State of Narragansett Bay and Its Watershed
2017 Technical Report

Landscape Stressor Indicators

CHAPTER 5: LAND USE

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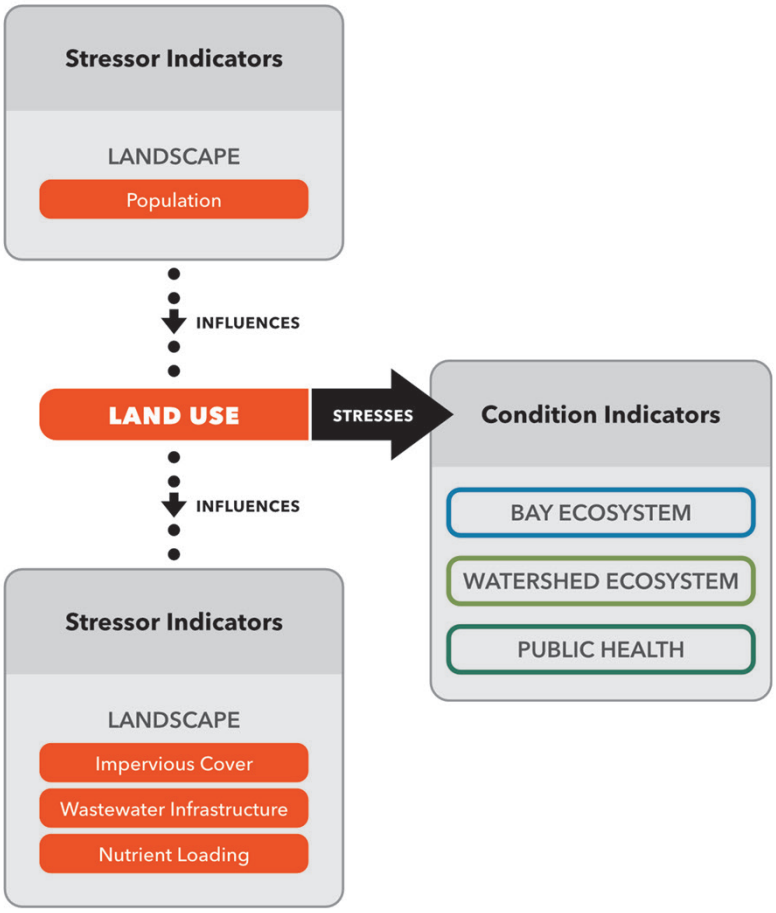
NARRAGANSETT BAY ESTUARY PROGRAM

Photo: Aerial view of Bristol, RI with Fall River and Somerset, MA in the distance (Ayla Fox)

Overview



BACKGROUND

- Changes in land use in the Narragansett Bay Watershed, especially the conversion of natural lands to urban areas, affects hydrologic functions, alters the delivery of nutrients to rivers and the Bay, affects terrestrial, aquatic and estuarine wildlife and habitat conditions, and contributes to increased pathogens in recreational and shellfishing waters. Land use changes that reduce natural lands are an indicator of habitat fragmentation, diminishing habitat value as well as water quality and quantity.

KEY FINDINGS

- ***Status:*** As of 2011, coastal subwatersheds (HUC12) were the most urbanized in the Watershed, ranging from 65 to 85 percent urban lands. Conversely, 70 percent of land in less-developed headwater subwatersheds was classified as forest.

- ***Trends:*** From 2001 to 2011, forest lands decreased in the Bay's Watershed by four percent, and urban lands increased by 8.5 percent, encroaching into rural areas. Watersheds (HUC10) of the Taunton River Basin experienced dramatic changes. Forest lands of the Upper-Taunton River and Ten Mile River decreased by nine percent, and the Middle-Taunton River had an 18 percent increase in urban lands as forest lands were lost to new developed areas.

Introduction

Land development and some types of land uses in the Narragansett Bay Watershed are stressors on water quality, water quantity, freshwater and estuarine habitats, and human health. The conversion of natural lands such as forests and wetlands to human-dominated uses can exert considerable influence on runoff quality and quantity, and contribute to increases in water pollution (Tu and Xia 2006).

Sources of water pollution are generally grouped into two categories: point sources and non-point sources. Over the past few decades, point source pollution, including from domestic and industrial wastewater discharges (see "Wastewater Infrastructure" chapter), has been greatly reduced through management actions and changes in industrial uses, as local economies shift from manufacturing-based sectors to service-based economies (USEPA 2008). Conversion of a natural land cover such as forests to an urban or developed land use can significantly increase non-point source stressors as well as the flow patterns of streams after rain events. Non-point source inputs are influenced by land use alteration (impervious land, agriculture, golf courses, residential and commercial development), riparian buffer degradation, sediment from poorly managed construction sites, stormwater runoff, road salt, atmospheric deposition of nitrogen, failing septic systems, and other factors. Human population growth is a fundamental driving force in land conversion. As the population grows, the infrastructure to support homes, transportation, and commerce increases (Meyer and Turner 1992, August et al. 2002).

Several studies have provided comprehensive historical analyses of watershed stressors and responses for Narragansett Bay from 1850 to 2000 (Nixon 1997, Hamburg et al. 2008, Vadeboncoeur et al. 2010, Pastore 2011). Others have assessed trends in historical land use and changes in impervious surface cover at the state level in Rhode Island and Massachusetts for large portions of the Narragansett Bay Watershed but not the entire Watershed (Novak and Wang 2004, Rhode Island Statewide Planning Program 2006, Stone 2007, Zhou and Wang 2007, Tu et al. 2007, Blumstein and Thompson 2015). Those studies highlighted the conversion of forest and agricultural lands to residential, commercial, and industrial developed lands as significant trends within the Watershed and the surrounding parts of Rhode Island and Massachusetts. The most recent assessment of land use change by the Massachusetts Audubon Society reported that approximately 38,000 acres of forest or other undeveloped land were converted to development in Massachusetts between 2005 and 2013 (Mass Audubon 2014).

The conversion rate of natural land cover to developed land has outpaced the population growth rate in this region (see "Population" chapter) over the last few decades. In addition, recent changes in land use have not been distributed uniformly across the Narragansett Bay Watershed; they have varied temporally and spatially as the population has moved from the urbanized centers to the more suburban and rural parts of the Watershed. This chapter presents an analysis of land use change in the Watershed, focusing on the changes in area (acreage) of forest lands and urban lands in the decade from 2001 to 2011. The chapter also discusses historical changes in land use and the rates of change since the industrial revolution.

Methods

The methods for analyzing land use as an indicator of environmental conditions in the Narragansett Bay Watershed were developed by the US Environmental Protection Agency (EPA) Office of Research and Development (ORD), National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division in collaboration with the Narragansett Bay Estuary Program and other partners. A work group of

GIS specialists examined and selected the data and data processing methods used for this indicator.

NATIONAL LAND COVER DATABASE (NLCD)

The National Land Cover Database (NLCD) was used to classify land use at a resolution of 30 meters (Homer et al. 2015). For this analysis, the NLCD's sixteen classes of land use were aggregated into seven land use categories based on the seven classes of the Anderson Level I classification scheme (Anderson et al. 1976) (see Table 14 in Extended Methods section of this chapter). Land use data were analyzed for the Narragansett Bay Watershed using an array of geospatial tools (Esri 2016, ArcGIS Desktop platform).

Using NLCD data from 2011, the Estuary Program calculated the status of the seven land use categories, including the total acreage in each category and the percentage of the Narragansett Bay Watershed in each category. This chapter focuses on two of the land use classes: urban lands and forest lands. Data for 2001, 2006, and 2011 were analyzed at three spatial scales: the Narragansett Bay Watershed, watersheds (HUC10), and subwatersheds (HUC12) (see the Appendix for definitions, lists, and maps).

The Estuary Program focused on two of the seven land use categories (urban lands and forest lands) for three reasons: (1) these two categories cover the majority (74 percent) of the Watershed, (2) an increase in urban and a decrease in forest lands can indicate that the Watershed is changing to a more disturbed condition, and (3) preliminary analysis of other land use types revealed that changes were not as large compared to urban and forest lands.

Land use data from NLCD 2001 (2011 Edition), 2006 (2011 Edition), and 2011 were utilized for the change analysis. NLCD land use datasets for years prior to 2001 are incompatible for comparison with the more recent datasets. The 2001, 2006, and 2011 NLDC datasets all have a sixteen-class land cover classification scheme and are based primarily on a decision-tree classification of circa 2001, 2006, and 2011 Landsat satellite data, respectively. The Multi-Resolution Land Characteristics Consortium cautions against using NLCD data in watersheds on a scale of less than tens of square kilometers (USGS 2012). However, a multiple-extents accuracy assessment suggested that NLCD data may be accurate for spatial extents as small as ten square kilometers, particularly for predominant land use classes or those with unique spectral signatures (Hollister et al. 2004). The smallest HUC12 subwatershed within the Narragansett Bay Watershed is 21 square kilometers, and thus the NLCD data were used with confidence at HUC10 watershed and HUC12 subwatershed scales.

Change analyses were based on total gross change in acreage and net percent change within each geographic scale. Total gross change represents the change in acreage by category, and net percent change is the change of area in percentage between two specific dates (Loveland et al. 2002, Sohl et al. 2004). Gross change and net percent change were calculated as follows:

$$Gross\ change = Acreage\ in\ 2011 - Acreage\ in\ 2001$$

$$(Net)Percent\ change = \frac{Acreage\ of\ 2011 - Acreage\ of\ 2001}{Acreage\ of\ 2001} x100$$

STATE-LEVEL LAND USE DATA

In addition, data with finer spatial resolution were available at the state level in both Massachusetts and Rhode Island (Massachusetts: 1.0-acre resolution; Rhode Island: 0.5-acre resolution), and those datasets offered the advantages of increased spatial resolution and interpretation of land use classification. However, using those data required matching or a "crosswalk" of land use classifications across state boundaries (Table 1; Tables 14, 15, and 16 in Extended Methods section of this chapter), both spatially and temporally. Because land use data are not consistent methodologically across states and years within each state, and it is unknown when the states would update their land use data, the Estuary Program decided it was most appropriate to use the NLCD data for tracking long-term trends across the Watershed. Results using the state land use data crosswalk are presented in this chapter only to compare between state and national land use datasets (Table 1; Tables 14, 15, and 16 in Extended Methods section of this chapter). For the state temporal crosswalk, the most recent data for Massachusetts were from 2005, while Rhode Island's most recent data were from 2011, making it necessary to match data from earlier years (2003–2004) for Rhode Island.

The Estuary Program compared land use categories from NLCD 2011 and bi-state crosswalk data (Massachusetts 2005 and Rhode Island 2003–2004) within the Watershed. There is close agreement between these two datasets, which supports the use of the National Land Cover Database data for the status and change analyses, despite the difference in geographical resolution, temporal scales, and methodology.

Table 1. Types of state land use classes compared to Anderson Level I classification scheme.

Anderson Level I Categories	Bi-state Crosswalk of Land Use Types[1]
Urban Land	high, medium, low residential; commercial, industrial, transportation, cemeteries, wastewater treatment facilities, waste disposal, landfills, commercial water-based facilities, airports, railroads, urban parks, zoos, golf courses
Agricultural Land	pasture, hay fields, orchards, concentrated animal feeding operations, cropland, nurseries
Forest Land	deciduous, evergreen, mixed
Brushland	shrub and brush areas undergoing reforestation
Wetland[2]	*Rhode Island:* non-forest wetlands; *Massachusetts:* forest and non-forest wetlands, and saltwater wetlands
Barren	beaches, sandy areas other than beaches, rock outcrops, gravel, mining pits
Water	reservoirs, lakes and ponds

[1] This is an overarching summary of Land Use classes by each state as listed in Tables 15 and 16 in Extended Methods section of this chapter.

[2] Differences between NLCD and across states for classifying wetlands is noteworthy since this chapter focuses on changes of forest lands and not wetlands. For instance, NLCD classifies forested wetland as "wetland", while Rhode Island classifies forested wetland as "forest land" for the 2004-2005 land use classification (RIGIS 2007).

Table 2. Land use in the Narragansett Bay Watershed[1] based on NLCD (2011) and state (2003–2005) data.

Land Use Category	National Land Cover Dataset 2011[2]		Crosswalk State Data 2003–2005	
	Acres	Percent	Acres	Percent
Urban or Built-up[3]	379,804	34.7	413,455	37.9
Forest Land[3]	424,642	38.8	429,234	39.3
Agricultural Land	68,358	6.2	51,095	4.7
Brushland	10,711	1.0	6,895	0.6
Barren	8,713	0.8	11,008	1.0
Wetland	164,895	15.1	135,115	12.4
Water	36,668	3.4	44,164	4.0

[1] Total area of Narragansett Bay Watershed is 1,091,112 acres.

[2] Data source used for change analysis of urban and forest lands.

[3] Land use categories used for change analysis.

Urban lands and forest lands constituted 35 percent and 39 percent of the Narragansett Bay Watershed, respectively, based on the most recent 2011 National Land Cover Database (Table 2). These results are very similar to the results based on the bi-state crosswalk data for Rhode Island (2003-2004) and Massachusetts (2005), which showed urban lands as 38 percent and forest land as 39 percent of the Watershed. The remaining 27 percent of the Watershed (based on NLCD) were a combination of land uses including agriculture, brushland, barren land, wetlands, and water (Table 2).

HISTORICAL TRENDS

Based on previous research by Vadeboncoeur and colleagues (2010), the Narragansett Bay Estuary Program calculated historical changes in urban and forest land that encompassed eras of industrialization and suburbanization.

Because Vadeboncoeur and colleagues (2010) calculated and provided data on historical land cover by percent of urban and forest and inland water[1] by subwatershed[2], as opposed to by total area, the Estuary Program analyzed each of these land cover types as percent point change (see Tables 17 and 18 in Extended Methods section of this chapter).

COMPARING METHODS ACROSS INDICATORS: LAND USE (FOREST LANDS) AND OPEN SPACE

In the "Open Space" chapter of this report, the Estuary Program developed a methodology, differing from the analysis used in this chapter, to analyze open space lands classified as protected natural lands and unprotected natural lands. The open space chapter did not use the NLCD data, and instead used the Conservation Assessment and Prioritization System (CAPS), which ranks natural lands, including forest and wetlands among other natural features in the landscape, from lowest to highest ecological integrity (Index of Ecological Integrity 0.01 to 1). Although the results using CAPS were similar to those based on NLCD–differing by one percent in total acreage in the Watershed–the results presented in this chapter and those in the "Open Space" chapter should be interpreted separately due to the methodological differences (Table 3).

[1] Inland waters accounted for greater than five percent of total cover in all subwatersheds (Vadeboncoeur et al. 2010).

[2] These subwatersheds are not comparable with any of the Estuary Program's geographical scales. Vadeboncoeur and colleagues (2010) defined the subwatersheds for their study by the municipal boundaries of the drainage areas.

Table 3. Comparison of forest lands data (NLCD) from this chapter with natural lands data from the "Open Space" chapter.

Estuary Program Method	Area (Acres)	Percent
Total NLCD (Forest Lands and Wetlands)	589,470	54
Forest Lands (NLCD 2011)(1)	424,642	39
Wetlands (NLCD 2011)	164,828	15
Index of Ecological Integrity (CAPS 0.01-1)(2)	600,140	55

- (1) Data used to analyze extent of forest land in this chapter.
- (2) Conservation Assessment and Prioritization System (CAPS) data used to analyze natural lands in "Open Space" chapter.

Status and Trends

As of 2011, the Narragansett Bay Watershed still had more forest lands than urban lands (Table 2).

STATUS OF URBAN LANDS

The urban land area of the Narragansett Bay Watershed totaled 379,804 acres in 2011, representing 35 percent of the Watershed (Figure 1; Table 2). In HUC10 watersheds, urban land ranged from a low of 22 percent (25,300 acres) in the Middle Taunton River watershed to a high of 55 percent (19,667 acres) in the Ten Mile River watershed (Table 8).

Of the 52 HUC12 subwatersheds, fifteen subwatersheds had more than 50 percent of their area classified as urban, while only four subwatersheds had ten percent or less of their land classified as urban (Table 4). All five of the HUC12 subwatersheds with the highest percentages of urban land were adjacent to and drain directly to Narragansett Bay (Seekonk River-Providence River, Greenwich Bay, Upper Narragansett Bay, Pawtuxet River, and the Aquidneck Island-Frontal Atlantic Ocean), and they correspond closely with the subwatersheds with the lowest percentages of forest land (Table 4).

STATUS OF FOREST LANDS

There were 424,642 acres of forest land in the Narragansett Bay Watershed in 2011, constituting 39 percent of the Watershed (Figure 2; Table 2). The HUC10 watershed with the lowest percentage of forest land was the Ten Mile River, which had only 24 percent (8,461 acres) forest. The watershed with the highest percentage was the Lower Blackstone River with 55 percent (94,731 acres) (Table 9).

Of the 52 HUC12 subwatersheds, twelve had more than 50 percent forest. The five subwatersheds with the highest percentages of forest land were the Barden Reservoir-Ponaganset River, Clear River,

Table 4. Subwatersheds (HUC12) in the Narragansett Bay Watershed with the highest and lowest percentages of urban lands.

Subwatershed (HUC12) Name	Urban Lands (NLCD 2011)	
	Acreage	Percent
Urban lands ≥50 percent of the subwatershed:		
Seekonk River-Providence River	5,978	85.5
Greenwich Bay	4,210	75.9
Upper Narragansett Bay	3,687	75.7
Pawtuxet River	2,751	75.7
Aquidneck Island-Frontal Atlantic Ocean	1,544	71.3
Moshassuck River	6,419	65.8
Tatnuck Brook-Blackstone River	1,706	63.3
South Branch Pawtuxet River	3,037	62.2
Lower East Passage	1,594	61.8
Matfield River	2,975	60.3
Barrington River-Warren River	14,182	59.3
Quinsigamond River	5,585	57.0
Pocassett River	10,347	56.9
Ten Mile River	2,110	55.2
Upper East Passage	6,236	50.8
Urban lands ≤10 percent of the subwatershed:		
Clear River	9,008	10.2
Big River	3,025	9.4
Scituate Reservoir	4,423	8.7
Barden Reservoir-Ponaganset River	14,459	7.3

(1) Total area and maps of the subwatershed (HUC12) are provided in the Appendix.

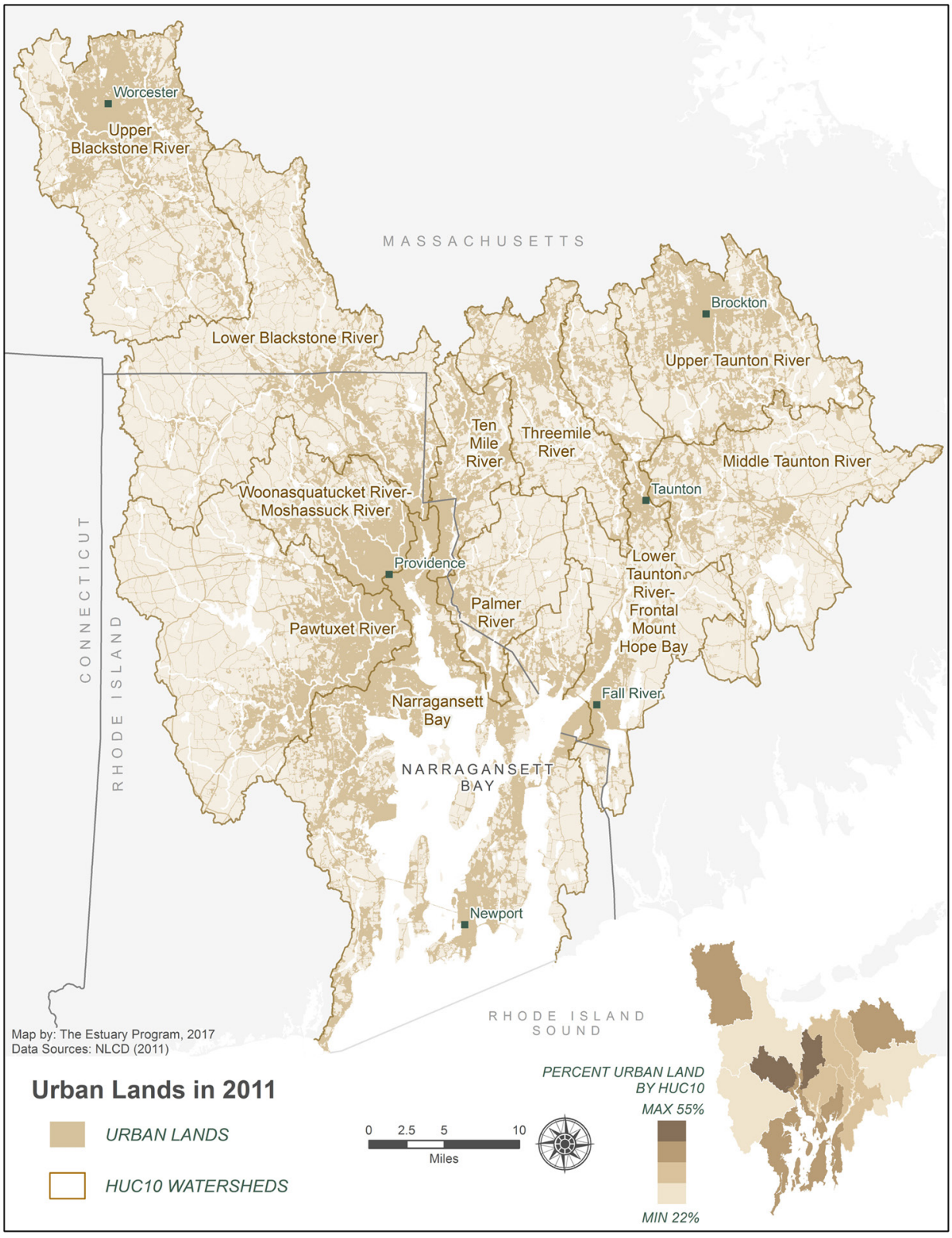


Figure 1. Urban lands (NLCD 2011) in the Narragansett Bay Watershed. Inset map: Percent of urban lands for each watershed (HUC10).

Figure 2. Forest lands (NLCD 2011) in the Narragansett Bay Watershed. Inset map: Percent of forest lands for each watershed (HUC10).

Table 5. Subwatersheds (HUC12) in the Narragansett Bay Watershed with the highest and lowest percentages of forest lands.

Subwatershed (HUC12)[1] Name	Forest Lands (NLCD 2011) Acreage	Percent
Forest lands ≥50 percent of the subwatershed:		
Barden Reservoir-Ponaganset River	7,956	71.9
Clear River	380	70.8
Big River	14,195	70.3
Chepachet River	12,014	66.4
Headwaters South Branch Pawtuxet River	15,142	66.1
Moswansicut Pond-Huntinghouse Brook	1,575	65.9
Scituate Reservoir	12,760	63.2
West River	10,218	63.1
Mumford River	9,094	60.4
Branch River	20,558	60.0
Assonet River	11,536	54.9
Emerson Brook-Blackstone River	11,887	54.2
Forest lands ≤10 percent of the subwatershed:		
Upper Narragansett Bay	14,970	8.5
Aquidneck Island-Frontal Atlantic Ocean	11,005	6.4
Seekonk River-Providence River	12,699	5.6

[1] Total area and maps of the subwatershed (HUC12) are provided the Appendix.

Table 6. Total area (acres) and percentage of forest and urban lands in the Narragansett Bay Watershed[1] in 2001, 2006, and 2011 (NLCD).

Land Use Category	2001		2006		2011	
	Acreage	Percent	Acreage	Percent	Acreage	Percent
Forest	443,800	40.6	430,793	39.4	424,642	38.8
Urban	350,369	32.0	371,836	34.0	379,804	34.7

[1] Total area of Narragansett Bay Watershed is 1,091,112 acres.

Table 7. Total gross change (acres) and percent change of forest and urban lands in the Narragansett Bay Watershed over five-year periods—2001 to 2006 and 2006 to 2011—and the full ten-year period of 2001 to 2011 (NLCD).

Land Use Category	2001 to 2006		2006 to 2011		2001 to 2011	
	Acreage	Percent Change	Acreage	Percent Change	Acreage	Percent Change
Forest	-13,007	-2.9	-6,151	-1.4	-19,158	-4.3
Urban	21,467	6.2	7,968	2.1	29,435	8.5

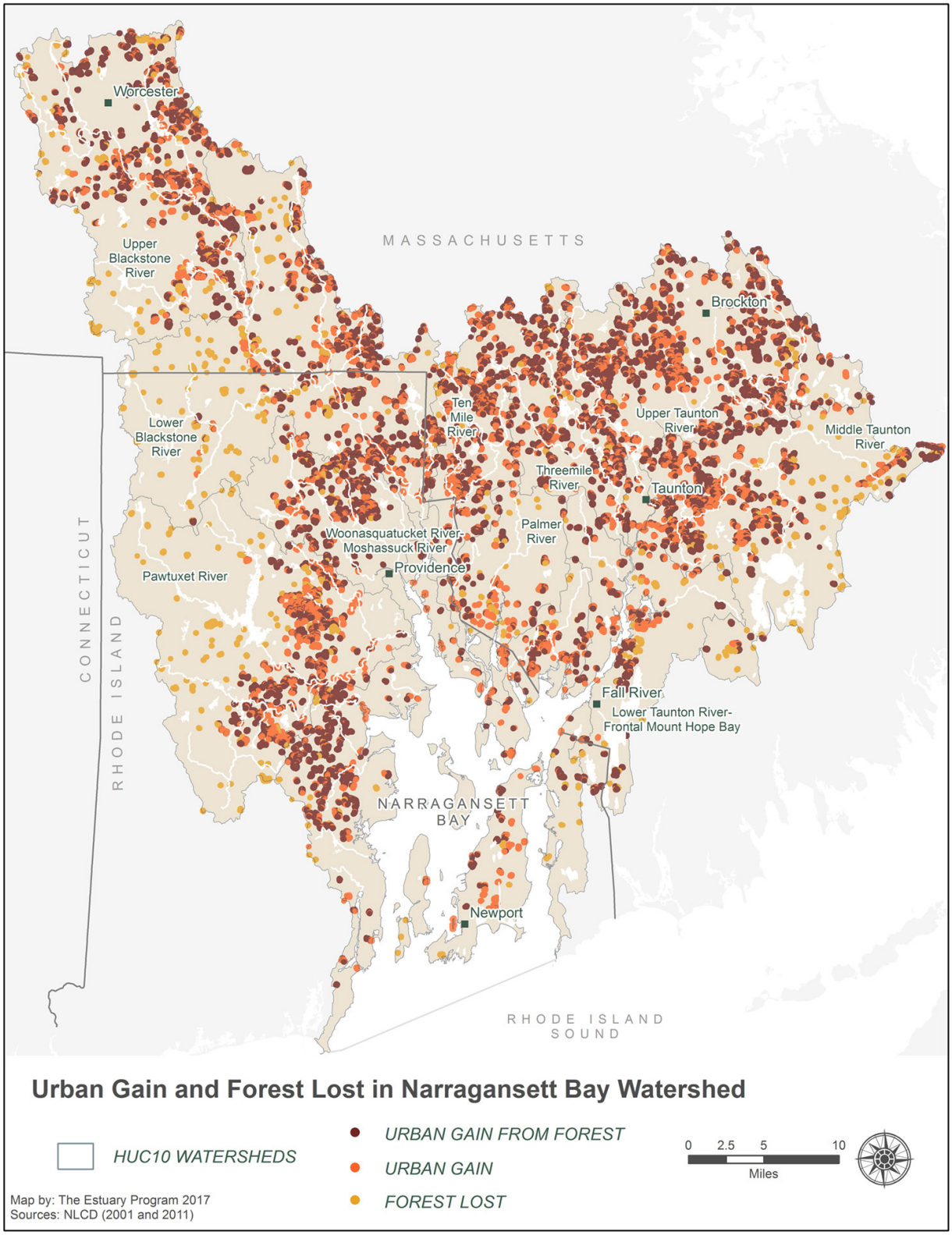


Figure 3. Changes from 2001 to 2011 in forest and urban lands.

Table 8. Total area and percent of urban lands in 2001, 2006, and 2011 in Narragansett Bay's HUC10 watersheds.

HUC10 watersheds[1]	2001		2006		2011	
Name	Percent	Acreage	Percent	Acreage	Percent	Acreage
Lower Blackstone River	21.2	36,508	22.8	39,224	23.5	40,463
Lower Taunton River-Frontal Mount Hope Bay	27.3	27,586	29.0	29,258	29.9	30,177
Middle Taunton River	18.7	21,472	21.3	24,441	22.0	25,300
Narragansett Bay	48.6	76,481	50.1	78,403	50.4	79,051
Palmer River	27.9	12,161	29.1	12,658	29.4	12,807
Pawtuxet River	25.6	37,971	27.2	40,396	27.4	40,662
Ten Mile River	51.0	18,160	54.5	19,410	55.2	19,667
Threemile River	31.7	17,283	34.6	18,862	36.4	19,885
Upper Blackstone River	34.3	45,102	36.4	47,805	37.3	49,078
Upper Taunton River	39.7	34,945	42.7	37,592	44.0	38,693
Woonasquatucket River-Moshassuck River	48.1	22,841	50.4	23,938	50.9	24,174

[1] Total area and maps of the watersheds (HUC10) are provided in the Appendix.

Table 9. Total area and percent of forest lands in 2001, 2006, and 2011 in Narragansett Bay's HUC10 watersheds.

HUC10 watersheds	2001		2006		2011	
Name	Percent	Acreage	Percent	Acreage	Percent	Acreage
Lower Blackstone River	56.6	97,469	55.6	95,750	55.0	94,731
Lower Taunton River-Frontal Mount Hope Bay	38.6	39,026	37.7	38,033	37.0	37,368
Middle Taunton River	38.8	44,603	37.2	42,769	36.6	42,108
Narragansett Bay	25.0	39,395	24.3	38,115	24.1	37,736
Palmer River	31.1	13,534	30.6	13,317	30.4	13,242
Pawtuxet River	52.7	78,202	51.9	76,989	51.5	76,482
Ten Mile River	26.2	9,332	24.3	8,651	23.7	8,461
Threemile River	38.0	20,746	36.2	19,741	34.9	19,070
Upper Blackstone River	45.2	59,415	43.9	57,660	43.1	56,617
Upper Taunton River	28.4	24,968	26.5	23,330	25.7	22,620
Woonasquatucket River-Moshassuck River	36.4	17,291	35.0	16,612	34.5	16,378

[1] Total area and maps of the watersheds (HUC10) are provided in the Appendix.

Table 10. Percent change and total gross change (acres) of urban lands from 2001 through 2011 in Narragansett Bay HUC10 watersheds.

HUC10 watersheds Name	2001–2006		2006–2011		2001–2011	
	Percent	Acreage	Percent	Acreage	Percent	Acreage
Middle Taunton River	13.8	2,968	3.5	859	17.8	3,826
Threemile River	9.1	1,578	5.4	1,023	15.1	2,601
Lower Blackstone River	7.4	2,714	3.2	1,239	10.8	3,953
Upper Taunton River	7.6	2,645	2.9	1,101	10.7	3,746
Upper Taunton River	7.6	2,645	2.9	1,101	10.7	3,746
Lower Taunton River-Frontal Mount Hope Bay	6.1	1,671	3.1	919	9.4	2,590
Upper Blackstone River	6.0	2,703	2.7	1,272	8.8	3,975
Upper Taunton River	7.6	2,645	2.9	1,101	10.7	3,746
Ten Mile River	6.9	1,250	1.3	257	8.3	1,507
Pawtuxet River	6.4	2,424	0.7	266	7.1	2,690
Woonasquatucket River-Moshassuck River	4.8	1,096	0.9	235	5.8	1,332

(1) Total area and maps of the watersheds (HUC10) are provided in the Appendix.

Table 11. Percent change and total gross change (acres) of forest lands from 2001 through 2011 in Narragansett Bay's HUC10 watersheds. Sorted from highest to lowest percent loss of forest lands.

HUC10 watersheds Name	Change 2001–2006		2006–2011		2001–2011	
	Percent	Acreage	Percent	Acreage	Percent	Acreage
Upper Taunton River	-7	-1,637	-3	-710	-9	-2,347
Ten Mile River	-7	-681	-2	-190	-9	-871
Threemile River	-5	-1,004	-3	-671	-8	-1,675
Middle Taunton River	-4	-1,834	-2	-661	-6	-2,494
Woonasquatucket River-Moshassuck River	-4	-678	-1	-234	-5	-912
Upper Blackstone River	-3	-1,754	-2	-1,043	-5	-2,797
Lower Taunton River-Frontal Mount Hope Bay	-3	-992	-2	-664	-4	-1,657
Narragansett Bay	-3	-1,280	-1	-379	-4	-1,659
Lower Blackstone River	-2	-1,718	-1	-1,018	-3	-2,736
Pawtuxet River	-2	-1,212	-1	-507	-2	-1,719
Palmer River	-2	-217	-1	-74	-2	-291

(1) Total area and maps of the watersheds (HUC10) are provided in the Appendix.

Big River, Chepachet River, and Headwaters South Branch Pawtuxet River (Table 5). The three HUC12 subwatersheds with the lowest percentages of forest land were the Seekonk River-Providence River, Aquidneck Island-Frontal Atlantic Ocean, and Upper Narragansett Bay (Table 5). The complete results of Tables 4 and 5 for all the HUC12 subwatersheds are available upon request.

TRENDS – CHANGES IN URBAN AND FOREST LANDS

In the Narragansett Bay Watershed, the amount of land classified as urban increased from 350,369 acres in 2001 to 379,804 acres in 2011. The increase of 29,435 acres represented a change of 8.5 percent (Tables 6 and 7). During the same time period, the Watershed lost 19,158 acres of forest land, a decline of 4.3 percent (Table 7). Figure 3 shows where these changes in forest lands and urban lands occurred. For both urban and forest lands, the rates of change were greatest from 2001 to 2006 (Table 7), when forest land declined by three percent and urban land increased by six percent.

All eleven HUC10 watersheds experienced increases in urban land and concomitant decreases in forest land from 2001 to 2011 (Tables 8 through 11). The Lower Blackstone River watershed had the largest percentage of forest lands, while the Ten Mile River watershed had the largest percentage of urban lands–over 55 percent–in each of the three years (2001, 2006, 2011) (Tables 8 and 9).

The HUC10 watersheds experiencing the largest net percentage increases of urban land were the Middle Taunton River and Threemile River watersheds (Table 10; Figure 3), while the percentage losses of forest land were largest in the Upper Taunton River, Ten Mile River, and Threemile River watersheds (Table 11; Figure 3).

At the finest scale of HUC12 subwatersheds, all but one (Barden River-Ponaganset River) of the 52 subwatersheds had increases in the amount of urban land.

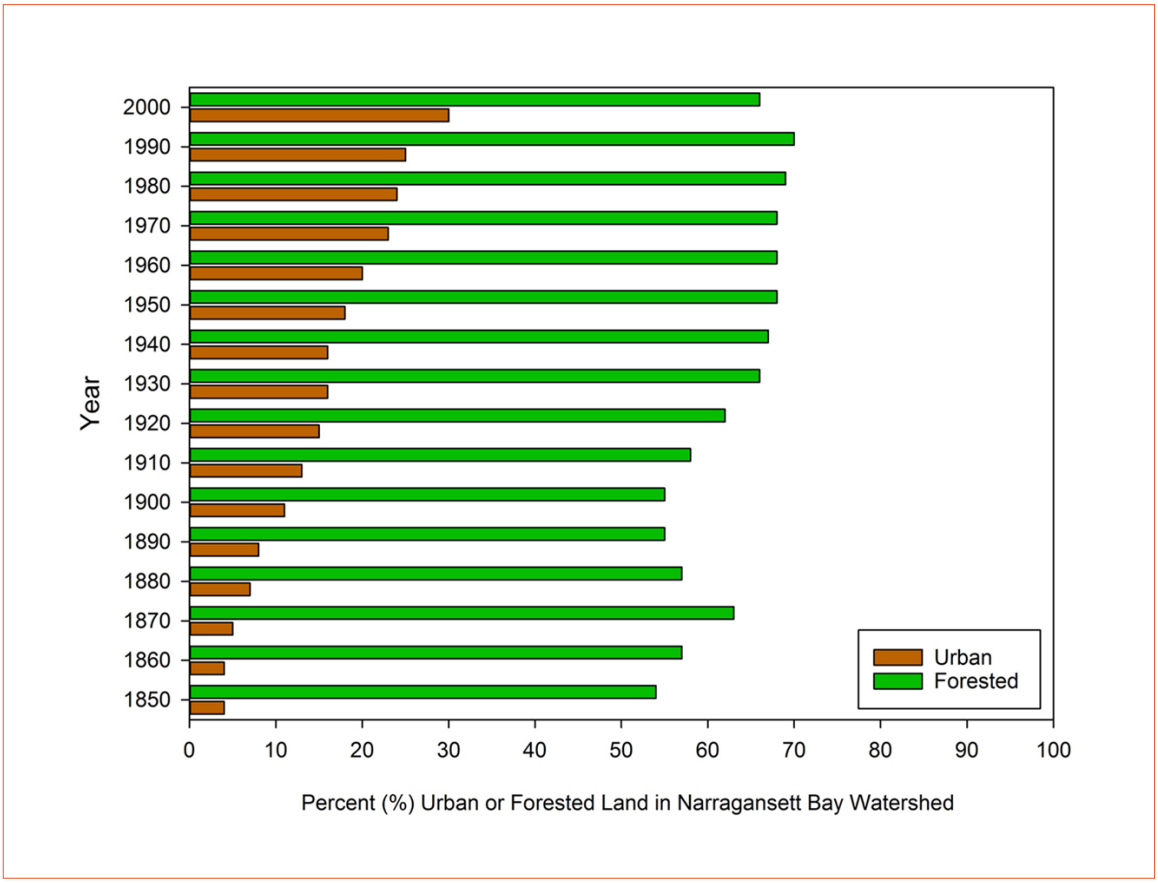


Figure 4. Historical changes in percentage of Narragansett Bay Watershed classified as forest (green) or urban (brown). Based on Vadeboncoeur and colleagues (2010).

All subwatersheds had decreases in forest land from 2001 to 2011. The subwatersheds with the largest gains in urban lands also experienced the largest losses in forest lands. Of the top 25 subwatersheds ranked by the largest increase in acres of urban land, 21 of those subwatersheds were also ranked for the largest loss of forest land. These results are available upon request.

HISTORICAL TRENDS

Between 1850 and 2000, the percentage of urban lands in the Narragansett Bay Watershed increased eightfold, doubling every fifty years on average. The greatest increase occurred between 1950 and 2000, when urban lands increased from 18 to 30 percent of the entire Watershed (Figure 4). The Blackstone River (above Millville) and the Upper Bay subwatersheds had threefold increases in percentage of urban lands. However, the small watersheds had the greatest percentage increase by a factor of four (Table 12). Some of the recent changes in the Taunton River Basin seem to have started in the 1950s, as the percentage of urban land in the Taunton River (below Taunton) subwatershed increased fourfold from 1950 through 2000. In the small watersheds, the amount of urban land increased by a factor of seventeen from two percent in 1850 to 33 percent in 2000 (Table 12).

The rates at which forest lands, including inland waters, changed over time were not more than twofold across time periods and across the Watershed or subwatersheds. However, Narragansett Bay Watershed lost most of the forest in the Taunton River subwatersheds between 1950 and 2000, and during the same period these subwatersheds had the greatest percent increase of urban lands (Tables 12 and 13). The increase of forest lands could be attributed to losses in agricultural lands during the industrial revolution, while forest was recovering. Later, during the suburbanization era, forest lands in the Pawtuxet River subwatershed increased by a factor of two; the Scituate Reservoir is an important

Table 12. Percent[1] change[2] and factor of percentage change[3] in urban lands in Narragansett Bay Watershed and subwatersheds as defined by Vadeboncoeur and colleagues (2010).

Subwatersheds	Industrialization 1850–1900		Industrialization 1900–1950		Suburbanization 1950–2000		1850–2000	
	%	*Factor*	%	*Factor*	%	*Factor*	%	*Factor*
Blackstone R. above Millville	9	*3*	9	*2*	6	*1*	24	*9*
Blackstone R. Millville to Manville	3	*2*	4	*2*	1	*1*	8	*5*
Pawtuxet R. above Pettaconsett	1	*2*	1	*2*	5	*3*	7	*8*
Taunton R. above Bridgewater	6	*2*	4	*1*	17	*2*	27	*10*
Taunton R. Bridgewater to Taunton	9	*2*	5	*1*	19	*2*	33	*7*
Taunton R. below Taunton	1	*1*	5	*2*	25	*4*	31	*11*
Small watersheds	7	*4*	10	*2*	14	*2*	31	*17*
Upper Bay	24	*3*	19	*2*	6	*1*	49	*7*
Lower Bay	5	*2*	11	*2*	15	*2*	31	*7*
Total Narragansett Bay Watershed	**7**	**2**	**7**	**2**	**12**	**2**	**26**	**8**

[1] Percent of urban lands for each decade by subwatershed from Vadeboncoeur et al. (2010) are presented in the Extended Methods of this chapter (Table 17).
[2] Result of subtracting the percent of urban lands by Watershed or subwatersheds, within the time period. For example, between 1850 (3 percent) and 1900 (12 percent), urban lands had a nine-percentage point change.
[3] Result of dividing the percent of urban land of the most recent year by the percent of the year to compare by Watershed or subwatersheds. For example, between 1850 (3 percent) and 1900 (9 percent), percent of urban lands increased by a factor of three.

drinking water source in Rhode Island and protecting its surrounding lands has been a priority.

There were substantial methodological differences between the analysis of NLCD by the Estuary Program and partners, and the analysis by Vadeboncoeur and colleagues (2010). The differences included data, spatial and temporal resolution, and the definition of boundaries for the Watershed and subwatersheds. While the percentages of urban lands in the Watershed for 2000 were similar between the two studies (Table 6; Figure 2), the percent of forest lands were not in agreement. This can be attributed mainly to the fact that Vadeboncoeur and colleagues (2010) included inland water bodies and perhaps wetlands, whereas the Estuary Program's analysis included only forest.

Discussion

Land use in the Narragansett Bay Watershed is subject to conversion, and these changes influence the Watershed's hydrologic functions. Changes of natural habitat such as wetlands and forests to urban lands have impacted how water is delivered to rivers and lakes, to groundwater, and ultimately to the Bay. Measuring the total area of land use change over time highlights the conversion of forest and other natural lands to residential, commercial, and industrial developed lands (Figure 3). It is important to highlight that acreage of forest lands reported in this chapter does not account for wetlands. However, no substantial changes in wetland extent between 2001 and 2011 were detected in preliminary analysis by the Estuary Program and partners. Wetlands are protected under federal, state, and local laws, which may explain the lack of detectable changes.

Table 13. Percent[1] change[2] and factor of percentage change [3] in forest lands in Narragansett Bay Watershed and subwatersheds as defined by Vadeboncoeur and colleagues (2010).

Sub-watersheds	Industrialization 1850–1900		Industrialization 1900–1950		Suburbanization 1950–2000		1850–2000	
	%	*Factor*	%	*Factor*	%	*Factor*	%	*Factor*
Blackstone R. above Millville	0	*1*	21	*2*	4	*1*	25	*2*
Blackstone R. Millville to Manville	9	*1*	11	*1*	5	*1*	25	*1*
Pawtuxet R. above Pettaconsett	9	*1*	25	*1*	4	*1*	38	*2*
Taunton R. above Bridgewater	0	*1*	7	*1*	-10	*1*	-3	*1*
Taunton R. Bridgewater to Taunton	-9	*1*	12	*1*	-13	*1*	-10	*1*
Taunton R. below Taunton	-2	*1*	13	*1*	-17	*1*	-6	*1*
Small watersheds	-5	*1*	15	*1*	-4	*1*	6	*1*
Upper Bay	-10	*1*	-3	*1*	2	*1*	-11	*1*
Lower Bay	17	*2*	13	*1*	1	*1*	31	*2*
Total Narragansett Bay Watershed	**1**	**1**	**13**	**1**	**-2**	**1**	**12**	**1**

[1] Percent of forest lands for each decade by subwatershed from Vadeboncoeur et al. (2010) are presented in the Extended Methods section of this chapter (Table 18).
[2] Result of subtracting the percent of urban lands by Watershed or subwatersheds, within the time-period. For example, in the Upper Bay between 1850 (52 percent) and 1900 (42 percent), there was a 10-percentage point decline in forest lands.
[3] Result of dividing the percent of urban land of the most recent year by the percent of the year to compare by Watershed or subwatersheds. For example, in the Lower Bay from 1850 (27 percent) to 1900 (44 percent), forest land nearly doubled.

The declining trend of forest lands in recent decades and historically points to the dramatic transformation of the Watershed's landscape. The losses weaken the protection that forest lands offer for estuarine and inland water quality, habitat, and human health. While efforts to preserve forested and other natural areas throughout the Watershed have been successful at local, state, regional, and national levels, this should be continued with urgency. For example, most of the forest lands in the Pawtuxet River watershed surround one of the most important drinking water sources in Rhode Island, the Scituate Reservoir and the upper reaches of the Watershed (Figure 2), where most of the forest lands are currently protected as open space; however, nearly thirty percent of ecologically significant natural lands, including unfragmented forests, in this watershed remain unprotected (see "Open Space" chapter).

Land use change analysis by the Estuary Program and EPA (ORD) show that most of the changes in the decade of 2001 to 2011 occurred in areas draining to the Taunton River and the Ten Mile River (Tables 10, 11, and 12). These areas had the largest increases of urban lands as well as the largest losses of forest lands, indicating that urban sprawl occurred and expanded from the urban corridors. These changes in land use are consistent with changes in population distribution, as more people settled in suburban areas (see "Population" chapter). In the Taunton River subwatersheds, these changes began to be more evident from 1950 through 2000 (Tables 12 and 13; Tables 17 and 18 in Extended Methods section of this chapter).

Changes in land use can impact water quality, water quantity, freshwater and estuarine habitats, and human health. The conversion of natural lands to developed lands affects these resources as changes in population demand new urban infrastructure in the form of impervious cover and wastewater infrastructure (see "Impervious Cover" and "Wastewater Infrastructure" chapters). Urban sprawl typically results in loss of forest lands, as shown in this analysis. Sprawl has contributed to habitat fragmentation with smaller areas remaining to protect the Watershed's natural resources (see "Open Space" chapter). In the Taunton River Basin, which had substantial declines in forest lands, natural lands protected as open space represent sixteen percent of the Basin, but nearly ten percent of the most ecologically significant natural lands for watershed protection remain unpreserved (see "Open Space" chapter).

Data Gaps and Research Needs

- Data from the NOAA Coastal Change Analysis Program (C-CAP) should be utilized to improve the spatial and classification accuracy of land cover classes and change analysis for the Watershed.
- Further data analysis to correlate land use and other attributes of the landscape with water quality and habitat conditions is needed to improve understanding of such relationships.
- Additional research is needed to provide better tools for estimating the value of ecosystem services provided by forest lands in the Watershed. Examples of these ecosystem services are water quality protection for both surface and groundwater, wildlife habitat conservation, climate change adaptation, and stormwater mitigation.

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Extended Methods

Table 14. National Land Cover Database sixteen classes and definitions aggregated into seven classes based on Anderson Level I.

Code	Description of 2001, 2006, and 2011 NLCD land cover classes	Aggregated Category
11	Open Water - All areas of open water, generally with less than 25% cover or vegetation or soil.	Water
21	Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.	Urban or Built Up
22	Developed, Low Intensity -Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.	Urban or Built Up
23	Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.	Urban or Built Up
24	Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.	Urban or Built Up
31	Barren Land (Rock/Sand/Clay) - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.	Barren Land
41	Deciduous Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.	Forest Land
42	Evergreen Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.	Forest Land
43	Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.	Forest Land
52	Shrub/Scrub - Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.	Brushland
71	Grassland/Herbaceous - Areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.	Agricultural land
72	Sedge/Herbaceous - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.	Agricultural land

Table 14 continued

Code	Description of 2001, 2006, and 2011 NLCD land cover classes	Aggregated Category
81	Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.	Agricultural land
82	Cultivated Crops - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.	Agricultural land
90	Woody Wetlands - Areas where forest or shrub land vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	Wetland
95	Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	Wetland

Table 15. Rhode Island land use categories (2003–2004) state "crosswalk" based on Anderson Level 1.

LCLU	Description	Aggregated Category
111	High Density Residential (<1/8 acre lots)	Urban or Built Up Land
112	Medium High Density Residential (1/4 to 1/8 acre lots)	Urban or Built Up Land
113	Medium Density Residential (1 to 1/4 acre lots)	Urban or Built Up Land
114	Medium Low Density Residential (1 to 2 acre lots)	Urban or Built Up Land
115	Low Density Residential (>2 acre lots)	Urban or Built Up Land
120	Commercial (sale of products and services)	Urban or Built Up Land
130	Industrial (manufacturing, design, assembly, etc.)	Urban or Built Up Land
141	Roads (divided highways >200' plus related faci	Urban or Built Up Land
142	Airports (and associated facilities)	Urban or Built Up Land
143	Railroads (and associated facilities)	Urban or Built Up Land
144	Water and Sewage Treatment	Urban or Built Up Land
145	Waste Disposal (landfills, junkyards, etc.)	Urban or Built Up Land
146	Power Lines (100' or more width)	Urban or Built Up Land
147	Other Transportation (terminals, docks, etc.)	Urban or Built Up Land
151	Commercial/Residential Mixed	Urban or Built Up Land
152	Commercial/Industrial Mixed	Urban or Built Up Land
161	Developed Recreation (all recreation)	Urban or Built Up Land
162	Vacant Land	Urban or Built Up Land
163	Cemeteries	Urban or Built Up Land
170	Institutional (schools, hospitals, churches, etc.)	Urban or Built Up Land
210	Pasture (agricultural not suitable for tillage)	Agricultural Land
220	Cropland (tillable)	Agricultural Land
230	Orchards, Groves, Nurseries	Agricultural Land
240	Confined Feeding Operations	Agricultural Land
250	Idle Agriculture (abandoned fields and orchards)	Agricultural Land

Table 15 continued

LCLU	Description	Aggregated Category
300	Brushland (shrub and brush areas, reforestation)	Brushland
410	Deciduous Forest (>80% hardwood)	Forest Land
420	Softwood Forest (>80% softwood)	Forest Land
430	Mixed Forest	Forest Land
500	Water	Water
600	Wetland	Wetland
710	Beaches	Barren Land
720	Sandy Areas (not beaches)	Barren Land
730	Rock Outcrops	Barren Land
740	Mines, Quarries and Gravel Pits	Barren Land
750	Transitional Areas (urban open)	Barren Land
760	Mixed Barren Areas	Barren Land

Table 16. Massachusetts land use categories (2005) state "crosswalk" based on Anderson Level 1.

LUCODE	Description	Aggregated Category
1	Cropland	Agricultural Land
2	Pasture	Agricultural Land
3	Forest	Forest Land
4	Non-Forested Wetland	Wetland
5	Mining	Barren Land
6	Open Land	Urban or Built Up Land
7	Participation Recreation	Urban or Built Up Land
8	Spectator Recreation	Urban or Built Up Land
9	Water-Based Recreation	Urban or Built Up Land
10	Multi-Family Residential	Urban or Built Up Land
11	High Density Residential	Urban or Built Up Land
12	Medium Density Residential	Urban or Built Up Land
13	Low Density Residential	Urban or Built Up Land
14	Saltwater Wetland	Wetland
15	Commercial	Urban or Built Up Land

Table 16 continued

LUCODE	Description	Aggregated Category
16	Industrial	Urban or Built Up Land
17	Transitional	Barren Land
18	Transportation	Urban or Built Up Land
19	Waste Disposal	Urban or Built Up Land
20	Water	Water
23	Cranberry Bog	Agricultural Land
24	Powerline/Utility	Urban or Built Up Land
25	Saltwater Sandy Beach	Barren Land
26	Golf Course	Urban or Built Up Land
29	Marina	Urban or Built Up Land
31	Urban Public/Institutional	Urban or Built Up Land
34	Cemetery	Urban or Built Up Land
35	Orchard	Agricultural Land
36	Nursery	Agricultural Land
37	Forested Wetland	Wetland
38	Very Low Density Residential	Urban or Built Up Land
39	Junkyard	Urban or Built Up Land
40	Brushland/Successional	Brushland

Table 17. Percent of urban lands in subwatersheds of the Narragansett Bay Watershed (Vadeboncoeur et al. 2010)

Sub-watersheds	1850	1860	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Blackstone R. above Millville	3	4	6	7	9	12	14	17	19	19	21	21	21	21	22	27
Blackstone R. Millville to Manville	2	2	3	3	4	5	6	7	8	8	9	9	9	10	10	10
Pawtuxet R. above Pettaconsett	1	2	2	2	2	2	2	2	3	3	3	4	6	6	7	8
Taunton R. above Bridgewater	3	4	4	5	6	9	11	12	12	12	13	16	21	24	25	30
Taunton R. Bridgewater to Taunton	6	8	10	11	13	15	17	18	18	18	20	21	24	25	28	39
Taunton R. below Taunton	3	3	4	4	4	4	5	6	7	8	9	12	17	20	22	34
Small watersheds	2	3	5	5	7	9	12	14	17	17	19	21	24	25	27	33
Upper Bay	8	10	12	18	24	32	39	43	47	48	51	51	52	52	52	57
Lower Bay	5	6	6	8	9	10	12	12	12	14	21	28	29	31	34	36
Total Watershed	**4**	**4**	**5**	**7**	**8**	**11**	**13**	**15**	**16**	**16**	**18**	**20**	**23**	**24**	**25**	**30**

Table 18. Percent of forest (includes inland waterbodies) in subwatersheds of the Narragansett Bay Watershed (Vadeboncoeur et al. 2010).

Sub-watersheds	1850	1860	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Blackstone R. above Millville	41	52	61	48	41	41	47	52	59	61	62	65	67	70	71	66
Blackstone R. Millville to Manville	60	60	72	67	70	69	71	74	77	78	80	81	83	84	85	85
Pawtuxet R. above Pettaconsett	50	51	51	55	57	59	66	74	81	83	84	86	86	88	89	88
Taunton R. above Bridgewater	70	71	77	69	69	70	71	73	75	77	77	76	73	72	72	67
Taunton R. Bridgewater to Taunton	65	63	83	69	58	56	59	62	66	67	68	68	67	67	66	55
Taunton R. below Taunton	69	73	70	67	65	67	71	75	79	80	80	79	76	74	74	63
Small watersheds	55	58	66	55	51	50	54	58	61	64	65	65	64	66	66	61
Upper Bay	52	55	58	51	47	42	38	38	38	39	39	41	42	44	46	41
Lower Bay	27	29	33	38	41	44	47	52	57	60	57	54	56	59	60	58
Total Watershed	**54**	**57**	**63**	**57**	**55**	**55**	**58**	**62**	**66**	**67**	**68**	**68**	**68**	**69**	**70**	**66**