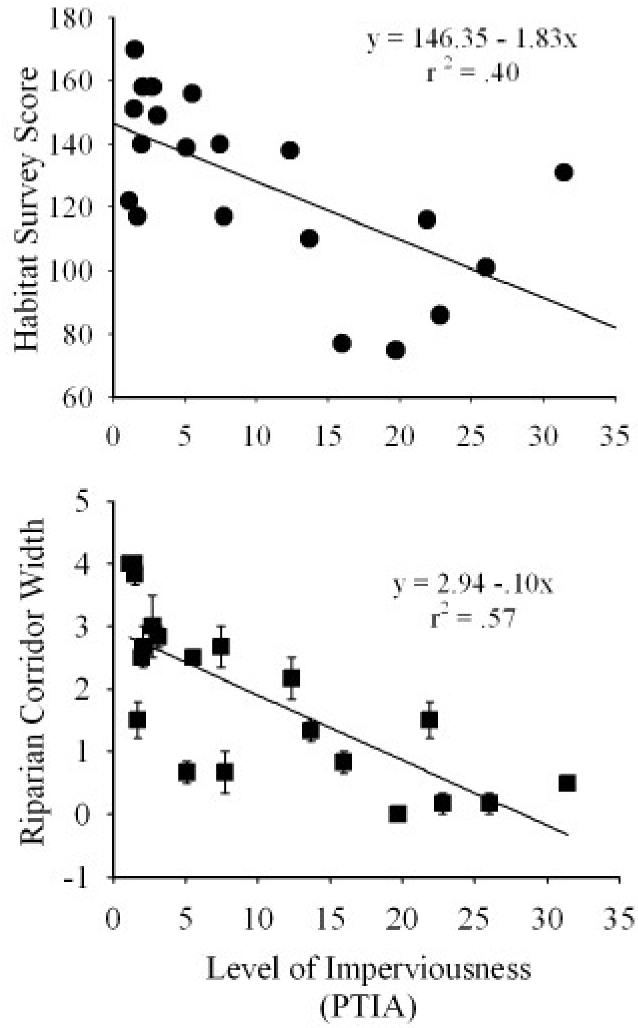

Figure 4. The influence of increasing urban intensity on the habitat quality and the riparian corridor widths of the study streams (riparian width classes include: 0 = <10m wide, 1 = 10-30m, 2 = 30-50m, 3 = 50-100m, 4 = >100m).

STUDYING MAINE'S URBAN STREAMS

Although much is known about the relationship between development and stream degradation, there has previously been little information on the specific impacts in Maine. In particular, *percent impervious area* as an indicator of degradation has not been well characterized. As Maine's urban and suburban areas expand, this indicator offers an opportunity to assist planning and protection efforts for our natural resources. A study to address these questions was completed in 2001 by Chandler Morse of the Ecology and Environmental Sciences graduate program at the University of Maine. In particular, this study:

- identified the nature and extent of changes to physical, water quality, and biological stream components from urban land-use;
- investigated the use of imperviousness as an indicator of the stream condition;
- identified a threshold level of urban development associated with degraded stream quality.

The study compared the characteristics of 20 small streams during 1998-99 with varying levels of development. These streams were similar in ecological character, with the exception of the level of development as measured from aerial photos. Percent Total Impervious Area ranged from undeveloped stream watersheds (PTIA = 1%) to the highly urbanized stream near Ohio Street in Bangor, which at PTIA of 31% was estimated to contain the highest level of imperviousness of watersheds in central and southern Maine. More than 300 watersheds were evaluated from aerial photos prior to the final site selection.

Characteristics of the major stream components were measured and compared across the development gradient, including:

- *Physical Component:* habitat quality, availability and stability, channel dimensions and substrate condition, riparian corridor width;
- *Water Quality:* nitrate and phosphorus concentrations, dissolved oxygen levels, total suspended solids;
- *Biological Component:* richness and community composition of the benthic macroinvertebrate community.

PHYSICAL AND WATER QUALITY RESULTS

Physical Condition within Maine's Urban Streams

The physical condition of Maine's urban streams was directly related to urban development intensity. The overall quality of the stream habitat decreased with increasing levels of imperviousness (Figure 4). The study used a qualitative habitat survey that assigned numerical values to several characteristics of stream habitat, including the level of erosion, the availability of different types of habitat, and the level of embeddedness of the stream bottom. Each stream received a rating of habitat quality based on the sum of these scores. Streams would normally contain a heterogeneous mix of shallow, fast-flowing, cobble riffles and deep, slow-flowing pools. Under increasingly urban watershed conditions, the streams contained more homogenous glade habitats and large areas of sediment accumulation, such as the channel pictured in Figure 5, as well as increased observations of other man-made debris.

Figure 5. A reach of Penjajawoc Stream in Bangor offers an example of habitat choked with sediments.

The width of the riparian corridors bordering the streams became narrower as imperviousness increased (Figure 4). With decreasing riparian width, there was a decrease in the presence of large woody debris in the stream channel, less shade, and less organic material — all factors that are important for habitat and energy for biota. Stream stability, measured with a protocol similar to the habitat survey, also decreased with increasing urban intensity, resulting in stream bottoms more prone to radical changes during high storm flows. Similar to stability, the average size of the streambed particles decreased with increasing PTIA, reflective of the overall influence of stream erosion and the input of large amounts of sediment.

Below an imperviousness of 6%, degradation to the stream was minimal for most parameters. As imperviousness increased above a threshold of 10%, the physical condition of the streams were increasingly degraded. Although habitat quality declined with increasing development, it declined only to a low score of "marginal" as opposed to "poor" found in more urbanized states.

Water Quality in Maine's Urban Watersheds

In parallel to physical condition, water quality of Maine's urban streams decreased with increased PTIA. Water samples for nutrient analysis, streamside pre-dawn dissolved oxygen, and total suspended solid samples were recorded during fall (1998), and spring, and summer of 1999. These samples were taken at least 48 hours after the last rainfall and were considered to reflect the typical ambient condition present in the streams.

Dissolved oxygen was lower with higher PTIA (Figure 6). Pre-dawn dissolved oxygen measures are indicative of the lowest concentrations of dissolved oxygen present in the stream and ranged from an average of 11 mg/L in non-urban streams to 5.8 mg/L in the most urban. Also, phosphorous and nitrogen concentrations were elevated in some of the streams with more developed watersheds (Figure 6). These water quality issues are indicative of non-point source pollution entering the streams from development. Although dissolved oxygen values were all above the 5 mg/L considered to be necessary for a healthy biological community, this study did not evaluate the seasonal variation in the dissolved oxygen, and did not include the low flow, low oxygen summer period of greatest biological stress.

BIOLOGICAL DEGRADATION

Invertebrates as Biological Indicators

This study evaluated potential degradation of the biological community as measured by the benthic macroinvertebrate community. Data were collected during the fall and spring from riffle habitats using standard sampling methods developed by Maine DEP. Macroinvertebrates are aquatic insects and other invertebrates that can be seen with the naked eye and have been widely accepted as an indicator of the condition of the living community within streams. Maine DEP uses them as a key monitoring tool for assessing the quality of Maine streams. The most important aspects of the benthic community are the community richness (the number of different types of organisms) and species composition (the kinds of organisms present).

Urban Benthic Communities

Degradation to the biological community was not linear with increasing PTIA. Above 10% PTIA the impacts were much greater than below 6% PTIA (Figure 7). Streams with less than 6% PTIA supported an average of 33 different taxa (species). Above 10% PTIA, streams support an average of 18 taxa.

The conclusions are the same for the macroinvertebrate data when considering the most sensitive of the organ-

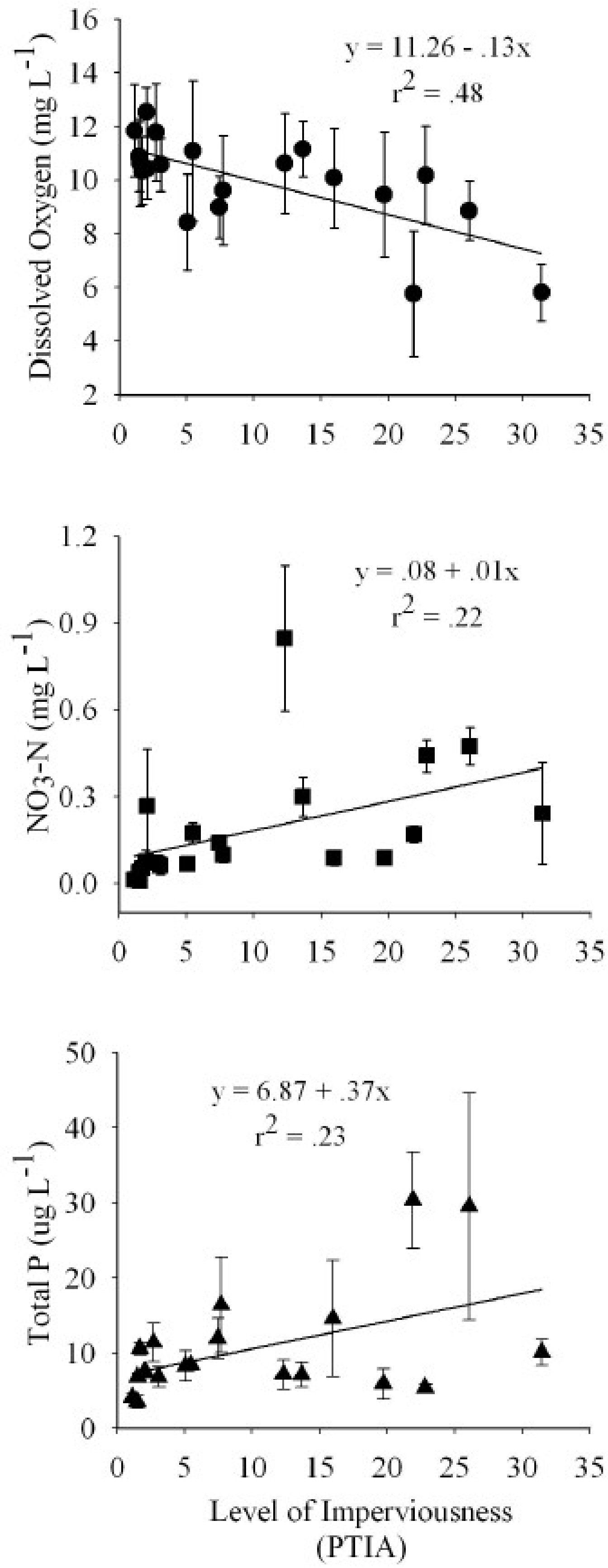

Figure 6. The influence of increasing urban intensity on the dissolved oxygen, nitrate, and total phosphorous concentration of the study streams.

isms: Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). These are insects that are known to vanish quickly from streams under stress. Those streams with less than 6% PTIA supported many more sensitive taxa than those with greater then 10% PTIA.

THE DEVELOPMENT THRESHOLD

The results of the biological analysis suggest that between 6%-10% is the typical level of impervious area for degradation of Maine streams. The apparent variability of the threshold is due to variations on the nature of the imperviousness (i.e. commercial vs. residential), its location in the watershed, and the intactness of the stream-side buffer. All streams, except one, that exhibited significant biological impairment had significant commercial, business or industrial development in their watersheds. The one exception was a small stream that drains a large, densely developed trailer park. Streams with greater than 10% total impervious area exhibited:

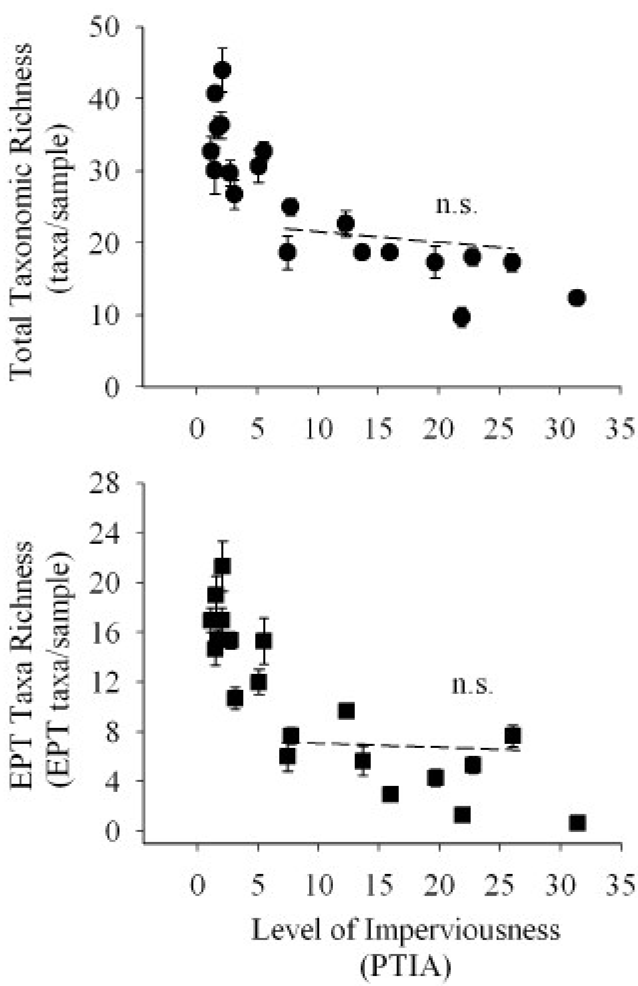

Figure 7. The influence of increasing urban intensity on the total richness and EPT (Ephemeroptera + Plecoptera + Trichoptera) richness of the benthic macroinvertebrate communities of the study streams (n.s. indicates the lack of a statistically significant relationship between the data points and the level of imperviousness.)

- benthic communities that were much less diverse;
- communities composed nearly exclusively of taxa tolerant to pollution and other stressors and nearly devoid of sensitive taxa.

CONCLUSION

Maine streams may have a somewhat lower threshold for impact from development compared to other geographic areas (Table I) because our streams are relatively pristine compared to many other regions.

The amount of imperviousness from development is very predictive of stream degradation. Stream response to imperviousness exhibits a threshold at 6%-10%, beyond which damage to the biotic community is significant. Moreover, because of the degradation of the physical habitat and loss of diversity in food species, we may expect that fisheries will be impacted in a manner parallel to the results for the invertebrates studied here.

This study did not attempt to control for buffer strip presence or absence. It is likely that impacts could be greatly reduced in watersheds with imperviousness above the 10% threshold, if buffer strips and stormwater control measures (such as detention ponds) are used according to ‘best management practices.’

SO NOW THAT WE KNOW… WHAT DO WE DO?

We now have a better understanding that:

a) the quality of Maine streams and aquatic biota is reduced with increasing imperviousness; and that,

b) there appears to be a threshold of 6% to 10% above which the biological community is degraded.

How do we use this threshold for imperviousness as an indicator to preserve Maine’s surface waters?

- We should recognize the irreplaceable value of our aquatic resources when planning development and urban expansion;
- We should support the laws and regulations that manage stormwater, such as the Stormwater Management Law;
- Local officials and land-use decision-makers should consider the proposed level of imperviousness in a development project when evaluating the magnitude of risk in a watershed. Watersheds that are shifting from purely residential to business-commercial land uses are most likely at greatest risk;
- Land developers as well as home and business owners should use ‘best-management practices’ such as vegetated buffer strips, stormwater detention methods, and minimal site clearance for reducing the impact of human activities on aquatic resources;

Table II. A review of our conclusions. From the results of our study, we know that:

the physical condition	is degraded with increasing urban intensity as shown by decreased habitat quality and stability, riparian corridor width, substrate particle size, and increased levels of erosion.
the water quality	is degraded with increasing urban intensity as shown by decreased dissolved oxygen and increased nitrogen, phosphorus, and suspended solids.
the biological community	is degraded, both with decreased richness and a shift in the taxa toward those tolerant to pollution, after relatively low levels of urban intensity.
imperviousness	is a very good indicator of the level of degradation within streams draining urban watersheds.
a threshold phenomenon	exists in Maine's urban watersheds, with greater than 6% - 10% imperviousness within the watershed resulting in degraded biological communities.

· The best and least expensive method to protect surface waters is simply to disturb as little soil as possible, and to maximize infiltration of rain and snowmelt.

From a water resources perspective, there is still much that is not understood about how development affects water bodies and their biological communities. The authors hope this study will serve as a catalyst for future research on the impacts and methods to mitigate the impacts.

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ADDITIONAL RESOURCES

This report is based on a thesis available at the University of Maine Fogler library and at the *Senator George J. Mitchell Center for Environmental and Watershed Research:*

Morse, Chandler, 2001. *The response of first and second-order streams to urban land-use in Maine*. MS thesis, Ecology and Environmental Science Program, University of Maine (98 p).

Additional related information is available from:

Maine Department of Environmental Protection Bureau of Land and Water Quality
http://janus.state.me.us/dep/blwq

Senator George J. Mitchell Center for Environmental and Watershed Research at UMaine
http://www.umaine.edu/WaterResearch/

The Center for Watershed Protection
http://www.cwp.org

U.S. Environmental Protection Agency
http://www.epa.gov/owm/mtbfact.htm

University of WA Center for Urban Water Resources
http://depts.washington.edu/cuwrm

Nonpoint Education for Municipal Officials
http://www.nemo.uconn.edu

Maine State Planning Office
http://www.state.me.us/spo/publications