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Environmental Indicator Report: Land Use and Development

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Environmental Indicator Report

LAND USE AND DEVELOPMENT

Final

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INTRODUCTION

During the fall and winter of 2001-2002, the New Hampshire Estuaries Project's Technical Advisory Committee (TAC) developed a suite of environmental indicators to track progress toward the NHEP's management goals and objectives. These indicators were fully described in terms of their performance criteria, statistical methods, and measurable goals in the NHEP's Monitoring Plan, which was most recently updated in March 2003 (NHEP, 2003).

The next step is to use these indicators to produce an updated "State of the Estuaries" report by mid-2003. The TAC decided to break this task into three sections: shellfish indicators in the fall of 2002; water quality indicators in the winter of 2002-2003; and land use/habitat indicators in the spring of 2003. For each group of indicators, the NHEP Coastal Scientist would prepare an "Indicator Report" that summarizes the available information and results of statistical tests for each of the indicators. The TAC would review and comment on this report, and then recommend a subset of the most important or illustrative indicators to be presented to the Management Committee. Finally, after being presented to both the TAC and the Management Committee, the indicator charts and interpretation would be incorporated in the State of the Estuaries report.

This report is the third of four indicator reports to be presented to the TAC. The focus of this report is the NHEP's land use and development indicators (see list below). In an effort to be brief, the details of the monitoring programs for each indicator are not included. Please refer to the NHEP Monitoring Plan (NHEP, 2003) for additional details for each indicator.

NHEP Indicators Included in this Report

Land Use and Development
LUD1: Impervious surfaces in coastal subwatersheds
LUD2: Rate of Sprawl – High impact development
LUD3: Rate of Sprawl – Low density, residential development
LUD4: Rate of Sprawl - Fragmentation

ENVIRONMENTAL INDICATORS OF LAND USE AND DEVELOPMENT

LUD1. Impervious Surfaces in Coastal Subwatersheds

a. Monitoring Objectives

The objective of this indicator is to estimate the percentage by land area of impervious surfaces in each subwatershed of the coastal watershed at different times. This indicator will answer the following monitoring question:

- Has there been a significant change over time in the number of coastal NH watersheds (first or second order) that exceed 10% impervious cover?
- Has the rate of creation of new impervious surfaces in NH coastal watersheds significantly changed over time?

which will, in turn, report on progress toward the following management objective:

- LND1-1A: Minimize the amount of impervious surfaces and assess the impacts of water quality by keeping the total impervious surface in each sub-watershed below 10%

b. Measurable Goal

The goal from the monitoring plan is have none of the subwatersheds on the coast with impervious surfaces covering more than 10% of the watershed area. In other states, impervious surfaces covering greater than 10% of the watershed area has resulted in water quality deterioration (Shueller, 1995). However, additional factors, such as the proximity of the impervious surfaces to water bodies, may be more important. Therefore, 10% impervious cover is not necessarily a clear threshold between watersheds with no water quality impacts and impaired watersheds.

c. Data Analysis and Statistical Methods

Impervious surfaces were mapped throughout the coastal watershed using satellite imagery (Landsat TM, 30-meter resolution) from 1990 and 2000 (Justice and Rubin, 2002). Using ArcInfo/ArcView software, the total area of impervious surfaces in each HUC12 subwatershed and town in the coastal watershed was calculated and then divided by the total land area of that watershed or town to estimate the percent impervious cover. Land area was calculated by subtracting the area in hydrography polygons from the total area of the watershed or town. The percent impervious values were then compared to the goal of 10%.

Confidence intervals for the percent impervious estimates for each watershed and town were generated using the method of partial derivatives from Kline (1985) assuming 10% error in the impervious area totals and 1% error in the land area totals. Justice and Rubin (2002) conducted an accuracy assessment of the satellite imagery classification for impervious surfaces and determined that the overall accuracy was between 93% and 99%. Therefore, 10% is a conservative estimate of the error in the sum of the impervious surface pixels across a watershed. The 1% error in the land area totals was assumed to account for any defects in the hydrography, watershed, and town polygon coverages. An average error was calculated using average values for the input variables (e.g. impervious acres per town, land area per town) and the assumed errors in the input values (10% and 1%, respectively). This average error was added to and subtracted from the calculated ratio for each watershed and town to approximate the 95th percentile upper and lower confidence interval for the result. The confidence interval was used to determine whether the percent impervious value was significantly different from 10% (i.e., confidence interval is entirely above 10%).

d. Results

The percent impervious results for the 37 HUC12 watersheds in the coastal basin are reported on Table 1, Figure 1, and Figure 4. Shaded rows in the table signify watersheds with greater than 10% impervious cover in 2000 (i.e., confidence interval is entirely above 10%). Six (6) of the 37 subwatersheds of the coastal watershed had impervious surfaces of >10% in 2000. Most of these subwatersheds are adjacent to the coast or along the Route 16 corridor. One watershed (Hampton Harbor) was between 15 and 20% impervious. Another watershed (Portsmouth Harbor) was between 20 and 30% impervious.

The percent impervious results for the 42 coastal watershed towns are shown in Table 2, Figure 2, and Figure 5. Eleven (11) of the 42 towns in the coastal watershed have more than 10% of their land area covered by impervious surfaces (i.e., confidence interval is entirely above 10%). The town with the highest percent impervious cover is New Castle which is approximately 30% impervious surfaces. Portsmouth and Seabrook both have percent impervious values between 20% and 30%. Impervious surfaces cover between 15 and 20 percent of Dover, Hampton, Newington, and Somersworth. Exeter, North Hampton, Rochester, and Rye have percent impervious values between 10 and 15%. Between 1990 and 2000, 12,200 acres of impervious surface were added in the 42 coastal watershed towns. Forty-seven (47) to 909 acres were added per town during the 10 years.

For both the HUC12 watersheds and the coastal towns, the total amount of impervious surfaces is divided over a large area. High densities of imperviousness within a town that is otherwise undeveloped would be "averaged out" and not picked up by this analysis. On Figure 3 (taken from Justice and Rubin, 2002, with permission), the pixels that were coded as being impervious have been plotted along with the outlines of the coastal subwatersheds. Each pixel is a 30 meter by 30 meter square (900 square meters).

The original goal from the NHEP Management Plan was to keep the percent impervious surfaces in all coastal watersheds less than 10%. Based on the results presented above, this goal is not being met, nor will the goal be met in the near future since impervious surfaces are unlikely to decline over time. A more reasonable goal would be to work to slow the growth of impervious surfaces in those watersheds that are still less than 10% impervious so that the number of watersheds exceeding 10% impervious does not increase from the current number of 6. In those watersheds and towns where there is already greater than 10% impervious, the priority should be to develop stormwater management plans to mitigate the effects of stormwater runoff.

Table 1: Impervious surface coverage in coastal subwatersheds

Watershed			Mapped Area (acres)			Impervious Surf. (acres)		Percent Impervious Surfaces (% of land area)		Percent Change	Comments
HUC10	HUC12	HUC12 Code	Total	Water	Land	1990	2000	1990	2000	1990-00	
Salmon Falls River	Upper Branch River-Lovell Lake	010600030401	18,383	840	17,543	403	555	1.6% - 3.0%	2.5% - 3.9%	37.9%	
Salmon Falls River	Junes Brook-Branch River	010600030402	17,240	166	17,074	319	443	1.2% - 2.6%	1.9% - 3.3%	38.9%	
Salmon Falls River	Headwaters-Great East Lake	010600030403	17,674	1,307	8,761	168	247	1.2% - 2.6%	2.1% - 3.5%	46.5%	(1)
Salmon Falls River	Milton Pond	010600030404	14,840	323	7,002	195	275	2.1% - 3.5%	3.2% - 4.6%	41.3%	(1)
Salmon Falls River	Middle Salmon Falls River	010600030405	38,449	193	15,563	1,094	1,536	6.3% - 7.7%	9.2% - 10.6%	40.4%	(1)
Salmon Falls River	Lower Salmon Falls River	010600030406	13,837	5	3,054	296	379	9.0% - 10.4%	11.7% - 13.1%	28.1%	(1)
Cocheco River	Upper Cocheco River	010600030601	27,657	516	27,141	700	970	1.9% - 3.3%	2.9% - 4.3%	38.6%	
Cocheco River	Axe Handle Brook	010600030602	7,397	310	7,087	212	290	2.3% - 3.7%	3.4% - 4.8%	36.7%	
Cocheco River	Middle Cocheco River	010600030603	15,952	98	15,853	1,267	1,685	7.3% - 8.7%	9.9% - 11.3%	32.9%	
Cocheco River	Bow Lake	010600030604	9,125	1,240	7,885	121	185	0.8% - 2.2%	1.7% - 3.0%	52.6%	
Cocheco River	Nippo Brook-Isinglass River	010600030605	17,389	250	17,139	266	374	0.9% - 2.2%	1.5% - 2.9%	40.4%	
Cocheco River	Long Pond	010600030606	10,153	324	9,829	148	221	0.8% - 2.2%	1.6% - 2.9%	49.1%	
Cocheco River	Lower Isinglass River	010600030607	14,609	337	14,271	803	1,184	4.9% - 6.3%	7.6% - 9.0%	47.5%	
Cocheco River	Lower Cocheco River	010600030608	16,184	100	16,084	1,502	2,080	8.7% - 10.0%	12.2% - 13.6%	38.5%	
Lamprey River	Headwaters-Lamprey River	010600030701	21,927	200	21,727	372	593	1.0% - 2.4%	2.0% - 3.4%	59.6%	
Lamprey River	North Branch River	010600030702	11,047	114	10,933	255	393	1.6% - 3.0%	2.9% - 4.3%	54.0%	
Lamprey River	Middle Lamprey River	010600030703	26,222	426	25,796	1,232	1,880	4.1% - 5.5%	6.6% - 8.0%	52.5%	
Lamprey River	Pawtuckaway Pond	010600030704	13,052	913	12,140	112	171	0.2% - 1.6%	0.7% - 2.1%	53.2%	
Lamprey River	Bean River	010600030705	15,072	252	14,820	256	374	1.0% - 2.4%	1.8% - 3.2%	46.1%	
Lamprey River	North River	010600030706	8,622	66	8,555	156	256	1.1% - 2.5%	2.3% - 3.7%	64.1%	
Lamprey River	Little River (Lamprey)	010600030707	13,173	369	12,804	289	446	1.6% - 2.9%	2.8% - 4.2%	54.3%	
Lamprey River	Piscassic River	010600030708	14,510	96	14,414	514	885	2.9% - 4.2%	5.5% - 6.8%	72.3%	
Lamprey River	Lower Lamprey River	010600030709	13,226	86	13,141	521	768	3.3% - 4.7%	5.2% - 6.5%	47.3%	
Exeter River	Watson Brook	010600030801	10,575	91	10,484	331	532	2.5% - 3.8%	4.4% - 5.8%	60.8%	
Exeter River	Towle Brook-Lily Pond	010600030802	21,208	222	20,985	650	1,091	2.4% - 3.8%	4.5% - 5.9%	67.9%	
Exeter River	Spruce Swamp-Little River	010600030803	14,384	46	14,338	649	1,023	3.8% - 5.2%	6.4% - 7.8%	57.5%	
Exeter River	Little River (Exeter)	010600030804	9,889	34	9,855	563	823	5.0% - 6.4%	7.7% - 9.0%	46.2%	
Exeter River	Great Brook-Exeter River	010600030805	12,363	53	12,309	497	783	3.4% - 4.7%	5.7% - 7.0%	57.5%	
Exeter River	Squamscott River	010600030806	13,294	25	13,269	915	1,380	6.2% - 7.6%	9.7% - 11.1%	50.8%	
Great Bay Drainage	Winnicut River	010600030901	11,214	67	11,147	778	1,190	6.3% - 7.7%	10.0% - 11.4%	52.9%	
Great Bay Drainage	Oyster River	010600030902	19,875	161	19,714	969	1,480	4.2% - 5.6%	6.8% - 8.2%	52.7%	
Great Bay Drainage	Bellamy River	010600030903	21,634	467	21,167	1,148	1,708	4.7% - 6.1%	7.4% - 8.8%	48.8%	
Great Bay Drainage	Great Bay	010600030904	18,327	135	18,192	810	1,186	3.8% - 5.1%	5.8% - 7.2%	46.4%	
Coastal Drainage	Portsmouth Harbor	010600031001	31,049	205	11,650	2,310	2,975	19.1% - 20.5%	24.9% - 26.2%	28.8%	(1)
Coastal Drainage	Berrys Brook-Rye Harbor	010600031002	10,634	123	10,503	843	1,237	7.3% - 8.7%	11.1% - 12.5%	46.8%	
Coastal Drainage	Taylor River-Hampton River	010600031003	14,607	195	14,412	1,157	1,745	7.3% - 8.7%	11.4% - 12.8%	50.9%	
Coastal Drainage	Hampton Harbor	010600031004	19,670	172	14,114	1,529	2,163	10.1% - 11.5%	14.6% - 16.0%	41.5%	(1)

(1) Only NH portion of watershed was mapped.

(2) The percent change from 1990 to 2000 based on mid-point of %impervious ranges for the two years.

(3) Impervious surface data from Justice and Rubin (2002).

(4) Confidence intervals for %impervious values are the value +/-0.7%. This value was used because it is the size of the error bars for an average size watershed with average imperviousness.

(5) Highlighted rows are watersheds for which the %impervious range in 2000 is entirely above 10%.

Table 2: Impervious surface coverage in coastal watershed towns

Town		Mapped Area (acres)			Impervious Surf. (acres)		Percent Impervious Surfaces (% of land area)		Percent Change	Comments
Name	FIPS	Total	Water	Land	1990	2000	1990	2000	1990-00	
BARRINGTON	17005	31,117	1,398	29,719	763	1,187	1.9% - 3.2%	3.3% - 4.7%	55.44%	
BRENTWOOD	15015	10,862	121	10,742	532	829	4.3% - 5.6%	7.1% - 8.4%	55.76%	
BROOKFIELD	3015	14,880	287	14,593	139	191	0.3% - 1.6%	0.6% - 2.0%	37.07%	
CANDIA	15020	19,557	215	19,342	531	794	2.1% - 3.4%	3.4% - 4.8%	49.41%	
CHESTER	15025	16,718	98	16,620	423	720	1.9% - 3.2%	3.7% - 5.0%	70.16%	
DANVILLE	15030	7,569	131	7,439	260	445	2.8% - 4.2%	5.3% - 6.7%	71.03%	
DEERFIELD	15035	33,349	762	32,587	492	768	0.8% - 2.2%	1.7% - 3.0%	56.11%	
DOVER	17010	18,592	1,498	17,094	1,873	2,626	10.3% - 11.6%	14.7% - 16.0%	40.26%	
DURHAM	17015	15,852	1,543	14,308	675	1,026	4.1% - 5.4%	6.5% - 7.8%	51.93%	
EASTKINGSTON	15045	6,381	62	6,319	221	335	2.8% - 4.2%	4.6% - 6.0%	51.38%	
EPPING	15050	16,776	308	16,468	658	1,071	3.3% - 4.7%	5.8% - 7.2%	62.78%	
EXETER	15055	12,814	261	12,553	937	1,376	6.8% - 8.1%	10.3% - 11.6%	46.76%	
FARMINGTON	17020	23,640	419	23,221	687	966	2.3% - 3.6%	3.5% - 4.8%	40.53%	
FREMONT	15060	11,143	107	11,036	329	538	2.3% - 3.6%	4.2% - 5.5%	63.34%	
GREENLAND	15065	8,524	1,744	6,780	455	713	6.0% - 7.4%	9.8% - 11.2%	56.63%	
HAMPTON	15075	9,071	754	8,317	1,179	1,605	13.5% - 14.8%	18.6% - 20.0%	36.14%	
HAMPTONFALLS	15073	8,077	358	7,719	342	536	3.8% - 5.1%	6.3% - 7.6%	56.84%	
KENSINGTON	15085	7,668	31	7,637	243	378	2.5% - 3.9%	4.3% - 5.6%	55.53%	
KINGSTON	15090	13,450	955	12,495	651	1,019	4.5% - 5.9%	7.5% - 8.8%	56.50%	
LEE	17025	12,928	248	12,680	468	740	3.0% - 4.4%	5.2% - 6.5%	58.36%	
MADBURY	17030	7,799	396	7,403	251	394	2.7% - 4.1%	4.7% - 6.0%	56.53%	
MIDDLETON	17035	11,843	283	11,560	204	284	1.1% - 2.4%	1.8% - 3.1%	38.96%	
MILTON	17040	21,935	836	21,099	597	839	2.2% - 3.5%	3.3% - 4.6%	40.39%	
NEW CASTLE	15100	1,348	843	504	108	155	20.8% - 22.1%	30.1% - 31.4%	43.32%	
NEWDURHAM	17045	28,054	1,707	26,347	458	628	1.1% - 2.4%	1.7% - 3.0%	37.00%	
NEWFIELDS	15105	4,647	105	4,542	142	251	2.5% - 3.8%	4.9% - 6.2%	76.93%	
NEWINGTON	15110	7,916	2,701	5,215	687	941	12.5% - 13.8%	17.4% - 18.7%	36.99%	
NEWMARKET	15115	9,080	1,007	8,073	480	707	5.3% - 6.6%	8.1% - 9.4%	47.29%	
NORTHHAMPTON	15125	8,922	57	8,865	647	958	6.6% - 8.0%	10.1% - 11.5%	47.89%	
NORTHWOOD	15130	19,356	1,380	17,976	424	610	1.7% - 3.0%	2.7% - 4.1%	43.85%	
NOTTINGHAM	15135	30,997	1,116	29,880	448	693	0.8% - 2.2%	1.7% - 3.0%	54.66%	
PORTSMOUTH	15145	10,763	762	10,001	2,128	2,726	20.6% - 21.9%	26.6% - 27.9%	28.08%	
RAYMOND	15150	18,944	495	18,448	977	1,484	4.6% - 6.0%	7.4% - 8.7%	51.80%	
ROCHESTER	17050	29,081	750	28,331	2,395	3,304	7.8% - 9.1%	11.0% - 12.3%	37.96%	
ROLLINSFORD	17055	4,843	161	4,682	266	381	5.0% - 6.3%	7.5% - 8.8%	43.62%	
RYE	15155	8,424	426	7,997	587	878	6.7% - 8.0%	10.3% - 11.6%	49.67%	
SANDOWN	15165	9,232	343	8,889	337	544	3.1% - 4.5%	5.5% - 6.8%	61.40%	
SEABROOK	15170	6,160	491	5,669	802	1,206	13.5% - 14.8%	20.6% - 21.9%	50.46%	
SOMERSWORTH	17060	6,399	179	6,220	768	1,021	11.7% - 13.0%	15.8% - 17.1%	33.02%	
STRAFFORD	17065	32,779	1,626	31,153	434	638	0.7% - 2.1%	1.4% - 2.7%	46.97%	
STRATHAM	15180	9,901	228	9,672	628	979	5.8% - 7.2%	9.5% - 10.8%	55.85%	
WAKEFIELD	3090	28,716	3,452	25,264	878	1,225	2.8% - 4.1%	4.2% - 5.5%	39.52%	

(1) The percent change from 1990 to 2000 based on mid-point of %impervious ranges for the two years.

(2) Impervious surface data from Justice and Rubin (2002) reprocessed to town boundaries by NHDES.

(3) Confidence intervals for %impervious values are the value +/-0.7%. This value was used because it is the size of the error bars for an average size town with average imperviousness.

(4) Highlighted rows are towns for which the %impervious range in 2000 is entirely above 10%.

Figure 1: Percent impervious surfaces in coastal subwatersheds in 2000

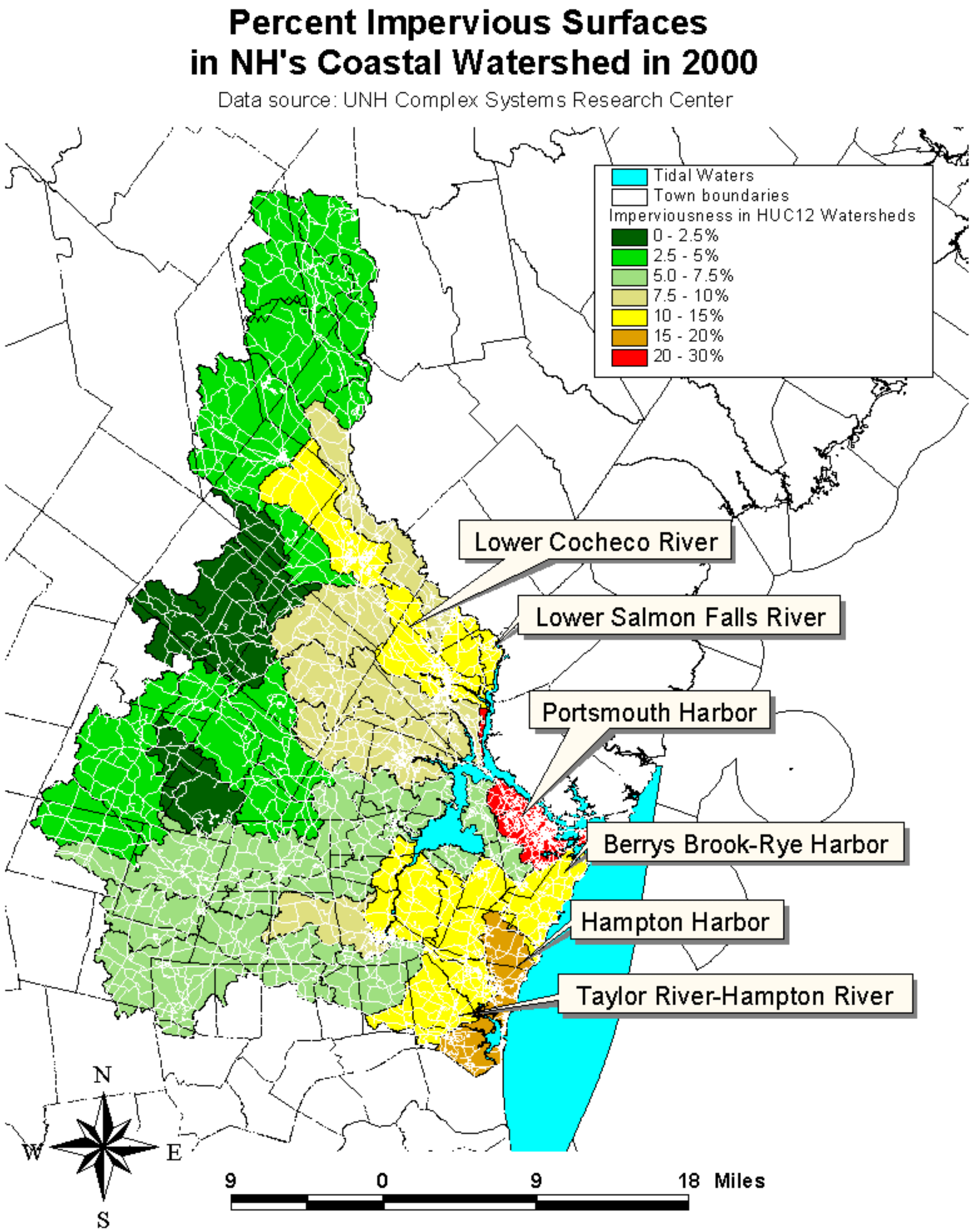


Figure 2: Percent impervious surfaces in coastal towns in 2000

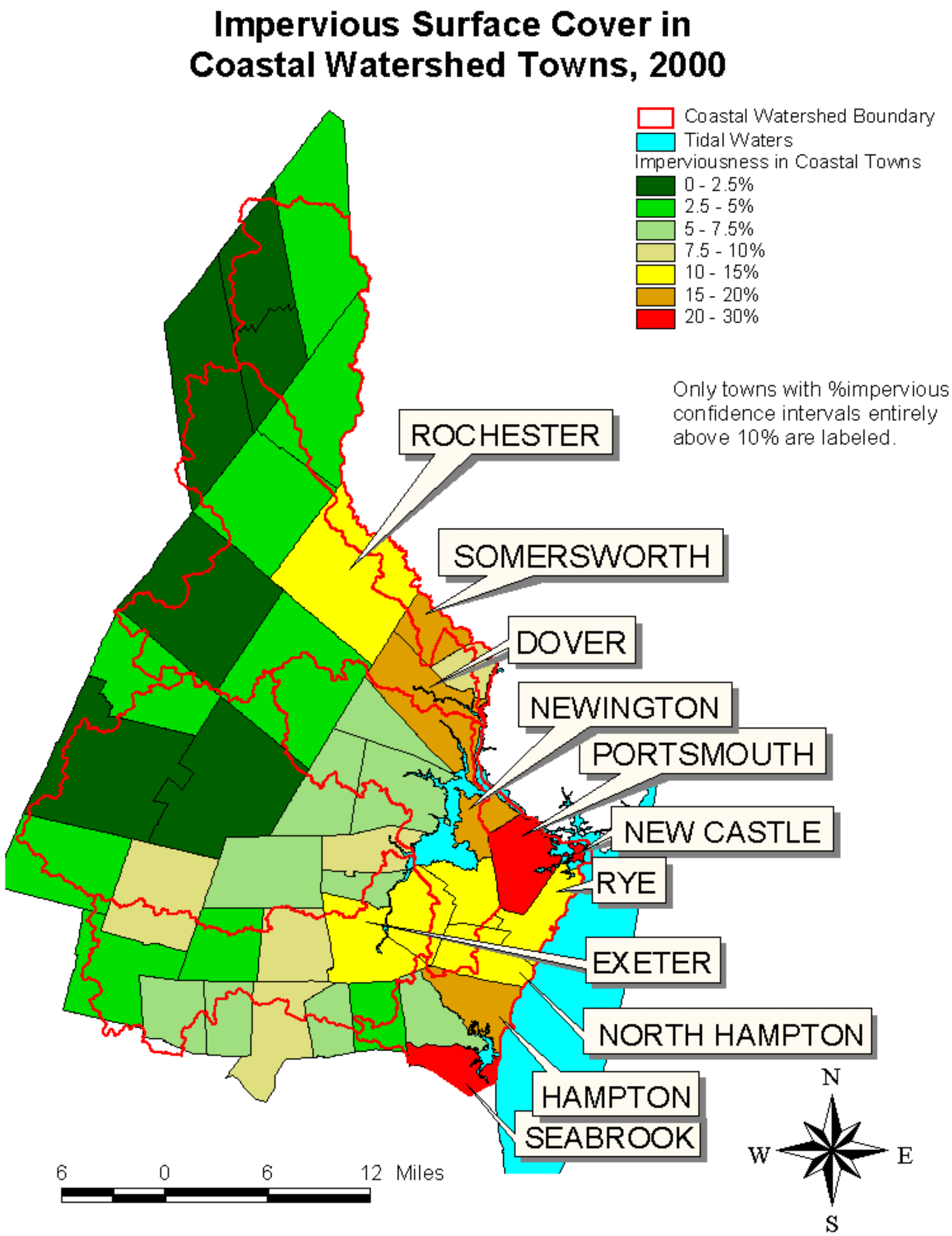


Figure 3: Location of high impervious surface pixels relative to watershed boundaries (from Justice and Rubin, 2002, with permission)

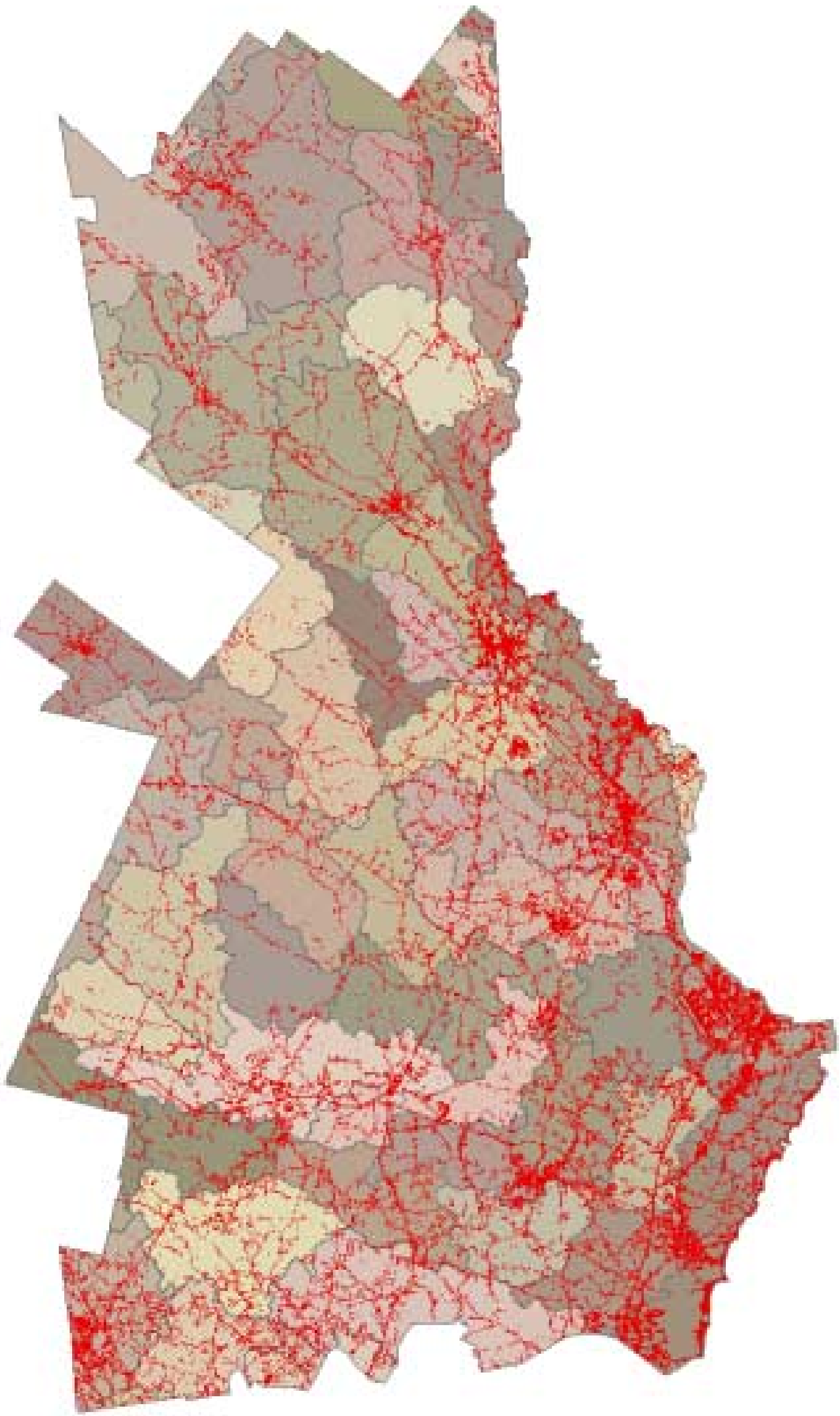


Figure 4: Percent impervious surfaces in each coastal subwatershed in 1990 and 2000

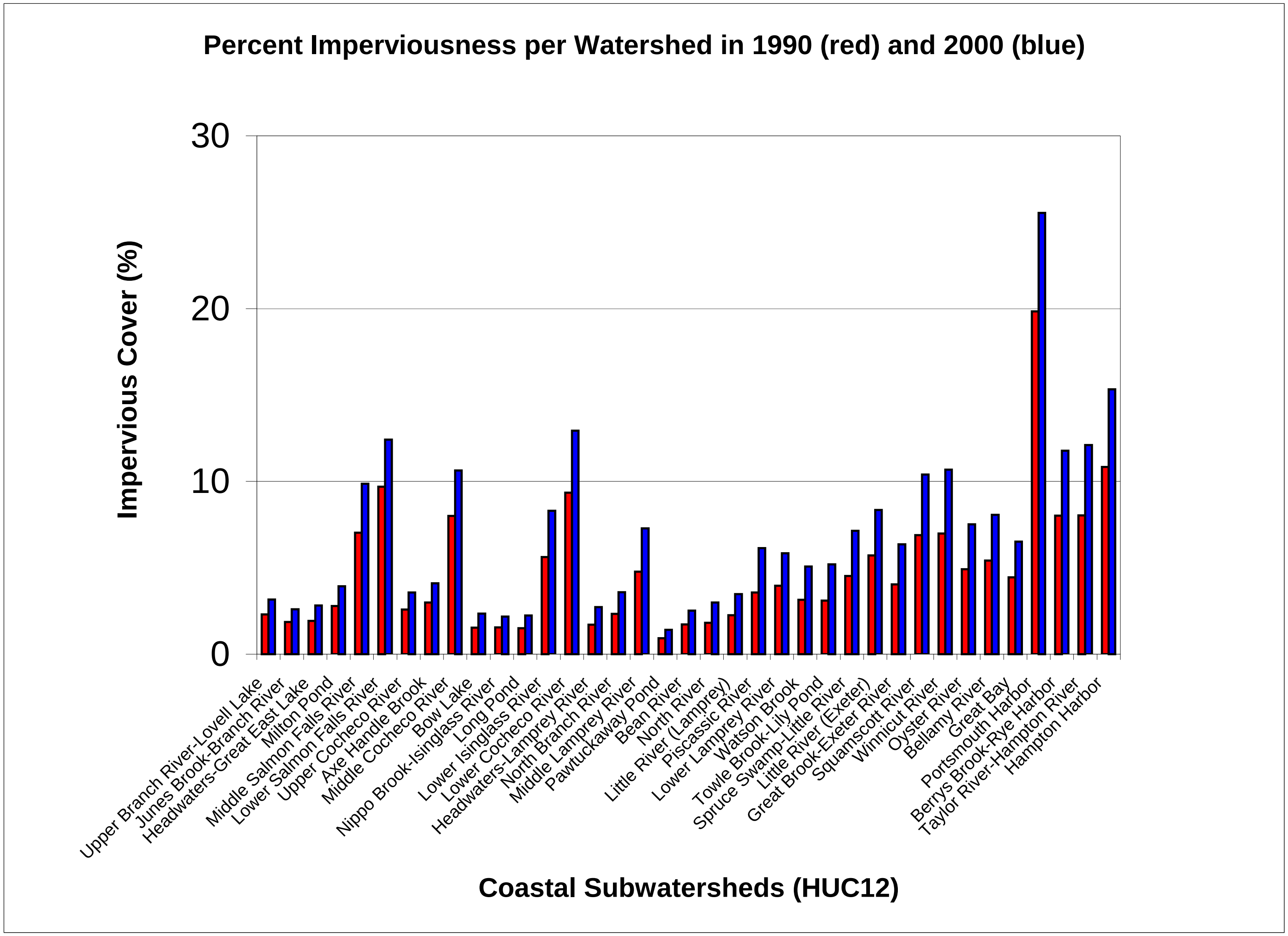
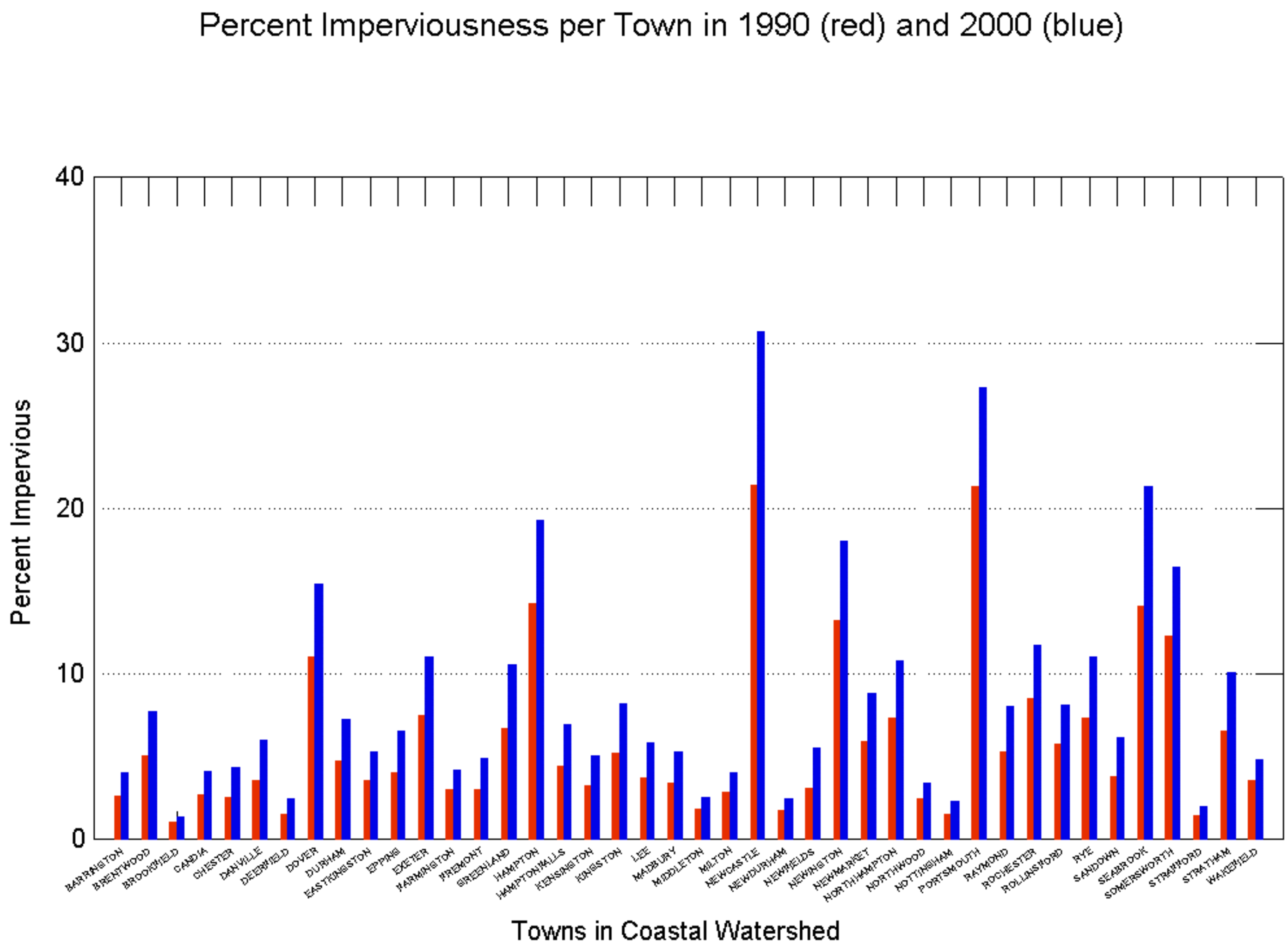


Figure 5: Percent impervious surfaces in each town in 1990 and 2000



LUD2. Rate of Sprawl – High Impact Development

a. Monitoring Objectives

There is no accepted metric for calculating the rate of sprawl. However, common attributes of land use associated with sprawl include increasing land consumption per person, increasing strip development along roadways, dispersed, low-density residential development and increasing loss and fragmentation of open space. Because there are many facets of land development associated with sprawl, the TAC decided to use three different indicators to assess the rate of sprawl: change in impervious surface relative to population growth; change in road miles relative to population growth; and change in land fragmentation relative to population growth. This indicator is the first of these three "sprawl indicators."

Development creates impervious surface in the form of new buildings, new roadways, new driveways, and new parking lots. Sprawl-type development, such as commercial strip development with large parking lots and dispersed low-density residential development with long roadways and driveways, typically creates more impervious surface than compact development and redevelopment activities. An increase of impervious surfaces in a town or watershed is also a particularly good indicator of the level of high impact development (e.g., large shopping malls, highways). Impervious surface is expected to be highly correlated with acres of developed land, but is expected to provide a more accurate measure of sprawl-type development.

For this first indicator of sprawl, the ratio of the acres of imperviousness to the total population ("imperviousness per capita") will be calculated for each town for 1990 and 2000. Ratios for different years will be compared to determine whether the imperviousness per capita is growing, declining, or remaining the same for a town. The rate of change in the ratios will be used to answer the following monitoring question:

- Has the rate of urban sprawl in coastal NH watersheds changed significantly over time?

which will, in turn, report on progress toward the following management objective:

- LND1-2: Minimize the total rate of land consumption in the NH coastal watershed (as measured by acres of development per capita)

b. Measurable Goal

The goal is for no towns in the coastal watershed to have increasing ratios over time (i.e., no increasing rates of sprawl).

c. Data Analysis and Statistical Methods

Impervious surfaces were mapped throughout the coastal watershed using satellite imagery (Landsat TM, 30 meter resolution) from 1990 and 2000 (Justice and Rubin, 2002). Using ArcInfo/ArcView software, the total area of impervious surfaces in each town in the coastal watershed was calculated. US census population totals for each town were obtained from the NH State Data Center. The "imperviousness per capita" for 1990 and 2000 was calculated by dividing the total acres of impervious surfaces in the town by the town population.

Error bars on the imperviousness per capita ratios were estimated by assuming that the population and impervious surface totals for each town had individual uncertainties of 1% and 10%, respectively, and propagating these errors through the equations for the ratio following the methods of partial derivatives in Kline (1985). The US Census population totals are purported to be 100% correct, so a 1% error is a conservative assumption. Justice and Rubin (2002) conducted an accuracy assessment of the satellite imagery classification for impervious surfaces and determined that the overall accuracy was between 93% and 99%. Therefore, 10% is a conservative estimate of the error in the sum of the impervious surfaces across a watershed. An average error was calculated using average values for the input variables (e.g. impervious acres per town, population per town) and the assumed errors in the input values (10% and 1%, respectively). This average error was added to and subtracted from the calculated ratio for each town to approximate the 95th percentile upper and lower confidence interval for the result. The confidence limits were used to determine whether the ratios from 2000 were significantly higher than those from 1990 (i.e., the lower confidence limit from 2000 > upper confidence limit from 1990).

d. Results

Population totals, impervious surface acres, and the imperviousness per capita for each town in the coastal watershed in 1990 and 2000 are shown in Table 4. In general, there is a strong linear correlation between total population and total impervious surfaces ($r=0.933$, $n=42$, $p<0.01$) as shown in the top two graphs on Figure 7. The relationships between the percent of the town covered by impervious surfaces and population are not as strong ($r=0.432$, $n=42$, $p<0.01$). The relationships shown in Figure 7 confirm the assumption that increasing population leads to increasing impervious surfaces due to road building and other development. Moreover, there appears to be an average amount of impervious surfaces that is added for each new resident because of the linear nature of the relationship. On average, 0.20 acres of impervious surfaces are created for each person. The 95th percentile upper and lower confidence limits on this average are 0.15 and 0.25 acres/person. (Note: the confidence limits on this average are based on the standard deviation of the imperviousness per capita value in the 42 coastal towns, not on the error bars described in the previous section.) This average value represents the "industry standard" for development in the coastal watershed. The imperviousness per capita values for individual towns can be compared to this average value to determine whether they are higher or lower than the average.

The imperviousness per capita in each town is plotted in Figure 8. This figure illustrates that imperviousness per capita is very similar for most coastal towns with the exception of Newington. Given the strong linear relationship between impervious surfaces and population from Figure 7, this is not unexpected. A handful of towns had imperviousness per capita ratios in 2000 that were higher than the upper confidence level of the mean value (0.25 acres/person). Therefore, these towns (Brentwood, Brookfield, Hampton Falls, Madbury, New Durham, Newington, Wakefield) tended to have more impervious surfaces per person than the "industry standard." In general, these were smaller towns with low populations that have experienced recent growth in imperviousness.

More than half of the 42 towns in the coastal watershed had significantly increasing ratios of imperviousness per capita between 1990 and 2000 (25 of 42 towns). The ratios increased for all of the other towns as well but the amount of change was smaller than the uncertainty in the estimate so it was not considered significant. The towns with the largest increases were Newington, Madbury, and Epping for which the imperviousness per capita ratio increased by 0.52, 0.08, and 0.07 acres/person, respectively. Figure 9 illustrates the general increase in imperviousness per capita by plotting the ratio for each town in 1990 versus its ratio in 2000. All of the towns plot either above the red 45 degree line, which shows that imperviousness per capita is increasing in all the towns even if the change is not significant.

The original goal for this indicator was to have none of the towns with increasing ratios of imperviousness per capita. This goal is not being met because 25 of the 42 towns were shown to have increasing ratios. The high ratio for Newington is likely caused by the loss of population following the closing of Pease Air Force Base. However, Portsmouth also lost population with the closing of Pease but the impervious per capita ratio for Portsmouth is lower than average.

The NHEP project teams will reconsider the goals for this indicator for the 2000 to 2010 time period and will record any changes to the goals in the NHEP Monitoring Plan.

This indicator is one of three indicators related to sprawl. The results should be interpreted in the context of the results from all three indicators.

Table 3: Impervious surfaces, population, and imperviousness per capita in coastal towns in 1990 and 2000

Town		Population (people)		Imperviousness (acres)		Imperviousness per Capita (acres/person)		Comments
Name	FIPS	1990	2000	1990	2000	1990	2000	
BARRINGTON	17005	6,164	7,475	763	1,187	0.11 - 0.14	0.14 - 0.17	
BRENTWOOD	15015	2,590	3,197	532	829	0.19 - 0.22	0.24 - 0.27	(1)
BROOKFIELD	3015	518	604	139	191	0.25 - 0.28	0.30 - 0.33	(1)
CANDIA	15020	3,557	3,911	531	794	0.13 - 0.16	0.19 - 0.22	
CHESTER	15025	2,691	3,792	423	720	0.14 - 0.17	0.18 - 0.20	
DANVILLE	15030	2,534	4,023	260	445	0.09 - 0.12	0.10 - 0.13	
DEERFIELD	15035	3,124	3,678	492	768	0.14 - 0.17	0.19 - 0.22	
DOVER	17010	25,042	26,884	1,873	2,626	0.06 - 0.09	0.08 - 0.11	
DURHAM	17015	11,818	12,664	675	1,026	0.04 - 0.07	0.07 - 0.10	
EASTKINGSTON	15045	1,352	1,784	221	335	0.15 - 0.18	0.17 - 0.20	
EPPING	15050	5,162	5,476	658	1,071	0.11 - 0.14	0.18 - 0.21	
EXETER	15055	12,481	14,058	937	1,376	0.06 - 0.09	0.08 - 0.11	
FARMINGTON	17020	5,739	5,774	687	966	0.11 - 0.13	0.15 - 0.18	
FREMONT	15060	2,576	3,510	329	538	0.11 - 0.14	0.14 - 0.17	
GREENLAND	15065	2,768	3,208	455	713	0.15 - 0.18	0.21 - 0.24	
HAMPTON	15075	12,278	14,937	1,179	1,605	0.08 - 0.11	0.09 - 0.12	
HAMPTONFALLS	15073	1,503	1,880	342	536	0.21 - 0.24	0.27 - 0.30	(1)
KENSINGTON	15085	1,631	1,893	243	378	0.13 - 0.16	0.19 - 0.21	
KINGSTON	15090	5,591	5,862	651	1,019	0.10 - 0.13	0.16 - 0.19	
LEE	17025	3,729	4,145	468	740	0.11 - 0.14	0.16 - 0.19	
MADBURY	17030	1,404	1,509	251	394	0.16 - 0.19	0.25 - 0.28	(1)
MIDDLETON	17035	1,183	1,440	204	284	0.16 - 0.19	0.18 - 0.21	
MILTON	17040	3,691	3,910	597	839	0.15 - 0.18	0.20 - 0.23	
NEW CASTLE	15100	840	1,010	108	155	0.11 - 0.14	0.14 - 0.17	
NEWDURHAM	17045	1,974	2,220	458	628	0.22 - 0.25	0.27 - 0.30	(1)
NEWFIELDS	15105	888	1,551	142	251	0.14 - 0.17	0.15 - 0.18	
NEWINGTON	15110	990	775	687	941	0.68 - 0.71	1.20 - 1.23	(1)
NEWMARKET	15115	7,157	8,027	480	707	0.05 - 0.08	0.07 - 0.10	
NORTHHAMPTON	15125	3,637	4,259	647	958	0.16 - 0.19	0.21 - 0.24	
NORTHWOOD	15130	3,124	3,640	424	610	0.12 - 0.15	0.15 - 0.18	
NOTTINGHAM	15135	2,939	3,701	448	693	0.14 - 0.17	0.17 - 0.20	
PORTSMOUTH	15145	25,925	20,784	2,128	2,726	0.07 - 0.10	0.12 - 0.15	
RAYMOND	15150	8,713	9,674	977	1,484	0.10 - 0.13	0.14 - 0.17	
ROCHESTER	17050	26,630	28,461	2,395	3,304	0.08 - 0.10	0.10 - 0.13	
ROLLINSFORD	17055	2,645	2,648	266	381	0.09 - 0.11	0.13 - 0.16	
RYE	15155	4,612	5,182	587	878	0.11 - 0.14	0.15 - 0.18	
SANDOWN	15165	4,060	5,143	337	544	0.07 - 0.10	0.09 - 0.12	
SEABROOK	15170	6,503	7,934	802	1,206	0.11 - 0.14	0.14 - 0.17	
SOMERSWORTH	17060	11,249	11,477	768	1,021	0.05 - 0.08	0.07 - 0.10	
STRAFFORD	17065	2,965	3,626	434	638	0.13 - 0.16	0.16 - 0.19	
STRATHAM	15180	4,955	6,355	628	979	0.11 - 0.14	0.14 - 0.17	
WAKEFIELD	3090	3,057	4,252	878	1,225	0.27 - 0.30	0.27 - 0.30	(1)

(1) Towns with mid-point imperviousness/person above the upper conf. limit of the mean (95%ile) for the 42 towns.

(2) Impervious surface data from Justice and Rubin (2002) reprocessed to town boundaries by NHDES.

(3) Confidence intervals for imperviousness per capita values are +/-0.015 acres/person. This error value was used because it is the size of the error bars for an average size town with average imperviousness.

(4) Highlighted rows are towns for which the imperviousness per capita range in 2000 is entirely above the imperviousness per capita range for 1990.

Figure 6: Imperviousness per capita in coastal towns in 2000

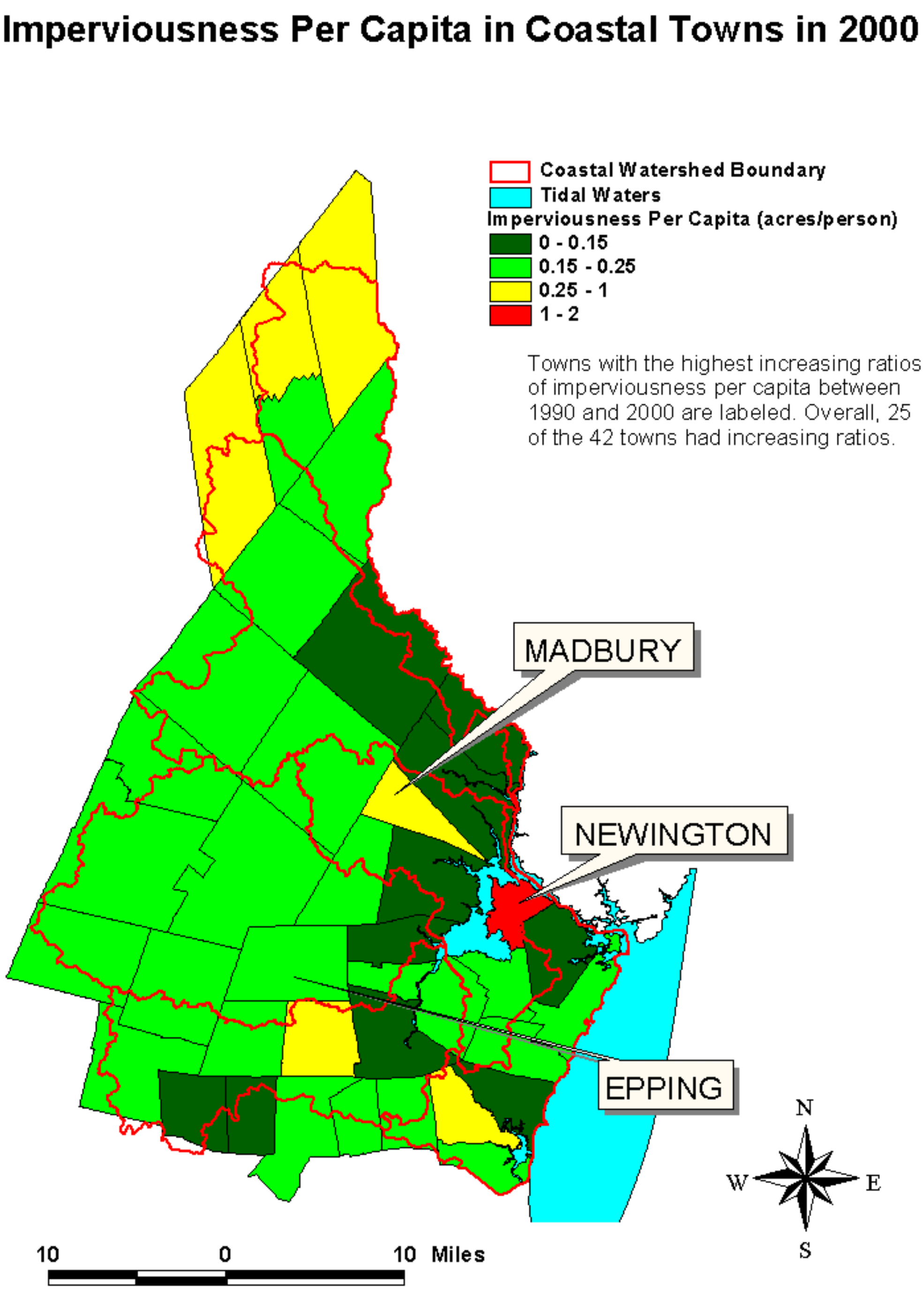


Figure 7: Relationships between impervious surfaces and population in coastal watershed towns

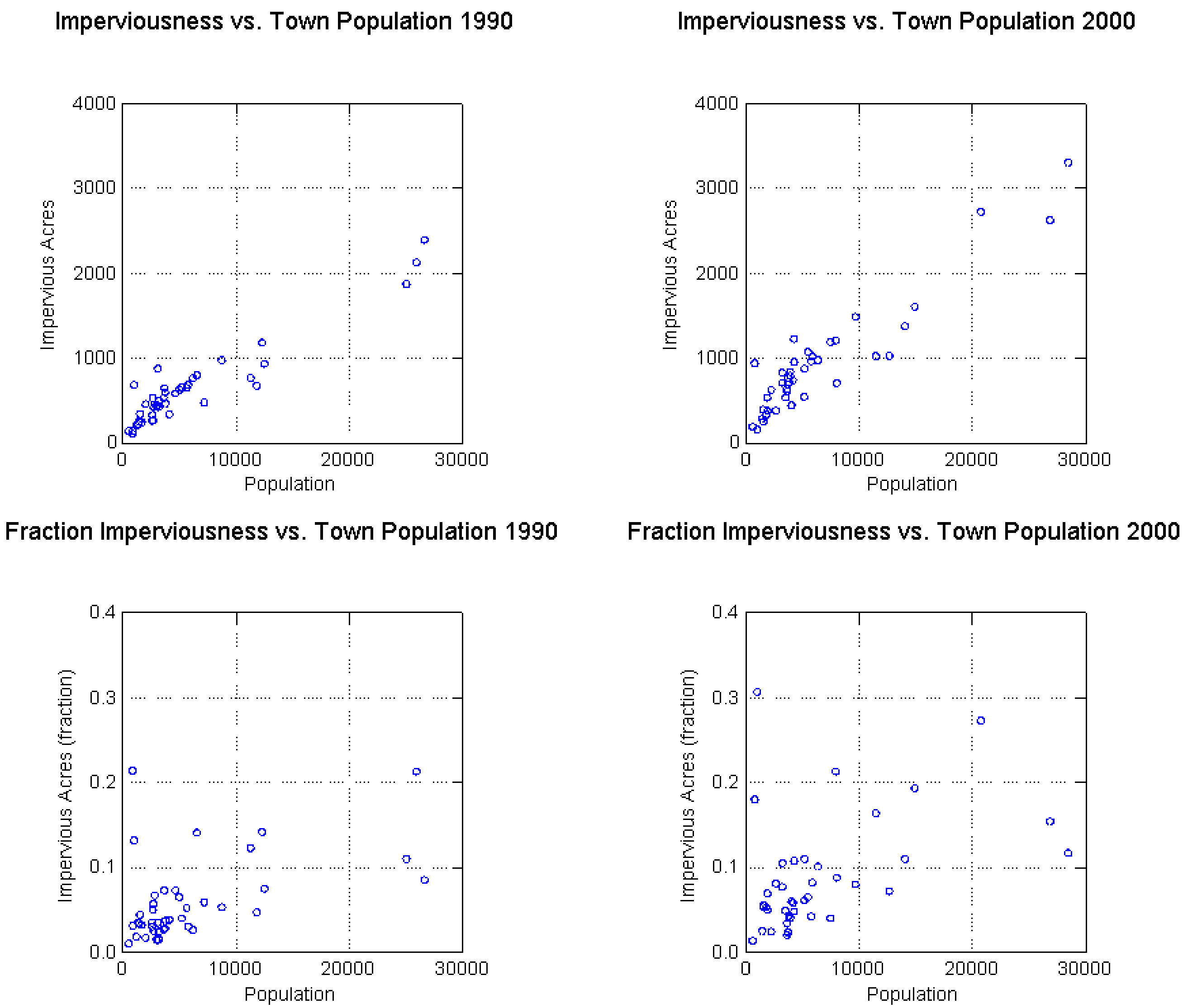


Figure 8: Imperviousness per capita in coastal towns in 1990 and 2000

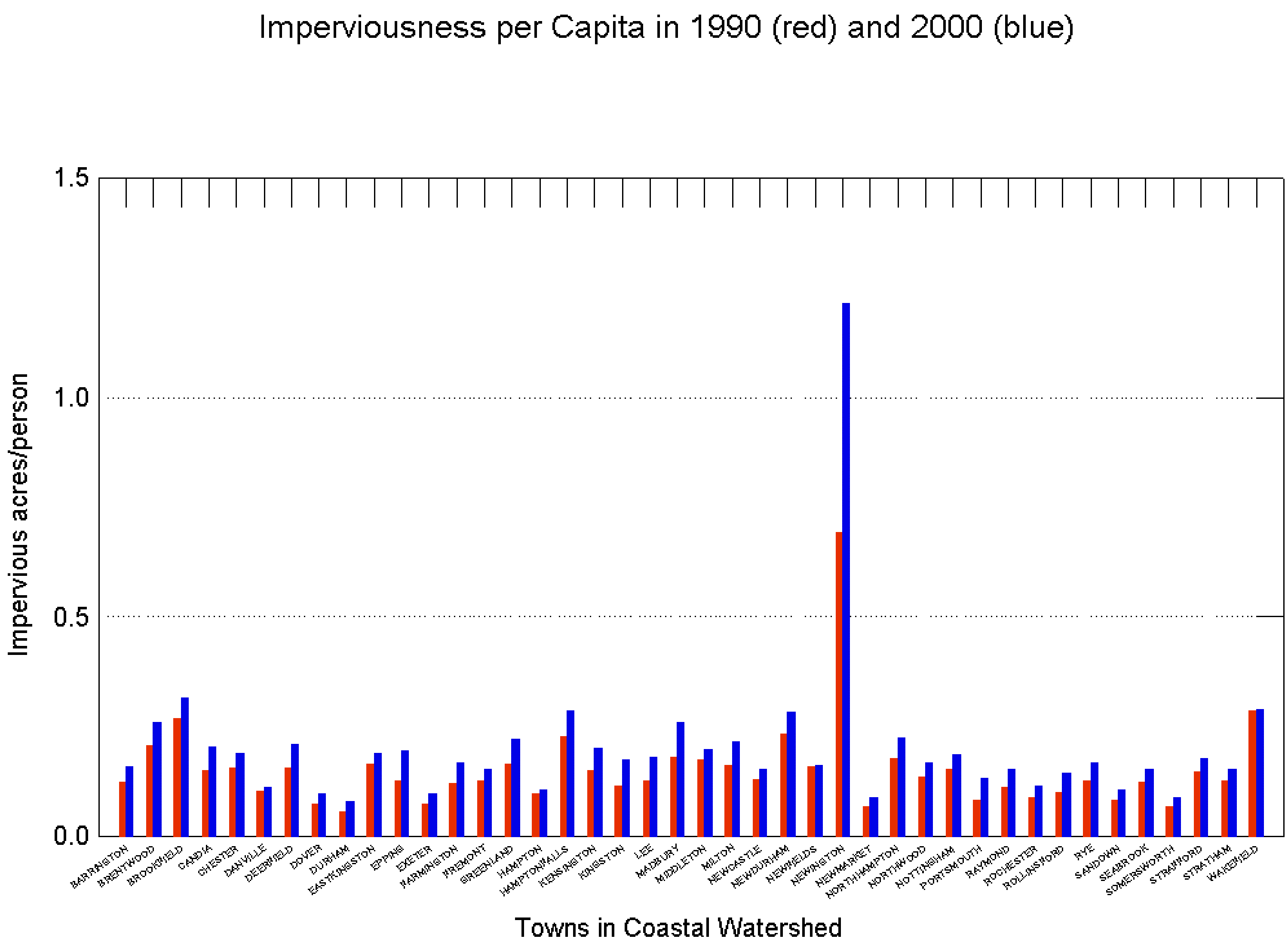
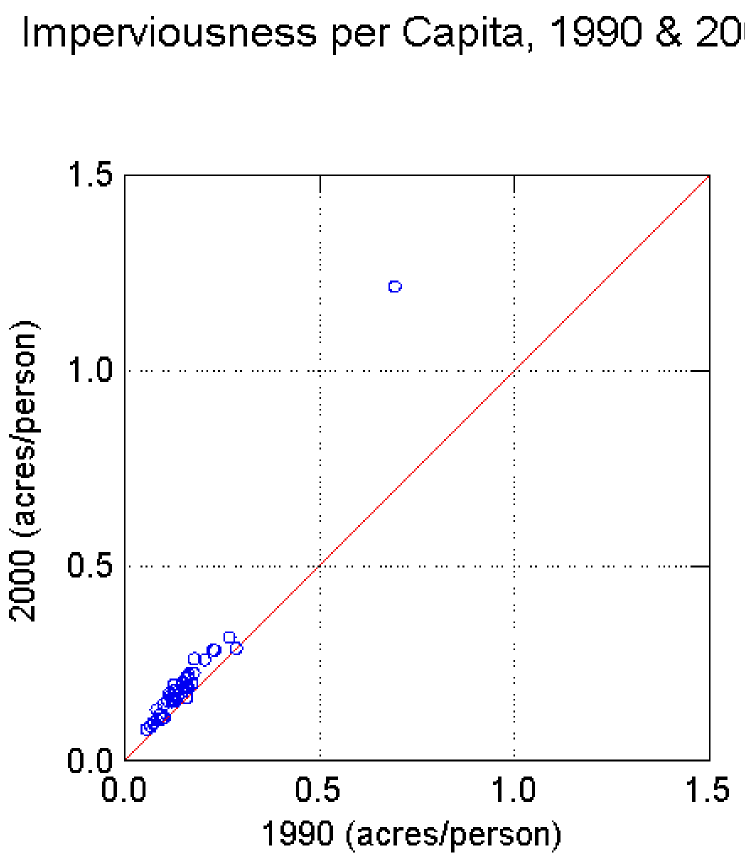
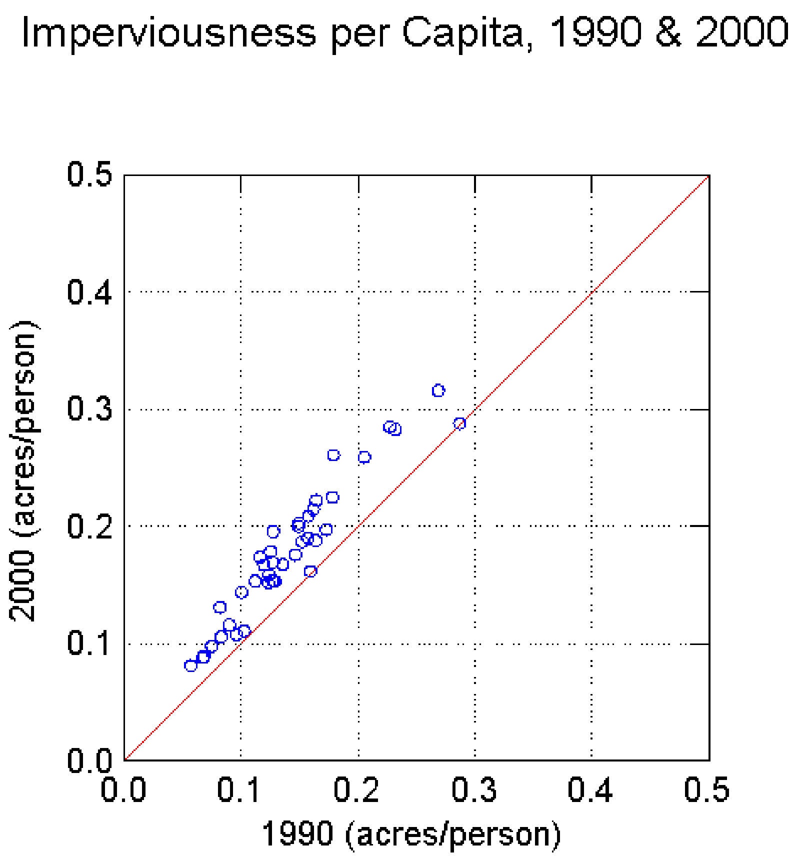


Figure 9: Comparison of imperviousness per capita in 1990 to 2000





Left Graph: This graph contains points for all 42 towns in the coastal watershed

Right Graph: This graph shows just the points in the lower left corner of the left graph. The point for Newington is not shown.

3. Rate of Sprawl – Low-Density, Residential Development

a. Monitoring Objectives

The objective of this indicator is to estimate the rate of low-density residential development in the towns of the coastal watershed. The second of three indicators of "sprawl" development, this indicator uses increases in road miles in each town as a proxy for new low-density, residential development (subdivisions). Changes in low density residential development are not expected to be accurately accounted for in the assessment of changes in impervious surface conducted under the previous indicator. Most rural, low-density residential development affects too small an area on the landscape to be identified using satellite imagery.

Similar to the previous indicator, the ratio of the total road miles to the population ("road miles per capita") will be calculated for each town. Ratios for 1990, 2000, and 2005 will be compared to determine whether the road miles per capita is growing, declining, or remaining the same for a town to answer the following monitoring question:

- Has the rate of urban sprawl in coastal NH watersheds changed significantly over time?

which will, in turn, report on progress toward the following management objective:

- LND1-2: Minimize the total rate of land consumption in the NH coastal watershed (as measured by acres of development per capita)

b. Measurable Goal

The goal is for no towns in the coastal watershed to have increasing ratios (i.e., no increasing rates of sprawl).

c. Data Analysis and Statistical Methods

Road miles per town were defined as the sum of Class I, II, III, IV, and V road miles as reported by the NH Department of Transportation (NHDOT). Private roads are not included in the road inventory maintained by NHDOT, so low density private subdivisions will not be included. US Census population for each town in 1990 and 2000 was obtained from the NH State Data Center. The "road miles per capita" for 1990 and 2000 was calculated by dividing the total road miles in the town by the town population.

Error bars on the road miles per capita ratios were estimated by assuming that the population and road mile totals for each town had individual uncertainties of 1%, and propagating these errors through the equations to the ratio following the methods of partial derivatives in Kline (1985). The US Census population totals are purported to be 100% correct, so a 1% error is a conservative assumption. NHDOT considers the road miles tallies for each town to be very accurate but acknowledges that errors are possible due to changes in measuring methods. Therefore, for this analysis, a +/-1% error was assumed as a reasonable way of accounting for potential errors. An average error was calculated using average values for the input variables (e.g. road miles per town, population per town) and the assumed errors in the input values (1% and 1%, respectively). This average error was added to and subtracted from the calculated ratio for each town to approximate the 95^{th} percentile upper and lower confidence interval for the result. The confidence limits were used to determine whether the ratios from 2000 were significantly higher than those from 1990 (i.e., the lower confidence limit from 2000 > upper confidence limit from 1990).

d. Results

Population totals, road miles, and the road miles per capita for each town in the coastal watershed in 1990 and 2000 are shown in Table 4. Total road miles and population are well correlated ($r=0.862$, $n=42$, $p<0.01$) as shown in the top two graphs on Figure 11. The relationships between the road density (i.e., road miles divided by town area in square miles) and population are not as strong ($r=0.575$, $n=42$, $p<0.01$). The relationships shown in Figure 11 confirm the assumption that increasing population leads to increasing miles of roads. Using the average of the 2000 data, approximately 0.014 miles (74 feet) of road are added for each person in the town. The 95th percentile upper and lower confidence limits on this average are 0.012 and 0.016 miles/person. (Note: the confidence limits on this average are based on the standard deviation of the road miles per capita value for the 42 coastal towns, not on the error bars described in the previous section.) This average value represents the "industry standard" for development in the coastal watershed. The road miles per capita values for individual towns can be compared to this average to determine whether they are higher or lower than the average.

The road miles per capita in each town is plotted in Figure 12. Several towns had road miles per capita ratios in 2000 that were higher than the upper confidence level of the mean value (0.016 miles/person). Therefore, these towns (Brookfield, Deerfield, Madbury, Middleton, Milton, New Durham, Newington, Nottingham, Strafford, Wakefield) tended to have more road miles per person than the "industry standard". With the exception of Newington, these towns tended to be in the western portion of the watershed, not immediately adjacent to the coast.

Out of the 42 towns in the coastal watershed, seven towns (Greenland, Kingston, Milton, Newington, Newmarket, Portsmouth, and Rollinsford) had significantly increasing ratios of road miles per capita between 1990 and 2000. In contrast, most of the other towns had decreasing ratios of road miles to population because no new roads were built but the population increased. The increasing ratios for Newington and Portsmouth were likely caused by these towns' loss of population following the closing of Pease Air Force Base. Figure 13 illustrates that most of the towns did not experience a growth in the road miles per capita ratio. Most of the points on this figure are either on or below the 45 degree line, which represents equal ratios in 1990 and 2000.

The original goal for this indicator was to have none of the towns with increasing ratios of road miles per capita. This goal is not being met because seven towns were shown to have increasing ratios. However, the accuracy of the road miles and the population data caused almost any increase in road miles per capita to be statistically significant, even if the magnitude of the change was not meaningful in reality.

This indicator is one of three indicators related to sprawl. The results should be interpreted in the context of the results from all three indicators. Moreover, the utility of this indicator would be improved if private road miles were also part of the total.

Table 4: Road miles and population in coastal towns in 1990 and 2000

Town		Population (people)		Road Miles (miles)		Road Miles per Capita (miles/person)		Comments
Name	FIPS	1990	2000	1990	2000	1990	2000	
BARRINGTON	17005	6,164	7,475	82.86	84.50	0.013 - 0.014	0.011 - 0.011	
BRENTWOOD	15015	2,590	3,197	38.54	45.03	0.015 - 0.015	0.014 - 0.014	
BROOKFIELD	3015	518	604	20.85	20.86	0.040 - 0.040	0.034 - 0.035	(1)
CANDIA	15020	3,557	3,911	63.74	63.61	0.018 - 0.018	0.016 - 0.016	
CHESTER	15025	2,691	3,792	46.98	46.98	0.017 - 0.018	0.012 - 0.013	
DANVILLE	15030	2,534	4,023	24.05	27.22	0.009 - 0.010	0.007 - 0.007	
DEERFIELD	15035	3,124	3,678	74.49	73.52	0.024 - 0.024	0.020 - 0.020	(1)
DOVER	17010	25,042	26,884	146.07	148.25	0.006 - 0.006	0.005 - 0.006	
DURHAM	17015	11,818	12,664	70.52	76.97	0.006 - 0.006	0.006 - 0.006	
EASTKINGSTON	15045	1,352	1,784	19.52	20.57	0.014 - 0.015	0.011 - 0.012	
EPPING	15050	5,162	5,476	72.21	73.86	0.014 - 0.014	0.013 - 0.014	
EXETER	15055	12,481	14,058	73.25	83.64	0.006 - 0.006	0.006 - 0.006	
FARMINGTON	17020	5,739	5,774	62.93	62.93	0.011 - 0.011	0.011 - 0.011	
FREMONT	15060	2,576	3,510	29.13	32.17	0.011 - 0.011	0.009 - 0.009	
GREENLAND	15065	2,768	3,208	27.89	34.81	0.010 - 0.010	0.011 - 0.011	
HAMPTON	15075	12,278	14,937	87.73	88.12	0.007 - 0.007	0.006 - 0.006	
HAMPTONFALLS	15073	1,503	1,880	29.10	29.12	0.019 - 0.019	0.015 - 0.016	
KENSINGTON	15085	1,631	1,893	26.76	27.20	0.016 - 0.017	0.014 - 0.015	
KINGSTON	15090	5,591	5,862	60.29	70.30	0.011 - 0.011	0.012 - 0.012	
LEE	17025	3,729	4,145	59.59	60.94	0.016 - 0.016	0.015 - 0.015	
MADBURY	17030	1,404	1,509	26.37	26.66	0.019 - 0.019	0.018 - 0.018	(1)
MIDDLETON	17035	1,183	1,440	25.27	29.22	0.021 - 0.021	0.020 - 0.020	(1)
MILTON	17040	3,691	3,910	70.39	76.63	0.019 - 0.019	0.019 - 0.020	(1)
NEW CASTLE	15100	840	1,010	6.01	6.11	0.007 - 0.007	0.006 - 0.006	
NEWDURHAM	17045	1,974	2,220	58.89	61.83	0.030 - 0.030	0.028 - 0.028	(1)
NEWFIELDS	15105	888	1,551	13.41	15.49	0.015 - 0.015	0.010 - 0.010	
NEWINGTON	15110	990	775	17.52	18.90	0.018 - 0.018	0.024 - 0.025	(1)
NEWMARKET	15115	7,157	8,027	37.71	45.31	0.005 - 0.005	0.006 - 0.006	
NORTHHAMPTON	15125	3,637	4,259	44.05	44.06	0.012 - 0.012	0.010 - 0.010	
NORTHWOOD	15130	3,124	3,640	45.99	45.96	0.015 - 0.015	0.012 - 0.013	
NOTTINGHAM	15135	2,939	3,701	67.47	71.30	0.023 - 0.023	0.019 - 0.019	(1)
PORTSMOUTH	15145	25,925	20,784	105.90	110.04	0.004 - 0.004	0.005 - 0.005	
RAYMOND	15150	8,713	9,674	83.16	88.74	0.009 - 0.010	0.009 - 0.009	
ROCHESTER	17050	26,630	28,461	170.11	179.53	0.006 - 0.007	0.006 - 0.006	
ROLLINSFORD	17055	2,645	2,648	25.35	26.75	0.009 - 0.010	0.010 - 0.010	
RYE	15155	4,612	5,182	52.58	54.16	0.011 - 0.012	0.010 - 0.011	
SANDOWN	15165	4,060	5,143	41.20	43.81	0.010 - 0.010	0.008 - 0.009	
SEABROOK	15170	6,503	7,934	39.74	40.12	0.006 - 0.006	0.005 - 0.005	
SOMERSWORTH	17060	11,249	11,477	52.46	54.32	0.005 - 0.005	0.005 - 0.005	
STRAFFORD	17065	2,965	3,626	68.89	71.53	0.023 - 0.023	0.020 - 0.020	(1)
STRATHAM	15180	4,955	6,355	47.30	49.06	0.009 - 0.010	0.008 - 0.008	
WAKEFIELD	3090	3,057	4,252	80.90	80.96	0.026 - 0.027	0.019 - 0.019	(1)

(1) Towns with mid-point road miles/person above the upper conf. limit of the mean (95%ile) for the 42 towns.

(2) Road mile data from NHDOT records of public classified roads, class I-V.

(3) Confidence intervals for road miles per capita values are +/-0.00014 miles/person. This error value was used because it is the error bar for an average size town with average road miles.

(4) Highlighted rows are towns for which the road mile per capita range in 2000 is entirely above the road mile per capita range for 1990.

Figure 10: Road miles per capita in coastal towns in 2000

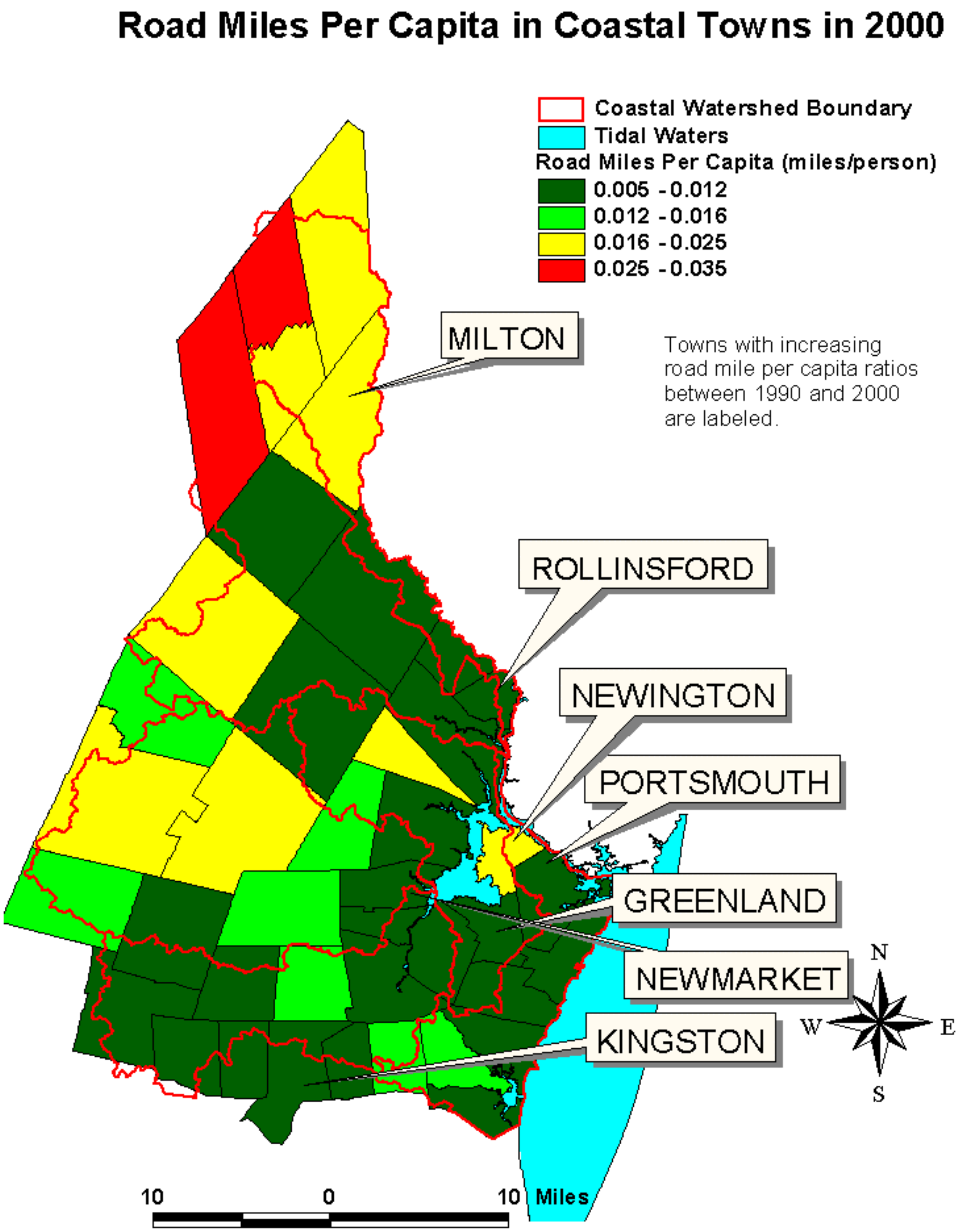


Figure 11: Relationships between road miles and population in coastal towns

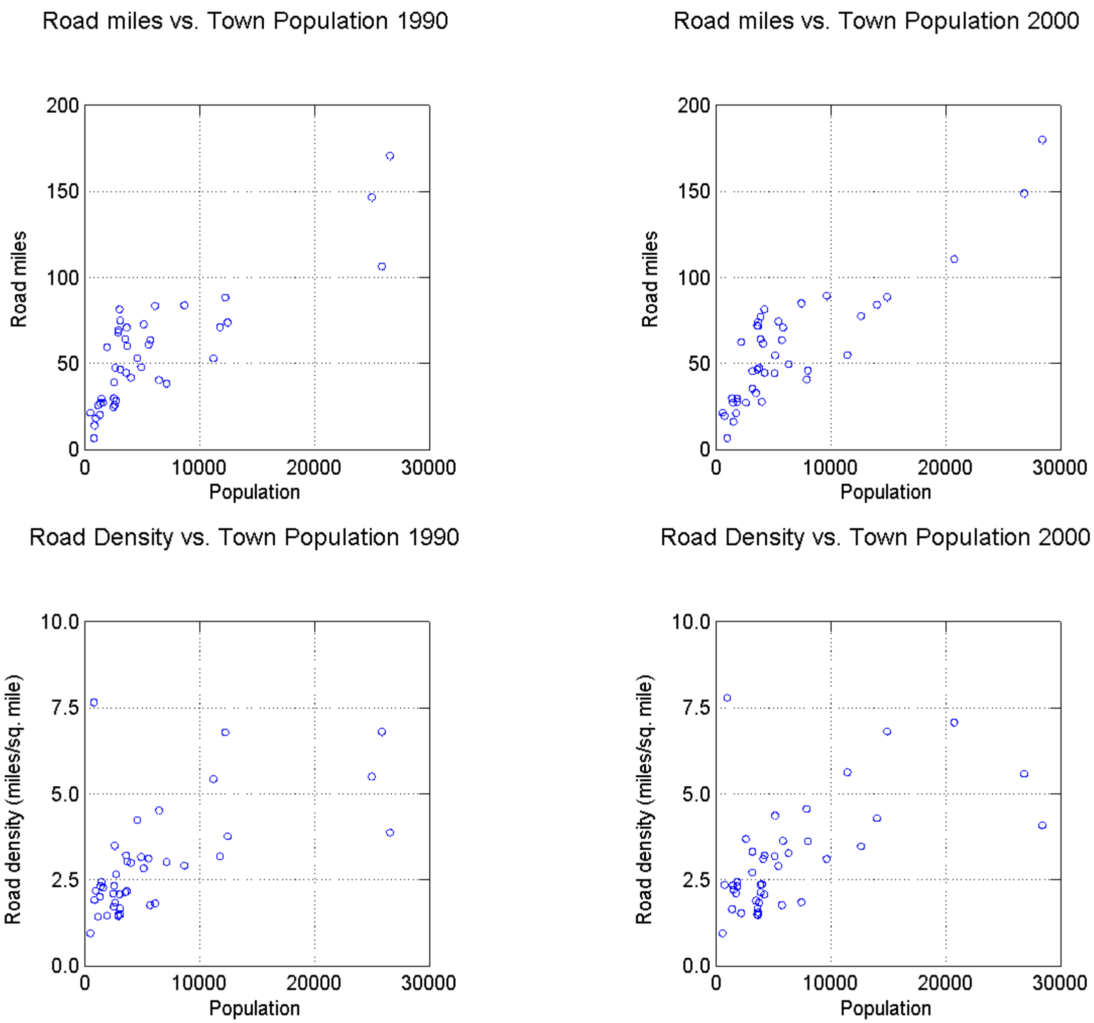


Figure 12: Road miles per capita for coastal watershed towns in 1990 and 2000

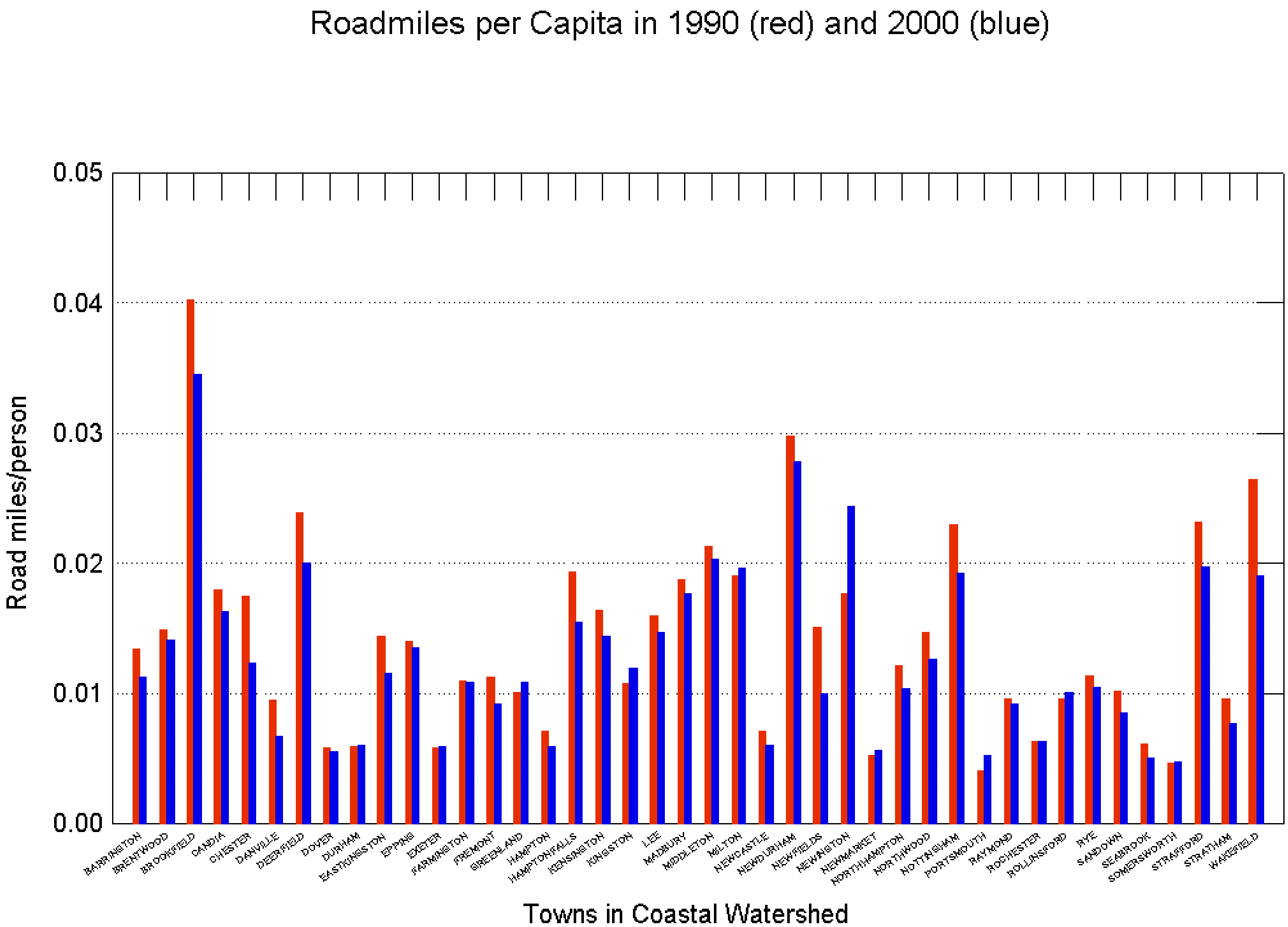
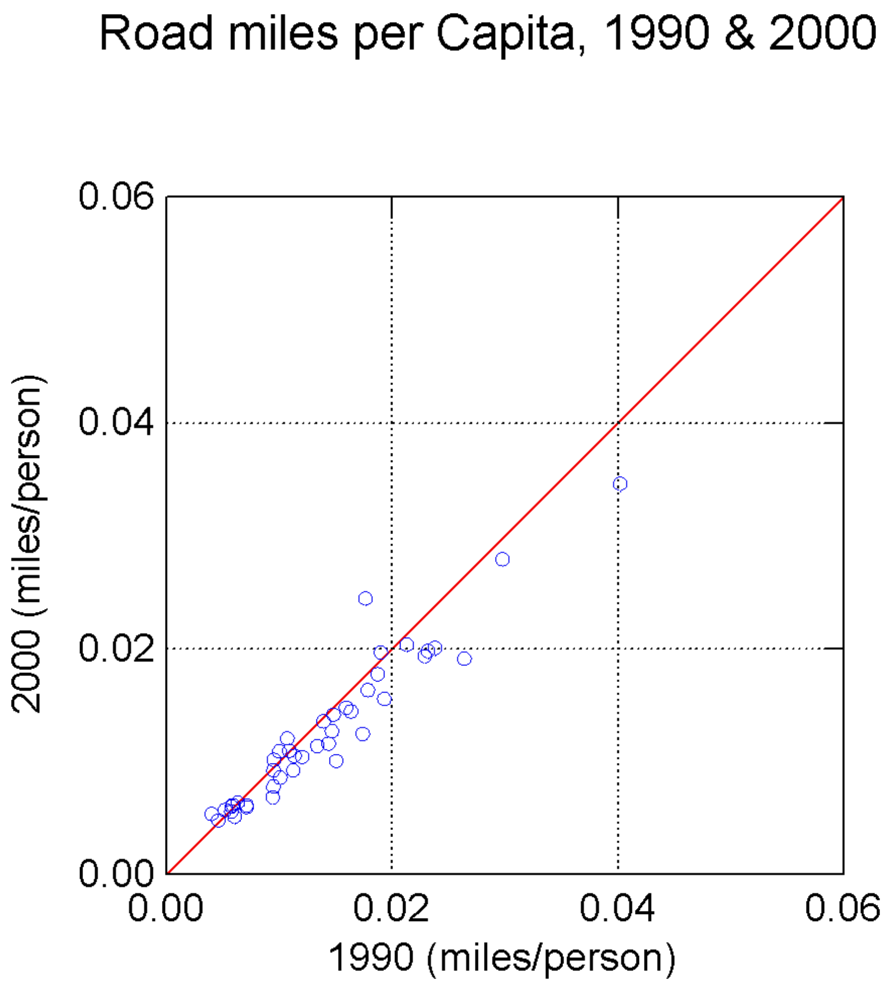


Figure 13: Road miles per capita in 1990 versus road miles per capita in 2000 for each coastal town



LUD4. Rate of Sprawl - Fragmentation

a. Monitoring Objectives

The objective of this indicator is to estimate the rate at which towns are losing unfragmented blocks of open space due to development patterns. The fragmentation of open lands due to new roads and sprawling patterns of development can have significant consequences on habitat and hydrologic functions within the coastal watershed. The changes in impervious surface and road miles examined by the first two sprawl indicators do not account for the impact of the location of these development activities. This third indicator of "sprawl" development uses the loss of unfragmented blocks of undeveloped land to assess the impacts of the location of new road construction and development. This indicator will be used to partially answer the following monitoring question:

- Has the rate of urban sprawl in coastal NH watersheds changed significantly over time?

which will, in turn, report on progress toward the following management objective:

- LND1-2: Minimize the total rate of land consumption in the NH coastal watershed (as measured by acres of development per capita)

b. Measurable Goal

For this report, the only data on unfragmented lands that was available was for 2001. Therefore, it was only possible to report on the status of unfragmented lands as of 2001. Change in unfragmented lands over time relative to population changes (as was done for impervious surfaces and road miles) could not be assessed. Therefore, none of the measurable goals from the Monitoring Plan (NHEP, 2003) apply.

c. Data Analysis, Statistical Methods and Hypothesis

Unfragmented lands data was obtained from the Society for the Protection of New Hampshire Forests (SPNHF). SPNHF had processed 2001 land cover data from GRANIT using USGS digital line graphs of roads and NHDOT's G_roads datalayer to identify blocks of unfragmented lands in southeastern New Hampshire. The methodology and assumptions used by SPNHF to process the data are included below.

> Natural land cover types were extracted from the GRANIT land cover data for the study area as a precursor to generating an unfragmented blocks datalayer. These land cover types included: all forest cover types except Alpine (440), forested and non-forested wetlands, and tidal wetlands; and bedrock/vegetated, sand dunes, and cleared or disturbed land covers. Active agriculture was excluded.
>
> A special roads datalayer was generated for use as a fragmenting feature; only traveled roadways were included. The USGS-based datalayer and the NHDOT datalayer were merged after selecting out all jeep trails, Cl 6 roads, and other non-traveled roadways; private roads in the NHDOT datalayer were included in the merged dataset even though some function only as occasional use access roads.
>
> Note that the influence of urban land uses and transportation land cover types as fragmenting features was automatically accounted for in the selection of natural land cover types above, but the transportation land cover type was found to be insufficient within the GRANIT land cover mapping due to tree cover occluding many road segments. Furthermore, frontage development could not be accounted for in the GRANIT land cover mapping, so a 300' buffer was created from the merged road datalayers.

NHDES clipped the unfragmented data layer from SPNHF to the coastal watershed boundary (HUC8 01060003) and then selected only those blocks that covered greater than 250 acres inside the watershed. The selected blocks were further stratified by town boundaries to determine the area of large, unfragmented forest blocks in each coastal watershed town. Forest blocks were allowed to straddle town boundaries. For instance, a 300 acre block that was half in one town and half in another was still counted an a “large, unfragmented block”. Since the data were not being compared to a management goal, no tests for statistical significance (e.g., with confidence intervals) were applied.

d. Results

Table 5 shows the percentage of land area in each coastal watershed town that is covered by unfragmented blocks greater than 250 acres in 2001. The towns with the greatest percentages of land area covered by unfragmented blocks are Middleton (70%), Nottingham (69%) and Milton (64%). The towns with the smallest percentages are New Castle (0%), Newington (5%) and Kingston (10%). Figure 16 is a map of the unfragmented blocks >250 acres in the coastal watershed.

Figure 14 and Figure 15 show the relationships between unfragmented lands and population, road miles, and imperviousness. The best relationships are between the percent of the town that is unfragmented and (1) road density ($r=-0.659$, $n=42$, $p<0.01$) and (2) the fraction of impervious surfaces ($r=-0.718$, $n=42$, $p<0.01$). These relationships are intuitive because increasing road density and development should result in decreasing unfragmented lands. The relationships between unfragmented lands and population are inverse and not statistically significant at the $p<0.05$ level.

This indicator is one of three indicators related to sprawl. The results should be interpreted in the context of the results from all three indicators.

Table 5: Coverage of large, unfragmented forest blocks in coastal watershed towns

Town	Town Area (acres)				Acres of Unfragmented	Percent of Land Area in Unfragmented
Name	FIPS	Land	Water	Total	Blocks >250 acres	Blocks >250 acres
MIDDLETON	17035	11,560	283	11,843	8,102	70.09%
NOTTINGHAM	15135	29,880	1,116	30,997	20,478	68.53%
MILTON	17040	21,099	836	21,935	13,585	64.39%
FARMINGTON	17020	23,221	419	23,640	14,525	62.55%
BARRINGTON	17005	29,719	1,398	31,117	18,434	62.03%
NEWFIELDS	15105	4,542	105	4,647	2,812	61.90%
BROOKFIELD	3015	14,593	287	14,880	8,729	59.81%
FREMONT	15060	11,036	107	11,143	6,543	59.29%
DEERFIELD	15035	32,587	762	33,349	18,699	57.38%
EPPING	15050	16,468	308	16,776	9,186	55.78%
BRENTWOOD	15015	10,742	121	10,862	5,725	53.30%
MADBURY	17030	7,403	396	7,799	3,809	51.45%
STRAFFORD	17065	31,153	1,626	32,779	15,874	50.95%
NORTH HAMPTON	15125	8,865	57	8,922	4,168	47.01%
RAYMOND	15150	18,448	495	18,944	8,328	45.14%
NORTHWOOD	15130	17,976	1,380	19,356	7,564	42.08%
HAMPTON FALLS	15073	7,719	358	8,077	3,240	41.98%
EXETER	15055	12,553	261	12,814	5,175	41.23%
KENSINGTON	15085	7,637	31	7,668	3,091	40.47%
CANDIA	15020	19,342	215	19,557	7,774	40.19%
CHESTER	15025	16,620	98	16,718	6,652	40.02%
ROCHESTER	17050	28,331	750	29,081	11,274	39.79%
STRATHAM	15180	9,672	228	9,901	3,734	38.60%
NEWMARKET	15115	8,073	1,007	9,080	3,102	38.42%
DURHAM	17015	14,308	1,543	15,852	5,367	37.51%
WAKEFIELD	3090	25,264	3,452	28,716	9,357	37.04%
RYE	15155	7,997	426	8,424	2,872	35.91%
NEW DURHAM	17045	26,347	1,707	28,054	9,127	34.64%
SANDOWN	15165	8,889	343	9,232	2,921	32.86%
ROLLINSFORD	17055	4,682	161	4,843	1,506	32.17%
GREENLAND	15065	6,780	1,744	8,524	2,053	30.28%
EAST KINGSTON	15045	6,319	62	6,381	1,843	29.17%
LEE	17025	12,680	248	12,928	3,338	26.33%
HAMPTON	15075	8,317	754	9,071	2,034	24.45%
SOMERSWORTH	17060	6,220	179	6,399	1,249	20.08%
DOVER	17010	17,094	1,498	18,592	3,336	19.51%
SEABROOK	15170	5,669	491	6,160	1,079	19.03%
DANVILLE	15030	7,439	131	7,569	1,341	18.02%
PORTSMOUTH	15145	10,001	762	10,763	1,687	16.87%
KINGSTON	15090	12,495	955	13,450	1,263	10.11%
NEWINGTON	15110	5,215	2,701	7,916	242	4.65%
NEW CASTLE	15100	504	843	1,348	0	0%

Data Source: 2001 Land cover with fragmentation analysis by SPNHF

Figure 14: Relationships between acres of unfragmented lands and population, road miles, road density, and imperviousness

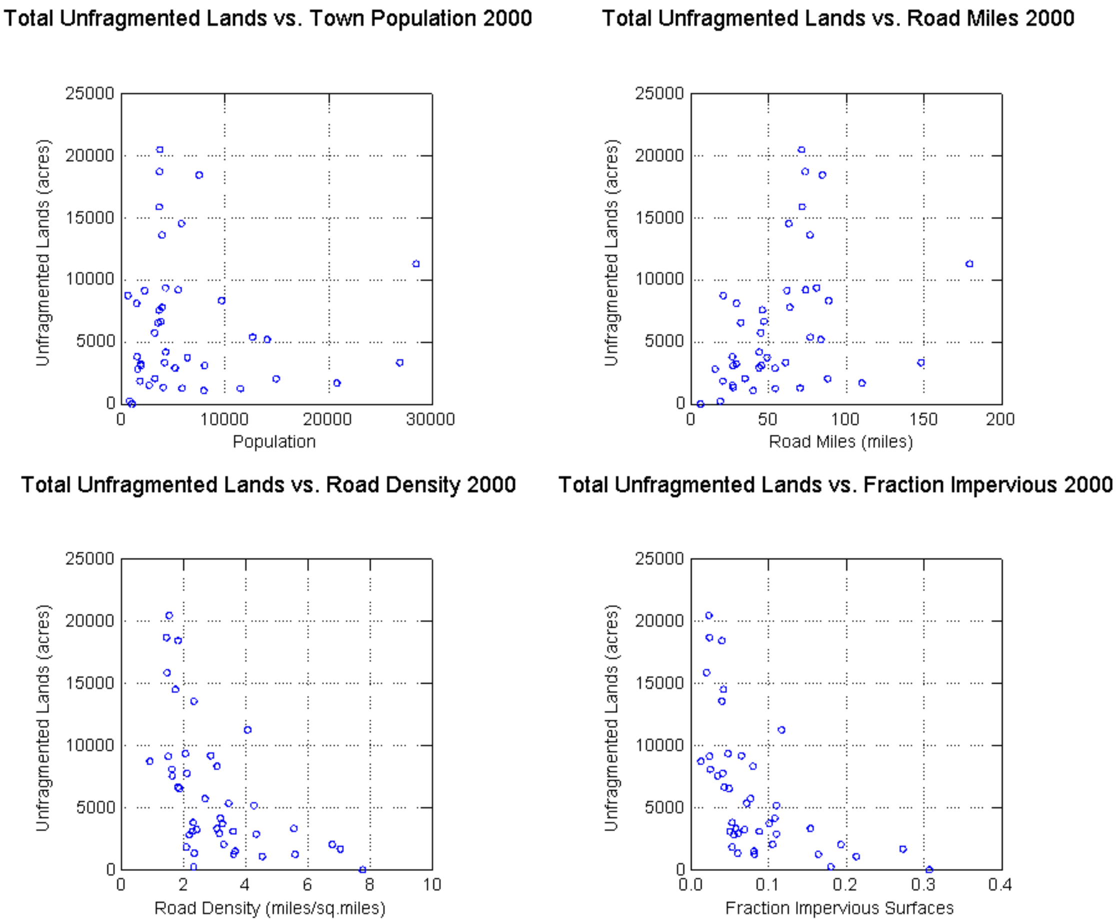


Figure 15: Relationships between fraction of town covered by unfragmented lands and population, road miles, road density, and imperviousness

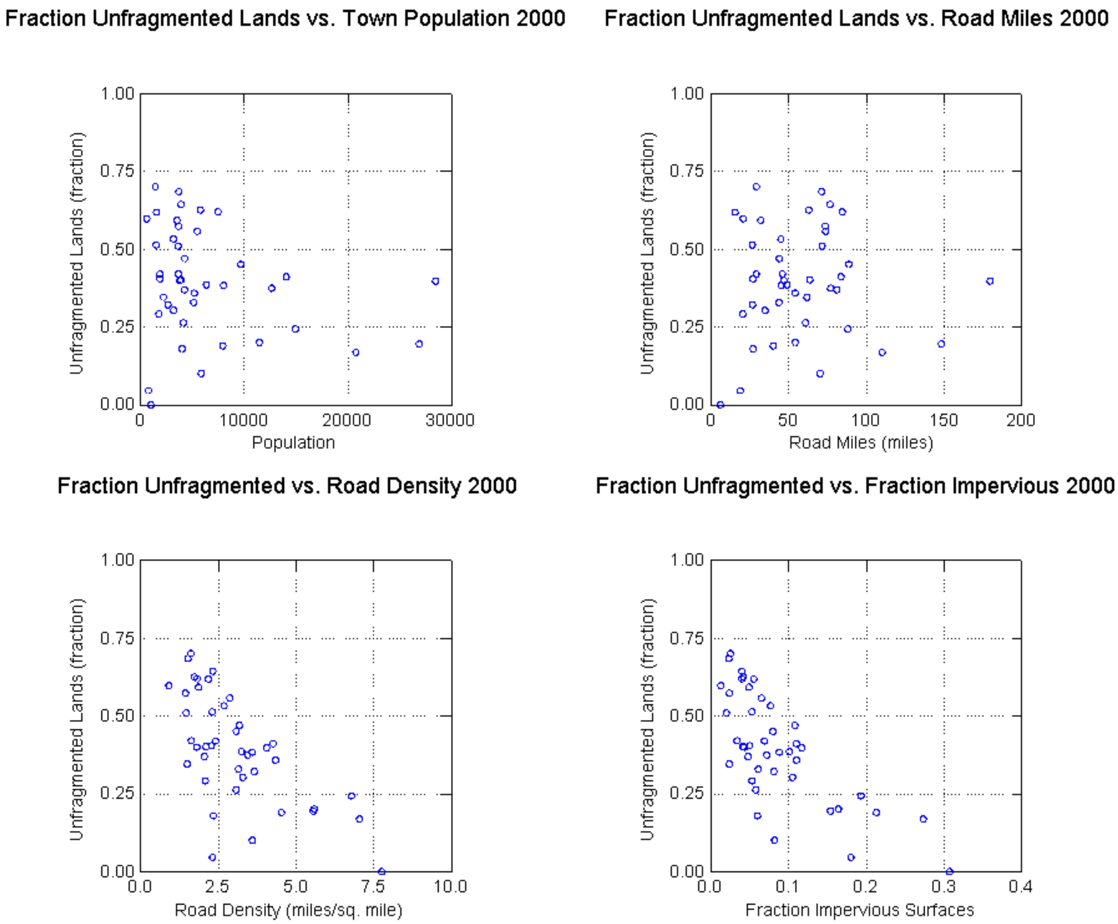


Figure 16: Large (>250 acres), unfragmented forest blocks in the coastal watershed

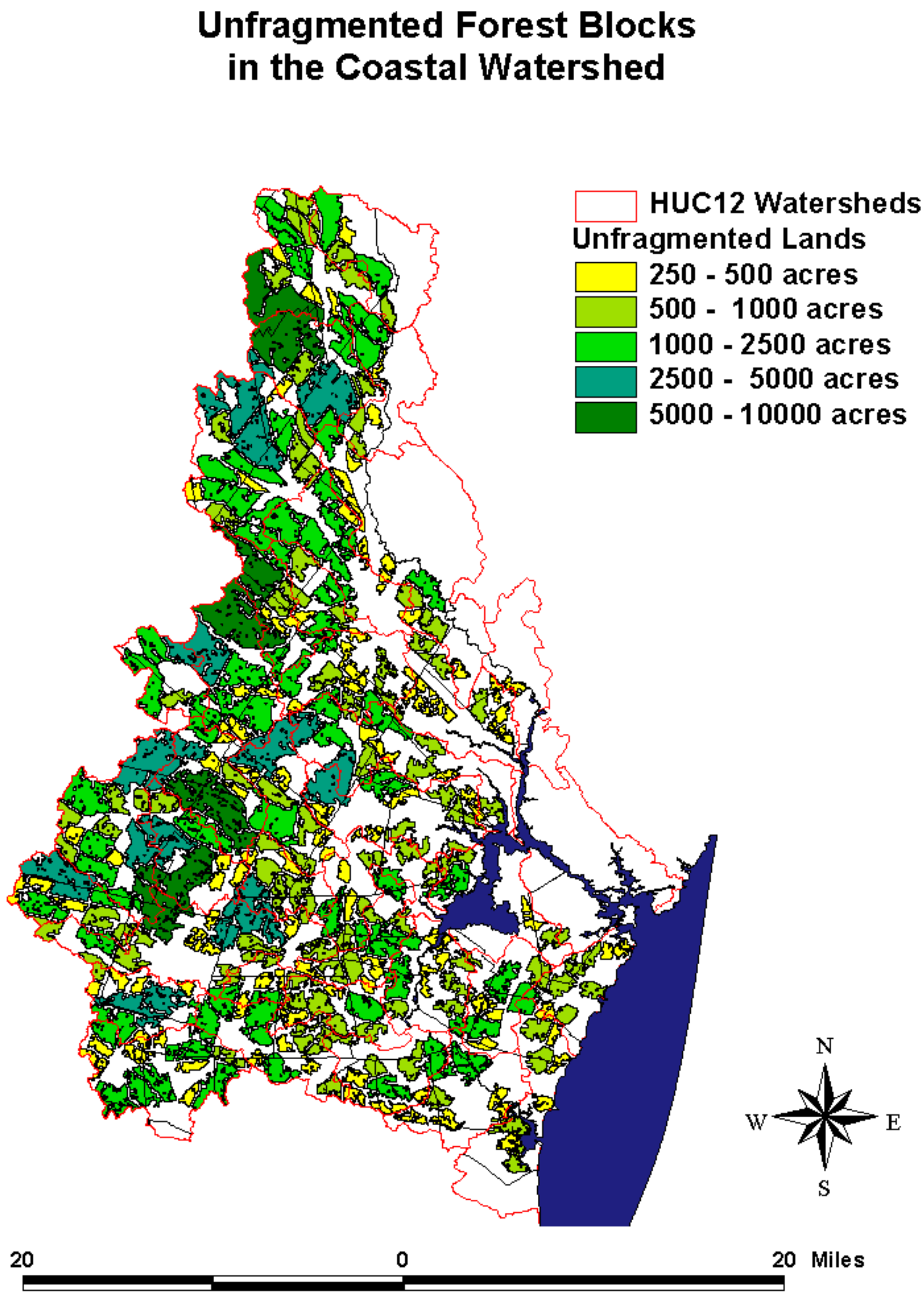
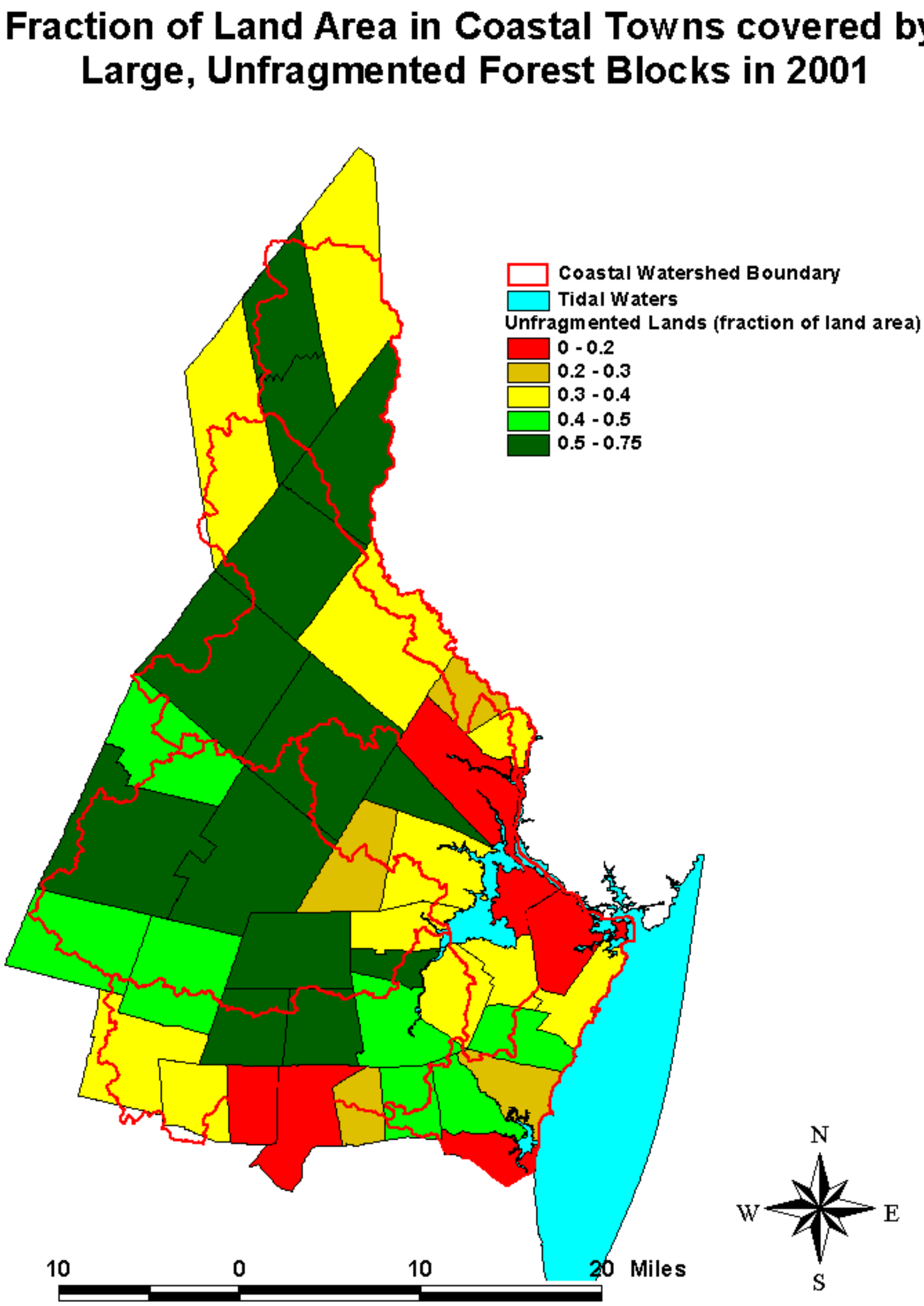


Figure 17: Fraction of land area in coastal towns covered by large, unfragmented forest blocks in 2001



SUMMARY

While it is hard to summarize overall conditions in the NHEP project area, the land use and development indicators presented in this report show that:

- Six (6) of the 37 subwatersheds in the coastal watershed of New Hampshire have more than 10% of their land area covered by impervious surfaces. These watersheds are clustered near the coast an along the Route 16 corridor. Eleven (11) of the 42 towns in the watershed are covered by more than 10% impervious surfaces. The towns with the highest percent impervious coverage are New Castle (30%), Portsmouth (27%), and Seabrook (21%).
- Impervious surfaces and road miles were strongly correlated with population in the 42 coastal towns. In 2000, the towns contained an average of 0.20 acres of impervious surface and 74 feet of road per person. The strong relationship between these variables and population indicate that planners can predict future impervious surface and road mile coverage based on population predictions and assuming the same development patterns and practices are continued in the future.
- Many towns exhibited increasing land consumption per person between 1990 and 2000. Increasing land consumption per person is a common indication of "sprawling" growth. Imperviousness per capita ratios increased between 1990 and 2000 for 25 of the 42 coastal towns. While only these towns had statistically significant increases, all 42 towns in the watershed had increasing ratios of imperviousness per capita. Road miles per capita ratios increased between 1990 and 2000 for a handful of towns. However, the small size of the error bars for the road miles and the population data caused almost any increase in road miles per capita to be statistically significant, even if the magnitude of the change was not meaningful in reality. Road miles per capita decreased between 1990 and 2000 in most of the towns in the watershed.
- The percent of each town that is covered by large, unfragmented forest blocks ranged from 0% for some coastal towns to 70% for towns in the western part of the watershed. Unfragmented lands were inversely correlated with road density and the percent of the watershed covered by impervious surfaces. Only 2001 data were available for unfragmented lands so the rate of loss of these lands could not be calculated for this report.

REFERENCES CITED

Justice D and Rubin F (2002) Developing Impervious Surface Estimates for Coastal New Hampshire, A Final Report to the New Hampshire Estuaries Project. Submitted by David Justice and Fay Rubin, Complex Systems Research Center, Institute for the Study of Earth, Oceans and Space University of New Hampshire, Durham, NH. December 2002.

Kline SJ (1985) The purposes of uncertainty analysis. *Journal of Fluids Engineering*, **107**: 153-160.

NHEP (2003) NHEP Monitoring Plan. New Hampshire Estuaries Project, Portsmouth NH. March 2003.

Schueller (1995). The importance of imperviousness. *Watershed Protection Techniques*, **1**(3): 100-111.