IMPERVIOUS COVER

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1. OVERVIEW

Water quality can become degraded when pavement, buildings, and other impervious surfaces cover natural lands within a watershed. Impervious cover is a known stressor of both water quality and water quantity, and it affects the natural hydrology and habitat condition of the watershed. Impervious cover promotes aboveground flow of stormwater directly into streams and rivers, rather than infiltration of runoff through the soil, resulting in more nutrients, pathogens and other pollutants entering water bodies.

Studies have shown that when the percentage of impervious cover in a watershed exceeds certain thresholds, it becomes a significant stressor on stream habitat indicators (including stream invertebrates and fish assemblages) and to public health indicators (shellfish and beach closures). Keeping impervious cover below 10 percent is considered an important guideline to protect water resources. However, thresholds of 1 percent to 3 percent impervious cover have been shown to affect sensitive communities such as stream invertebrates. Among the Narragansett Bay's 52 subwatersheds, 36 subwatersheds (69 percent) have impervious cover exceeding the 10 percent threshold, and they account for 85 percent of the total impervious cover in the entire Narragansett Bay watershed.

2. INTRODUCTION

The term impervious cover refers to buildings, pavement, and other unnatural, solid surfaces in a watershed that cause water to flow aboveground, rather than being absorbed by soils or vegetation. By promoting greater runoff from the land into streams and water bodies, impervious cover results in multiple stressors to a watershed, such as increased pollutant loads, altered stream flow, decreased stream bank stability, decreased groundwater recharge, increased peak flows, and increased water temperatures. These stressors have direct impacts on aquatic habitat and associated species.

The amount of impervious cover in a watershed is an integrative, comprehensive, and measurable indicator of the impacts of urban development on ecosystems and water resources (Schueler 1994 and 2003, Allan 2004, Wickham et al. 2016). Impacts in four broad categories include changes in hydrologic, physical, water quality, and biological indicators (Schueler 2003). Impervious cover can influence many hydrologic aspects of streams by shortening the time to flood peaks, causing increases in bankfull discharges and higher surface runoff. Impervious cover is considered a key environmental indicator because of its impacts on aquatic systems and its role in increasing the transport and concentration of pollutants (Arnold and Gibbons 1996, Leopold 1968).

There are numerous studies suggesting that watershed degradation increases substantially when impervious cover reaches a threshold of 10 to 20 percent of the watershed's land area. Schueler (1994, 2003) was among the first to establish, and later refine (Schueler et al. 2009), a conceptual model to apply impervious surface as an index of environmental disturbance. According to the conceptual model, threshold ranges of impervious cover are associated with different degrees of stream quality: sensitive (1–10 percent impervious cover), impacted (11–25 percent impervious cover), non-supporting (26–60 percent impervious cover), and urban drainage (greater than 60 percent impervious cover).

In Maryland, King et al. (2011) documented declines in macroinvertebrate taxa at very low thresholds of less than 2 percent impervious cover. The states of Connecticut and Maine presently use impervious cover thresholds as a mechanism to identify stream segments that are deemed impaired under the Clean Water Act. Connecticut uses a 12 percent impervious cover threshold to identify aquatic life impaired waters, and Maine uses thresholds of 5, 9, and 15 percent for different stream classifications (Wickham et al. 2014). These threshold levels appear to agree with the ranges provided by Schueler et al. (2009), as the impervious cover model clearly identifies the wide variability in stream quality that can occur, especially at lower percentages of impervious cover.

3. METHODS

The Narragansett Bay Estuary Program calculated the status of impervious cover in the Narragansett Bay watershed as the percent of land area that is covered by impervious surfaces. Impervious cover datasets were obtained from Rhode Island (RIGIS) and Massachusetts (MassGIS) and were combined into a seamless dataset by the Rhode Island Department of Environmental Management. The RIGIS data were based on imagery captured in 2011 with a spatial resolution of 2 feet (0.61 meter). The MassGIS data include imagery acquired in 2005 with a 1-meter (3.28 feet) spatial resolution. While the differing dates of the imagery could not be reconciled, the differing spatial resolutions were addressed through the creation of a seamless dataset that had a resolution of 25 feet (7.62 meters). This resolution was deemed appropriate for an analysis at the watershed and subwatershed scale.

Impervious surface data are also available through the National Land Cover Database (NLCD). However, the resolution of the national dataset is in most cases 30 meters (98.4 feet). The high-resolution datasets provided by RIGIS and MassGIS include smaller cell areas, or pixels, and the seamless dataset with a resolution of 25 feet more accurately reflect the extent of impervious cover at the watershed and subwatershed scales. Further, studies in Massachusetts and Rhode Island concluded that the NLCD underestimated impervious cover in low-development areas and overestimated it in highly urbanized areas (Weiskel et al. 2010, Smucker et al. 2016).

We used the seamless dataset to determine the total area of impervious cover and the percentage of impervious cover within the Narragansett Bay watershed, which we calculated using geostatistical analysis software at the HUC12 subwatershed scale and at the HUC10 watershed scale. Trends could not be calculated for impervious cover in the watershed, as the older methods used to map impervious cover and the spatial resolution were not comparable to the more recent dataset (see "Land Use" chapter for urban development trends); however, the Estuary program is coordinating with researchers at USEPA to examine trends in impervious cover. We used impervious cover thresholds similar to those offered by Schueler et al. (2009) to relate impervious cover to stream quality within the Narragansett Bay watershed. Specifically, we categorized HUC12 subwatersheds with less than 10 percent impervious cover as sensitive and those with 10 percent or more impervious cover as impacted.

4. STATUS AND TRENDS

According to the 2005 and 2011 data, areas of impervious cover constituted 14 percent of the Narragansett Bay watershed, as there were an estimated 155,274 acres of impervious cover in the 1,091,120-acre watershed (Table 1). The Pawtuxet River, Taunton River, and Blackstone River basins all had 12 percent impervious cover. In contrast, the coastal Narragansett Bay basin had 20 percent impervious cover (Table 1).

Table 1. Extent and percent of impervious cover in the Narragansett Bay watershed and river basins. Sorted by highest to lowest percent of impervious cover.

River Basins	Extent (Acres)	Percent of Watershed Area
Narragansett Bay Watershed	**155,274**	**14**
Coastal Narragansett Bay Basin	58,956	20
Blackstone River Basin	37,586	12
Taunton River Basin	41,105	12
Pawtuxet River Basin	17,627	12

Of the Narragansett Bay's 52 HUC12 subwatersheds, 36 subwatersheds (69 percent) were categorized as impacted because they exceeded the 10 percent impervious cover threshold, and 16 subwatersheds (31 percent) were deemed sensitive as they were below that threshold (Tables 2 and 3). Figure 1 illustrates the variation in impervious cover among HUC12 subwatersheds according to percentage thresholds.

Table 2. Number of Narragansett Bay HUC12 subwatersheds with impervious cover above ecologically important thresholds. Gray indicates those above the Estuary Program's threshold of 10 percent impervious cover.

1%	3%	5%	10%	15%	20%
0	5	11	17	6	13

Table 3. Extent and percent of impervious cover in Narraganset Bay HUC12 subwatersheds. Sorted from lowest to highest percent impervious cover. Shading indicates thresholds of 5 percent (light gray), 10 percent, 15 percent, and 20 percent (darkest gray) impervious cover.

HUC12 Subwatershed Name	Extent (Acres)	Percent
Big River	580	3.2
Scituate Reservoir	801	3.2
Barden Reservoir-Ponaganset River	683	3.2
Clear River	1,385	4.8
Chepachet River	669	4.9
Headwaters South Branch Pawtuxet River	1,005	5.6
Assawompsett Pond	1,784	5.7
Moswansicut Pond-Huntinghouse Brook	824	5.8
West River	1,546	6.5
Assonet River	1,495	6.9
Mumford River	2,711	7.5
Branch River	1,313	7.7
Palmer River	2,590	8.0
Sakonnet River	1,924	8.6
Winnetuxet River-Taunton River	2,729	8.6
Nemasket River	1,275	9.5

Mill River – Blackstone	2,429	11.2
Wading River	3,213	11.5
Mill River	3,330	11.5
North Branch Pawtuxet River	1,048	11.6
Satucket River	2,626	11.7
Emerson Brook-Blackstone River	2,584	11.8
Singletary Brook-Blackstone River	3,088	12.1
Kettle Brook	2,540	12.2
Abbott Run	2,294	12.5
Hunt River	1,962	12.6
Cotley River-Taunton River	4,837	12.6
Town River	5,043	13.0
Pettaquamscutt River-Frontal Atlantic Ocean	1,432	13.2
Lower West Passage	2,318	13.5
Threemile River	3,706	13.9
Upper West Passage	723	14.0
Taunton River-Frontal Mount Hope Bay	4,569	14.9
Upper East Passage	1,538	16.2
Quequechan River	3,152	16.4
Mount Hope Bay	4,525	17.5
Peters River-Blackstone River	5,127	19.1
Quinsigamond River	4,688	19.3
Woonasquatucket River	6,459	19.7
South Branch Pawtuxet River	2,458	23.1
Ten Mile River	8,394	23.6
Matfield River	6,497	24.3
Pocassett River	3,196	24.3
Barrington River-Warren River	2,611	24.3
Aquidneck Island-Frontal Atlantic Ocean	1,629	27.4
Lower East Passage	1,988	28.5
Tatnuck Brook-Blackstone River	7,211	29.0
Greenwich Bay	3,972	29.7
Upper Narragansett Bay	1,945	30.3
Moshassuck River	4,627	31.3
Pawtuxet River	7,033	36.0
Seekonk River-Providence River	7,143	47.2

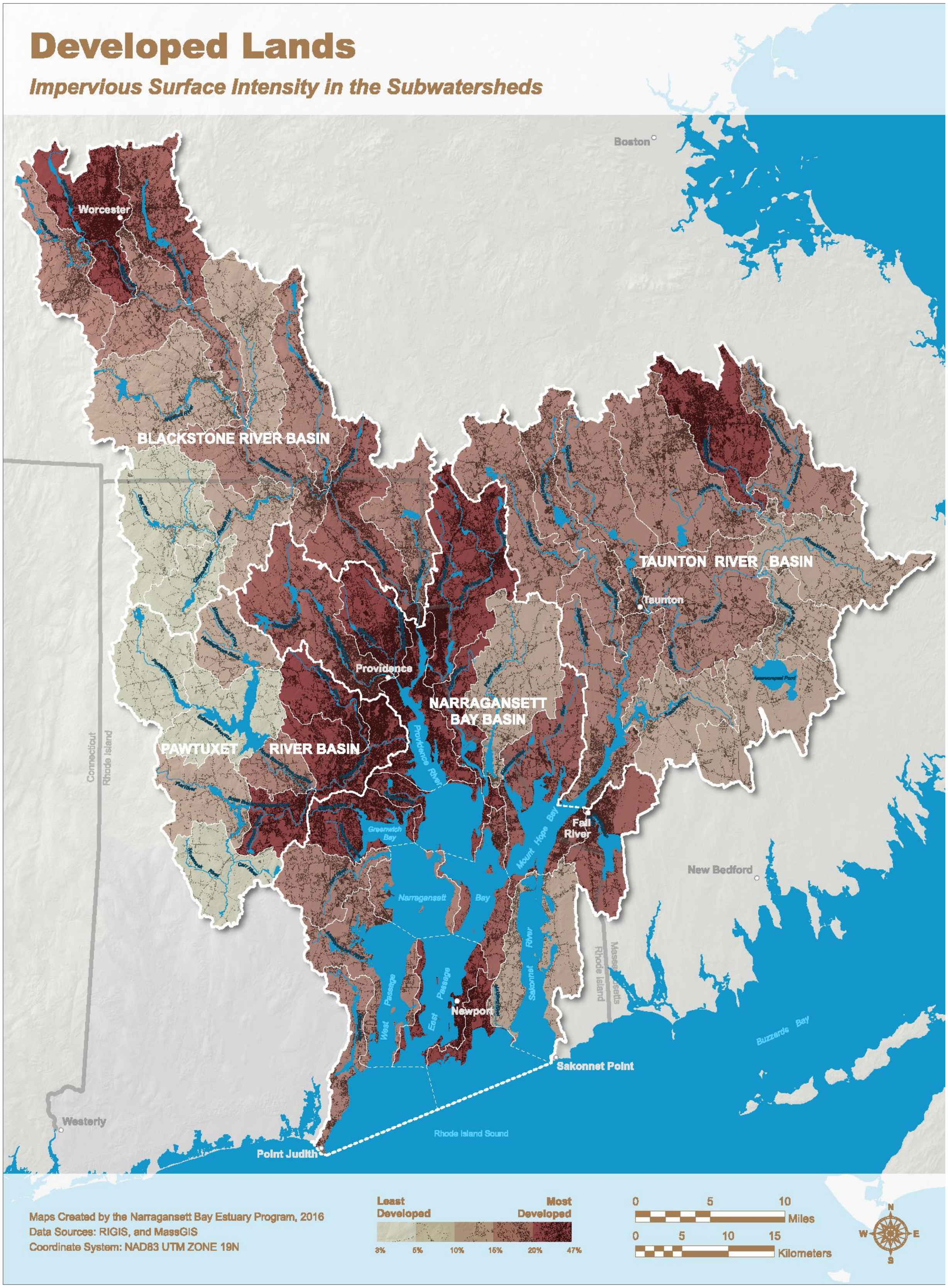

Figure 1. Impervious cover in the Narragansett Bay watershed.

We also calculated the extent and percent of impervious cover at the scale of HUC10 watersheds as an alternative way to examine watershed impacts (Table 4). The Middle Taunton River HUC10 watershed had the least developed land with an impervious coverage area of just over 9 percent, and the Lower Blackstone River HUC10 was the second least developed watershed with just over 10 percent impervious cover. The two most developed watersheds were the Ten Mile River and Woonasquatucket River-Moshassuck River HUC10s with over 23 percent impervious cover (Table 4).

Table 4. Extent and percent of impervious cover in Narragansett Bay HUC10 watersheds. Sorted by highest to lowest percent impervious cover.

HUC10 Watershed Name	**Extent (Acres)**	**Percent**
Ten Mile River	8,394	23.6
Woonasquatucket River-Moshassuck River	11,085	23.3
Narragansett Bay	31,100	20.1
Upper Taunton River	14,167	16.1
Upper Blackstone River	20,238	15.4
Threemile River	6,919	12.7
Lower Taunton River-Frontal Mount Hope Bay	12,546	12.5
Palmer River	5,201	12.0
Pawtuxet River	17,627	11.9
Lower Blackstone River	17,346	10.1
Middle Taunton River	10,624	9.2

5. DISCUSSION

The amount of impervious cover in Narragansett Bay's HUC12 subwatersheds demonstrates the considerable extent of urbanization around the Bay. Impervious cover exceeded the 10 percent ecological threshold in 36 of the 52 subwatersheds, which together contained 131,933 acres of impervious cover or 85 percent of all the impervious cover in the Narragansett Bay watershed (Table 5). In fact, HUC12 watersheds with greater than 10 percent impervious cover constituted 66 percent of the total Narragansett Bay watershed area (722,357 acres) (Figure 1; Table 5).

Using the impervious cover model prepared by Schueler et al. (2009), 28 subwatersheds were deemed impacted (11–25 percent impervious cover), and 8 were deemed non-supporting (greater than 26 percent impervious cover). Non-supporting streams are defined as no longer supporting hydrological, habitat, water quality, and biological diversity functions (Schueler et al. 2009). The urbanized areas around Providence, Worcester, Brockton, Fall River, and Newport contained the vast majority of impervious cover (Figure 1).

Table 5. HUC12 subwatersheds with total area and percent within impervious cover thresholds.

HUC12 subwatersheds within Impervious Cover Thresholds	Number of HUC12 subwatersheds within thresholds	Total area of the HUC12 subwatersheds within thresholds (Acres)	Percent of the Narragansett Bay watershed within thresholds	Total area of impervious cover within thresholds (Acres)	Percent of total impervious cover within thresholds
Between 0% and 5%	5	106,740	10	4,118	3
Between 5% and 10%	11	262,014	24	19,196	12
Between 10% and 15%	17	379,968	35	47,743	31
Between 15% and 20%	6	138,491	13	25,487	16
Over 20%	13	203,898	19	58,703	38

The 5 most sensitive HUC12 subwatersheds—all of which had less than 5 percent impervious cover—were located in the western portion of the watershed. The three lowest were located in the Pawtuxet River Basin (including two near the Scituate Reservoir), and the two next lowest were in the southwestern portion of the Blackstone River basin (Figure 1; Tables 3 and 5). The remaining eleven subwatersheds with impervious cover of 5 to 10 percent were distributed throughout the watershed in the upper reaches. The two HUC12 subwatersheds that stand in stark contrast to other urbanized areas in the coastal Narragansett Bay basin were the Palmer River and the Sakonnet River with 8 percent and 8.6 percent impervious cover, respectively. Neighboring subwatersheds had more than 20 percent impervious cover (Figure 1; Table 3). Importantly, the 16 HUC12 subwatersheds in which impervious cover was below 10 percent (sensitive subwatersheds) encompassed 368,755 acres (34 percent of the Narragansett Bay watershed) and should be examined for continued protection through open space and stream corridor protection (see "Open Space" chapter).

It is noteworthy that percent imperviousness is irreversible in most cases, and it can typically only increase over time. However, the effects of increased impervious cover can be mitigated to some degree by retrofitting urban drainage infrastructure with storage areas to contain stormwater (Novotny et al. 2005). While numerous management efforts have been undertaken in the Narragansett Bay watershed to implement green infrastructure through stormwater best management practices, these efforts are not widely inventoried, monitored, or assessed for their effectiveness.

Not all impervious cover is directly connected hydrologically to surface water bodies through storm drains or other drainage infrastructure (Weiskel et al. 2010). Connected impervious area has a greater effect on water quality than impervious areas separated from waterbodies (Schuler 2004). The development of a functional relationship between total impervious cover and connected impervious cover is a topic of active research (Weiskel et al. 2010). Wickham et al. (2014 and 2016) argue that there is a distinction among the total impervious cover in a watershed, the connected impervious cover, and the impervious cover in the vicinity of surface waters.

It seems appropriate to consider refinement of the impervious cover indicator. This would require further analysis of connected impervious cover and proximal distribution of impervious cover, and extensive information on stormwater infrastructure. Better management of stormwater runoff from impervious surfaces will help municipalities become more resilient. Gathering an inventory of stormwater infrastructure, the locations of best management practices, and drainage areas to which they are connected is essential, particularly given climate change and the projection of more intense storms and rainfall (see "Precipitation" chapter).

6. DATA GAPS AND RESEARCH NEEDS

Fine-scale mapping of impervious cover at broad spatial extents is needed to provide a reliable and reproducible indicator for predicting and tracking trends in aquatic condition in freshwater and estuarine systems. Additional research involving high-resolution image analyses is needed to develop impervious surface area estimates at regional, watershed, and subwatershed level scales. Data sources of high-resolution imagery (1 meter or less resolution) for these analyses include the National Agriculture Imagery Program (NAIP), RIGIS, and MassGIS. Cost-effective methods are being developed using readily available National Agriculture Imagery Program data, developed by the United States Department of Agriculture, for characterizing impervious cover from high-resolution data.

As previously mentioned, further research is needed to evaluate relationships of impervious cover to stream connectedness. Findings from these studies may support refinements to the impervious cover indicator.

Stormwater regulations, created in response to concerns of impervious cover impacts on watersheds, have increased the implementation of stormwater best management practices, but there is no centralized database that documents or maintains information. This could be accomplished through the permit process by requiring that information on the location and type of stormwater management practice (e.g., swales, detention basin) be submitted and then managed as GIS shapefiles. Collection of these data, coupled with data on water quality, biotic indices, and hydrologic condition, among others, will provide an opportunity to evaluate the effectiveness of stormwater management practices at the watershed scale.

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