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Assessing the Risk of 100-year Freshwater Floods in the Lamprey River Watershed of New Hampshire Resulting from Changes in Climate and Land Use: Review of Land Development (Build-out) and Climate Scenarios

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Assessing the Risk of 100-year Freshwater Floods in the Lamprey River Watershed of New Hampshire Resulting from Changes in Climate and Land Use

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Review of Land Development (Build-out) and Climate Scenarios

Cameron Wake, Fay Rubin, Robert Roseen, Ann Scholz, Michael Simpson and Cliff Sinnott
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1. Introduction

Estimating future changes in run-off from the 214 square mile (136,851 acres) Lamprey River watershed[1] resulting from changes in land use and climate requires first developing scenarios of future land development and future climate. These scenarios must not be viewed as predictions. Rather, they represent plausible story lines of what could happen (not what will necessarily happen) and therefore provide a basis for comparing the effects of different land development and different climate over the course of the next 90 years in the watershed. The scenarios approach is therefore not meant to forecast the *most likely* configuration of the landscape and climate, but rather to *bracket* possible run-off scenarios, and thus possible future 100 year floodplains.

2. Land Development (Build-out) Scenarios

Multiple build-out scenarios were considered and, because they were discussed in detail at several project Advisory Committee meetings, are reviewed below. The *first* build-out scenario was based upon projected changes in population out to 2035, as adopted for regional transportation planning (Fig 2.1, Rockingham Planning Commission, 2008). Based on those population projections, we estimated growth in residential development of 1.2% per year and growth in commercial/industrial development of 1.7% per year, for the period from 2010 – 2030. After 2030, we estimated a reduced growth of 0.6% per year for residential development and 1.1% for commercial/industrial development. However, these estimates were not consistent with historical trends in residential and industrial/commercial development over the period from 1962-2005 (Table 1; Figure 1). The land conversion in the watershed resulting from residential and commercial/industrial developments has averaged 4.0% and 4.7% per year respectively since 1962. Furthermore, population growth in the communities that have at least some of their land within the watershed has increased at an average of 2.9% per year since 1960 (Table 2; Figure 1). Historical build-out rates over the period of analysis are therefore approximately 1.6 times larger than increases in population. Note also that the rate of population change has decreased since 1990 while the rate of land conversion has increased since 1998.

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[1] The 214 square miles represents the Lamprey River watershed under normal flow conditions. Under flood consitions, the size of the watershed increases as water from the Lamprey River flows over and under a one mile strech of Route 108 south of Durham and flows out Longmarsh Brook and Hamil Brook into the Oyseter River.

Table 1. Historical build-out rates for land used for residential development and non-residential development (including commercial, industrial, transportation [airports, railroads, roads, ports, parking lots], outdoor recreation, cemeteries, communication facilities, and wastewater facilities) from 1962 to 2005 in the Lamprey River watershed. Data from NH GRANIT.

Year	Residential Development (acres)	Percent change per year	Non-Residential Development (acres)	Percent change per year
1962	3,381	-	531	-
1974	4,983	3.9%	829	4.7%
1998	11,201	5.2%	1,526	3.5%
2005	13,504	2.9%	2,169	6.0%
Mean	-	4.0%	-	4.70%

Table 2. Population data for all towns that have at least a portion of their area that lies within the Lamprey River watershed. Data from the US Census Bureau.

Year	Population	Percent change per year
1960	28,915	-
1970	39,749	3.7%
1980	56,306	4.2%
1990	76,987	3.7%
2000	88,333	1.5%
2010	98,990	1.2%
Mean	-	2.9%

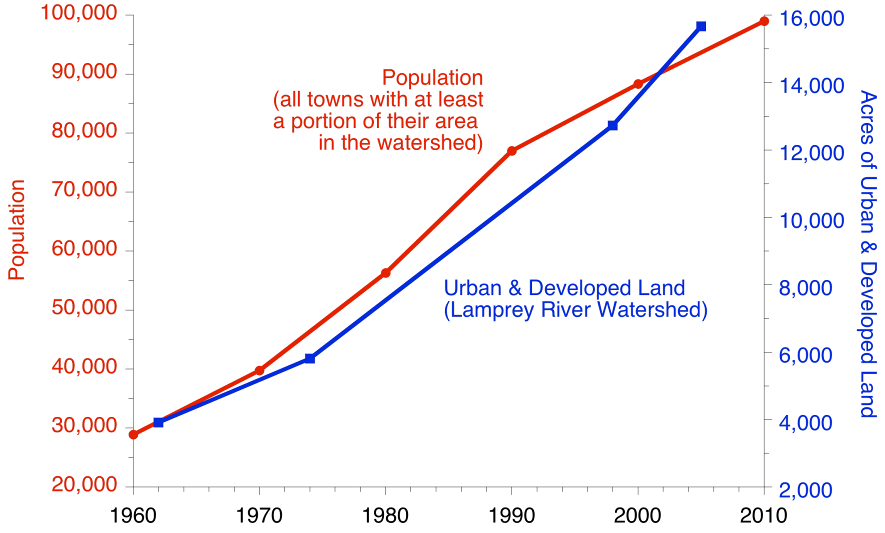

Figure 1: Trends in population and land use in the Lamprey River watershed. Population data from the US Census; land use data from NH GRANIT. Numerical values provided in Tables 1 and 2.

The *second* build-out scenario was based on a linear extrapolation of the average 1962 - 2005 residential and non-residential development rates of 4.0% and 4.7% per year respectively (Figure 2). This results in 239.1 acres of residential and 35.4 acres of commercial/industrial land developed each year. This scenario projects that the 2005 residential land use of 13,504 acres would grow to 36,218 acres by 2100; the 2005 commercial/industrial land use of 2,169 acres would grow to 5,532 acres by 2100.

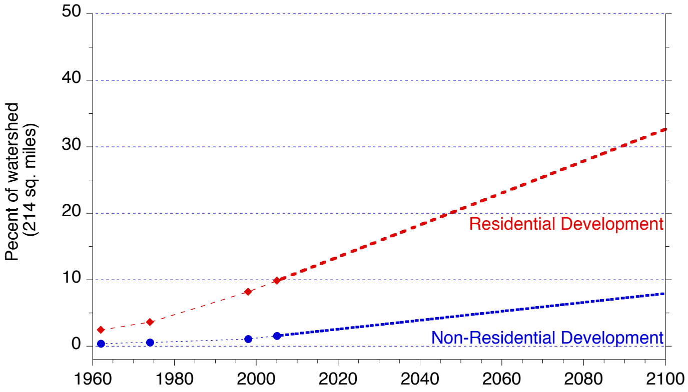

Figure 2. Linear extrapolation of historical residential and non-residential development in the Lamprey River watershed out to 2100.

The *third* build-out scenario, and the one used as input for the hydrological modeling efforts, was based on a polynomial best fit to the historical 1962-2005 residential and non-residential developed land data (Figure 3). This third build-out scenario extrapolates the observed exponential increase in the rate of land use development in the Lamprey River watershed since 1962, even as the rate of increase in population had begun to decrease in 1990 (this divergence is clearly illustrated in Figure 1). The growth rates for all residential and non-residential development over the past 50 years (i.e. from 1962 – 2005) were used as a basis to project future growth in development. The historic land use data for the years 1962, 1974, and

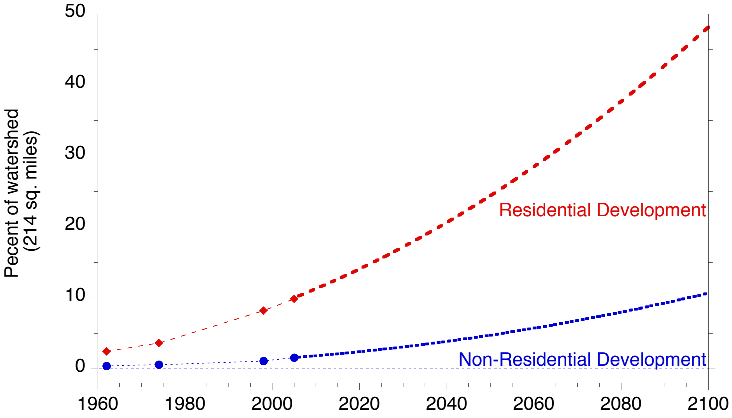

Figure 3. Exponential extrapolation of historical residential and non-residential development in the Lamprey River watershed out to 2100.

1998 included generalized commercial and industrial development classes, and did not parse out roads, airports, parking lots, ports, and other infrastructure. Accordingly, we relied upon these generalized commercial and industrial development classes (i.e., total non-residential land-use) growth rates in the past to estimate future development of commercial and industrial zoned land. This approach assumes that an increase in growth of associated infrastructure is required to support the development of commercial and industrial land use. Using this exponential growth scenario, residential development covers 66,002 acres (48% of total watershed area) and non-residential development covers 14,620 acres (11% of total watershed area) by 2100.

While the third land use scenario (exponential growth of both residential and commercial/industrial development) does represent considerable growth in the area of developed land in the Lamprey River watershed (59% of total land area in the watershed by 2100), it was eventually selected as the input for the hydrological and hydraulic modeling by the project team for two reasons. First, it most accurately captured the trends in past land use development. Second, it serves to maximize the differences between current and projected future conditions with respect to build-out and flood risk and thus provides a valuable reference point for discussions with coastal decision-makers.

3. GIS Methodology Used to Apply the Build-out Scenario to the Landscape

Once the projected rate of land development was agreed upon, the next step in estimating future build-out conditions in the watershed was to map potentially buildable areas. Standard GIS tools were utilized to overlay a suite of constraint layers, and thereby eliminate areas where no future development could occur. The remaining, buildable land area was then evaluated relative to its current zoning. The exponential residential land development scenario was applied in residentially-zoned areas to map future residential acreage. This was followed by the application of the exponential growth rate for commercial/industrial uses in commercial/industrial zones based on two development scenarios – conventional and low impact development (LID).

The complete build-out protocol is outlined below.

Map Buildable Areas

- Start with all acreage in the watershed and then eliminate development constraints:
    - Existing developed land (from GRANIT 2005 Land Use layer)
    - Wetlands (palustrine wetlands only, from National Wetlands Inventory [NWI] layer)
    - Surface water (from National Hydrography Dataset layer)
    - Conservation lands (from GRANIT 2011 Conservation Lands layer)

Result: Buildable lands in the watershed (Figure 4)

- Overlay the composite town zoning layer to identify buildable lands within each zone.

Conduct Residential Buildout

- Calculate target residential acreage for each increment (2050 and 2100) by factoring the starting residential acreage by the appropriate growth rate.
- Apply the growth to buildable lands within residential zones based on proximity to roads.

Result: Newly developed lands within residential zones in 2050 and in 2100.

Conduct Non-Residential (i.e. Commerical/Industrial) Buildout – Conventional Zoning

Non-residential development comprises both new development and redevelopment activities, with 50% of the non-residential growth rate in each year allocated to each type. However, under the conventional scenario, redevelopment activity is assumed to have no net impact on the landscape. Thus, only new development is calculated.

- Calculate the target commercial/industrial acreage for each increment (2050 and 2100) by factoring the starting commercial/industrial acreage by the appropriate growth rate.
- Starting with buildable lands, identify lands that have not already been "consumed" by the residential buildout. (Note: this step was required as some zones support both residential and commercial uses.)

Result: Remaining buildable lands

- Apply the commercial/industrial growth to remaining buildable lands within commercial/industrial zones based on proximity to roads.

Result: Newly developed lands within commercial/industrial zones in 2050 and in 2100.

Conduct Non-Residential Buildout – LID Zoning

As under the conventional zoning, the buildout addresses both new development and redevelopment activities. However, under the LID scenario, commercial/industrial redevelopment is assumed to have a substantive impact on the landscape. The first component of the LID buildout is identical to the conventional non-residential buildout and is applied to only currently undeveloped and unconstrained lands. To accommodate redevelopment, existing commercial/industrial land uses are re-introduced into the "remaining buildable lands" data set, and the growth rate is applied only to those existing uses. The growth is again applied based on proximity to existing roads.

Result: Redeveloped lands within commercial/industrial zones in 2050 and in 2100.

There is no assumption of "iterating" through the analysis. Thus, only existing (2005) commercial/industrial land uses are eligible for redevelopment, and not acreage that may be identified as commercial/industrial in later years through the buildout analysis.

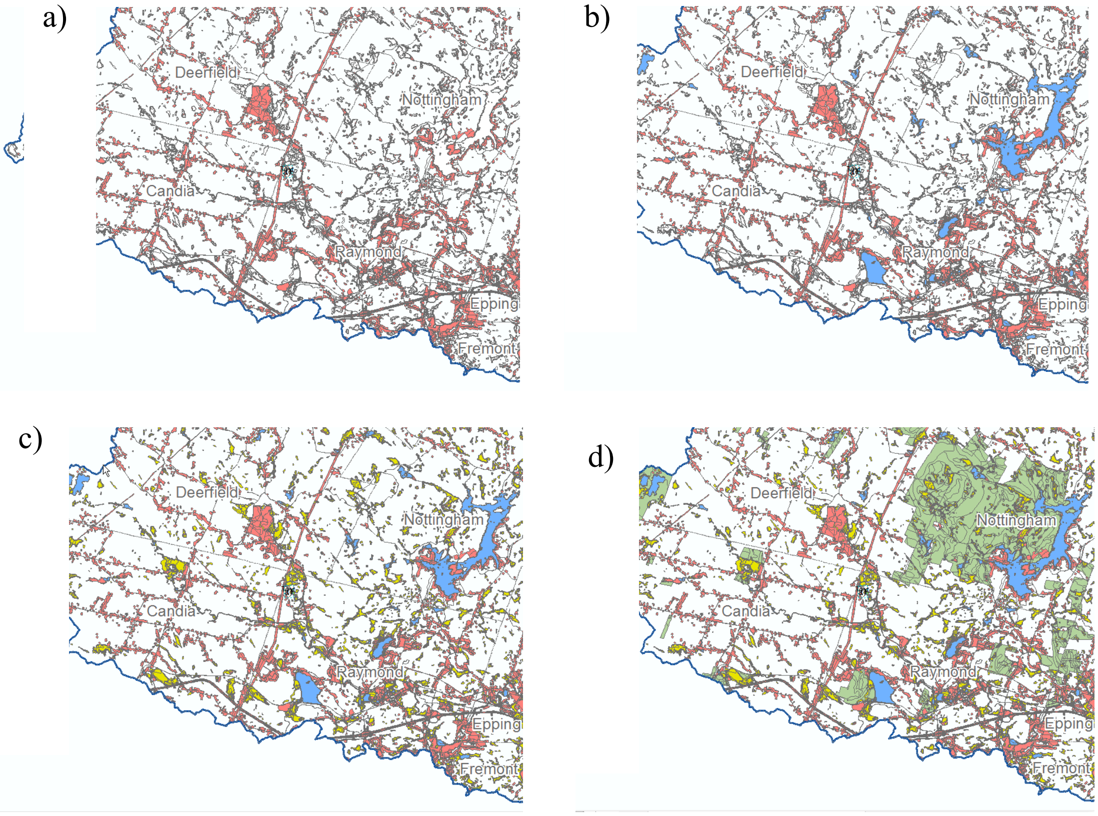

Figure 4. Example from the southwest region of the Lamprey River watershed illustrating how buildable lands were mapped by starting with all acreage in the watershed and then eliminating: (a) existing developed land; (b) surface water; (c) wetlands; and (d) conservation lands.

There are essentially six land cover maps that have been used in the project (Appendix A). Four historical maps (1962, 1974, 1998 and 2005) provide the basis for extending past land development trends out into the future, and two maps show projected build-out for the years 2050 and 2100 based on exponential growth (Figure 3).

4. Estimates of Historical, Current, and Future 24-hour 100-year Rainfall Depths

4.1 Historical and Current 24-hour 100-year Rainfall Depths

The Rainfall Frequency Atlas of the United States (TP-40; Hershfield, 1961) has served as the primary reference used for engineering design and regulations for structures and facilities for several decades. The rainfall atlas was based on the analysis of precipitation data from thousands of meteorological stations across the U.S. ending in 1957 and extending back a maximum of 48 years (i.e., to 1910). However, during the last fifty years there has been a well documented change in precipitation across the northeast as annual rainfall amounts have increased and the frequency and magnitude of large precipitation events has increased as well (e.g., Easterling et al., 2000; Kunkel et al., 2003; Karl and Trenberth, 2003; Trenberth et al., 2003; 2007; Groisman et al., 2005; Huntington et al., 2006; Hayhoe et al., 2007; Spierre and Wake, 2010).

Recently, a collaboration between the NOAA Northeast Regional Climate Center (NRCC) and the USDA Natural Resource Conservation Service (NRCS) has produced an updated and comprehensive climatology of extreme precipitation in New York and New England. Data products and methods are easily accessible via an interactive web tool for extreme precipitation analysis provided at: http://precip.eas.cornell.edu.

The difference between the TP-40 and the more recent NRCC/NRCS estimates of the 24-hour 100-year rainfall depth are considerable (Table 3). The old TP-40 estimate was 6.3 inches, while the more recent estimate reflecting precipitation data collected up through at least 2008 of the 24-hour 100-year rainfall depth is 8.5 inches.

Table 3. Summary of developed land (acres) and 24-hour rainfall depths (inches) used as input for the hydrologic and hydraulic modeling.

Year	**Acres of Developed Land**						**24-hr Precipitation (in)**
	Residential		**Commercial & Industrial**				
			Conventional		**LID**		
	Target	Actual	Target	Actual	Target	Actual	
FIRM*	na	na	na	na	na	na	6.3
2005	13,707	13,707	1,258	1,258	1,258	1,258	8.5
2050	33,431	33,418	3,886	3,879	6,514	5,112	8.5
2100	66,002	66,001	7,939	7,811	14,620	9,045	11.4

* Flood Insurance Rate Maps (FIRM)

4.2 Future 24-hour 100-year Rainfall Depths

Atmosphere-ocean general circulation models (AOGCM) simulations driven by future emission scenarios were used to evaluate possible future changes in climate, including changes in precipitation. An emissions scenario incorporates assumptions about population, energy use, and technology. Each scenario is associated with a unique “signature” of greenhouse gases emissions. Here, we use model output from the high (A1fi) and low (B1) emissions scenarios from the Intergovernmental Panel on Climate Change’s (IPCC) Special Report on Emissions Scenarios (SRES) (Nakicenvoic et al. 2000). Under the A1fi “higher-emissions” scenario, SRES assumes a world with fossil fuel-intensive economic growth and a global population that peaks mid-century and then declines. New and more efficient technologies are introduced toward the end of the century. In this scenario, atmospheric carbon dioxide concentrations reach 940 parts per million (ppm) by 2100—more than triple pre-industrial levels. The B1 “lower-emissions” scenario also represents a world with high economic growth and a global population that peaks mid-century and then declines. However, this scenario includes a shift to less fossil fuel-intensive industries and the introduction of clean and resource-efficient technologies. Emissions of greenhouse gases peak around mid-century and then decline. Atmospheric carbon dioxide concentrations reach 550 ppm by 2100—about double pre-industrial levels. As diverse as they are, the SRES scenarios still do not cover the entire range of possible futures. By choosing a high

CO_2 and a low CO_2 scenario, we hope to create an envelope of future climate change that the Lamprey River watershed region may fall within by the end of the 21st century.

The future emission scenarios such as those described above are used as input to atmosphere-ocean general circulation models (AOGCMs) (Solomon et al., 2007). These large, three-dimensional coupled models incorporate the latest understanding of the physical processes of the atmosphere, oceans, and Earth's surface. As output, AOGCMs produce geographic grid-based projections of precipitation, temperature, pressure, cloud cover, humidity, and a host of other climate variables at daily, monthly, and annual scales. Historical simulations by AOGCMs used here were driven by the Coupled Model Intercomparison Project's "20th Century Climate in Coupled Models" scenario (Meehl et al., 2007). The intent of those simulations was to reproduce the climate conditions observed over the past century as closely as possible. Hence, they included observed changes in solar radiation, volcanic eruptions, human emissions of greenhouse gases, emissions of other gases and particles that interact with the energy emitted by the Earth and the sun, and secondary changes in lower-atmosphere ozone and water vapor from the 1800s to 1999.

The spatial resolution of AOGCMs limits them from providing information on climate change on scales smaller than hundreds of miles. To address this issue, we used advanced statistical downscaling methods to relate projected large-scale changes in climate to local conditions on the ground. Local-scale climate projections are generated for two reliable long-term weather stations located near the Lamprey River watershed (Durham, NH and Lawrence, MA). A more detailed description of the advanced statistical downscaling methods used in this study is provided in Wake et al. (2011).

For this study, we relied on simulations from four different AOGCMs: the U.S. National Atmospheric and Oceanic Administration's Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1; the United Kingdom Meteorological Office's Hadley Centre Climate Model, version 3 (HadCM3); and the National Center for Atmospheric Research's Community Climate System Model version 3 (CCSM3), and Parallel Climate Model (PCM). These models were chosen based on several criteria. First, only well-established models were considered, those already extensively described and evaluated in the peer-reviewed scientific literature. The models must have been evaluated and shown to adequately reproduce key features of the atmosphere and ocean system. Second, the models chosen must encompass the greater part of the IPCC range of uncertainty in climate sensitivity. Climate sensitivity is defined as the temperature change resulting from a doubling of atmospheric carbon dioxide concentrations relative to pre-industrial times, after the atmosphere has had years to adjust to the change. Climate sensitivity determines the extent to which temperatures will rise under a given increase in atmospheric concentrations of greenhouse gases. The last requirement was that simulations of temperature, precipitation, and other key variables had to be available at daily resolution for both the SRES A1fi and B1 emission scenarios. The AOGCMs selected for this analysis are the only four for which daily output from A1fi and B1 simulations are available. Results from statistical downscaling of a wide range of measures of temperature and precipitation for the Great Bay watershed are detailed in Wake et al. (2011).

The main objective of using daily downscaled model output for the Lamprey River watershed 100-year floodplain study was to estimate the maximum 24 hour precipitation event projected to occur over the next 90 years from either the high or low emissions scenario for two reliable long-term weather stations located within or near the Great Bay watershed (Durham, NH and Lawrence, MA). While both the low and high emissions scenarios show an overall increase in annual precipitation, extreme precipitation events across New England are higher under the high emission (A1fi) scenario. The maximum 24-hour rainfall depths for the period 2010 to 2100 from each of the four AOGCMs driven by the high emission scenario are presented in Table 4. In order to maximize the difference between current conditions and those in the future, we used the highest estimate of 24-hour rainfall depths (11.4 inches for Lawrence, MA) derived from downscaling output from the AOGCMs.

Table 4. Maximum 24-hour rainfall depths (inches) derived from downscaling of output from the four AOGCMs used in this study.

AOGCM	Max 24-hr Precip (2010-2100); A1fi	
	Durham, NH	Lawrence, MA
CCSM	6.3"	11.4"
GFDL	6.5"	6.7"
HADCM3	7.8"	9.0"
PCM	7.5"	10.0"

5. Final Input to the Hydrologic and Hydraulic Models

The final inputs for the hydrologic and hydraulic models in terms of acres of developed land (residential and commercial/industrial) as well as 24-hour rainfall depths for 2005, 2050, and 2100 are detailed in Table 3.

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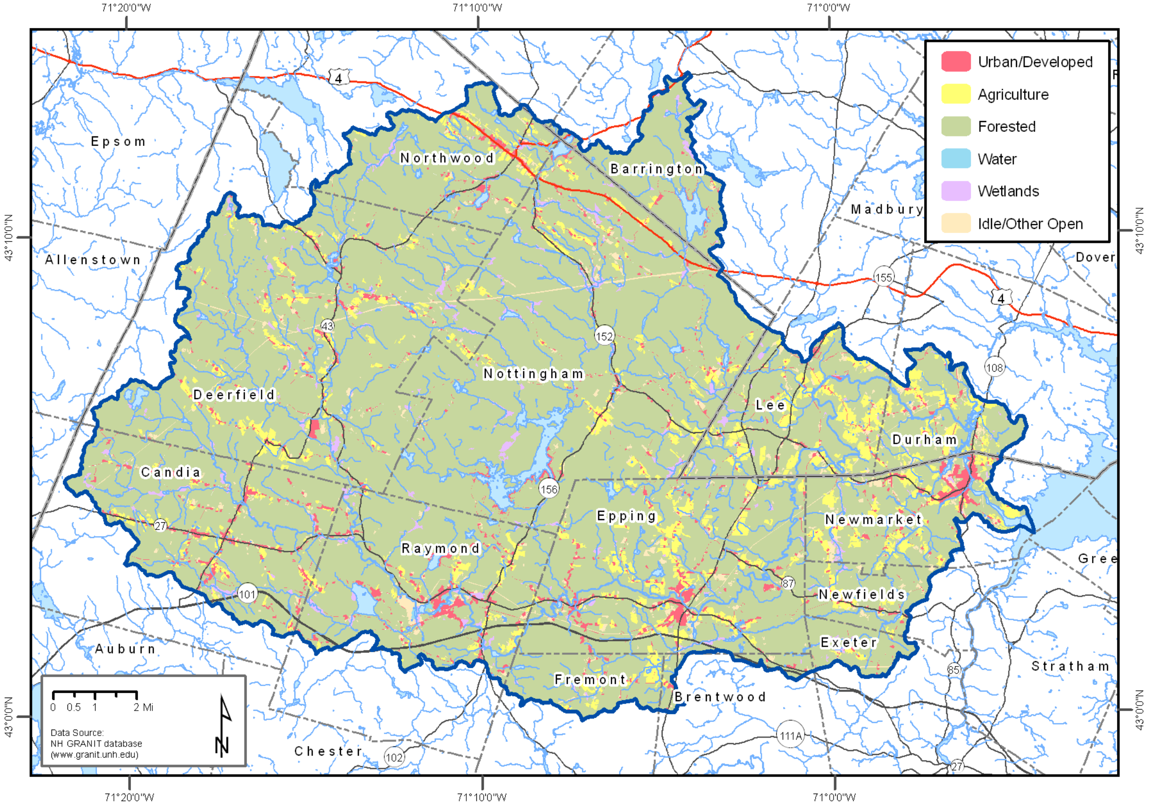
APPENDIX A

Lamprey River Watershed Generalized Land Use

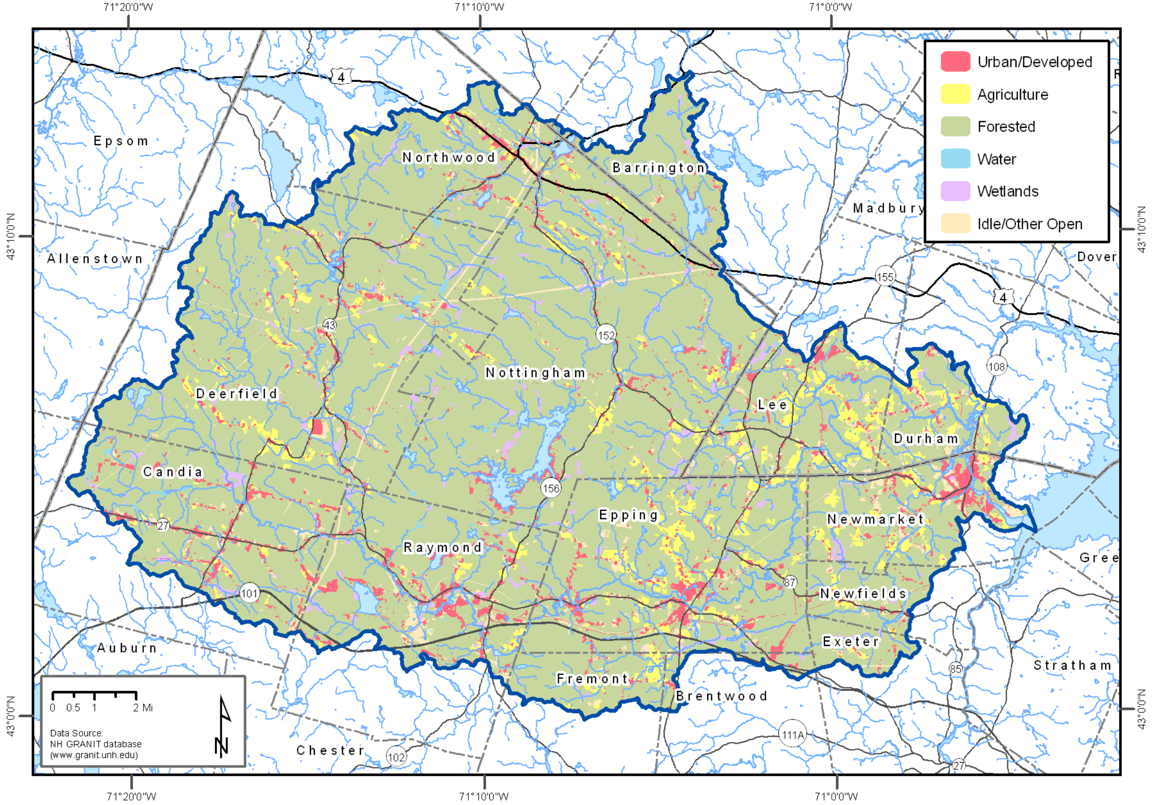
1962, 1974, 1998, and 2005 data derived from NH GRANIT database
(http://www.granit.unh.edu)

2050 and 2100 maps derived from this project and the NH GRANIT database
(http://www.granit.unh.edu)

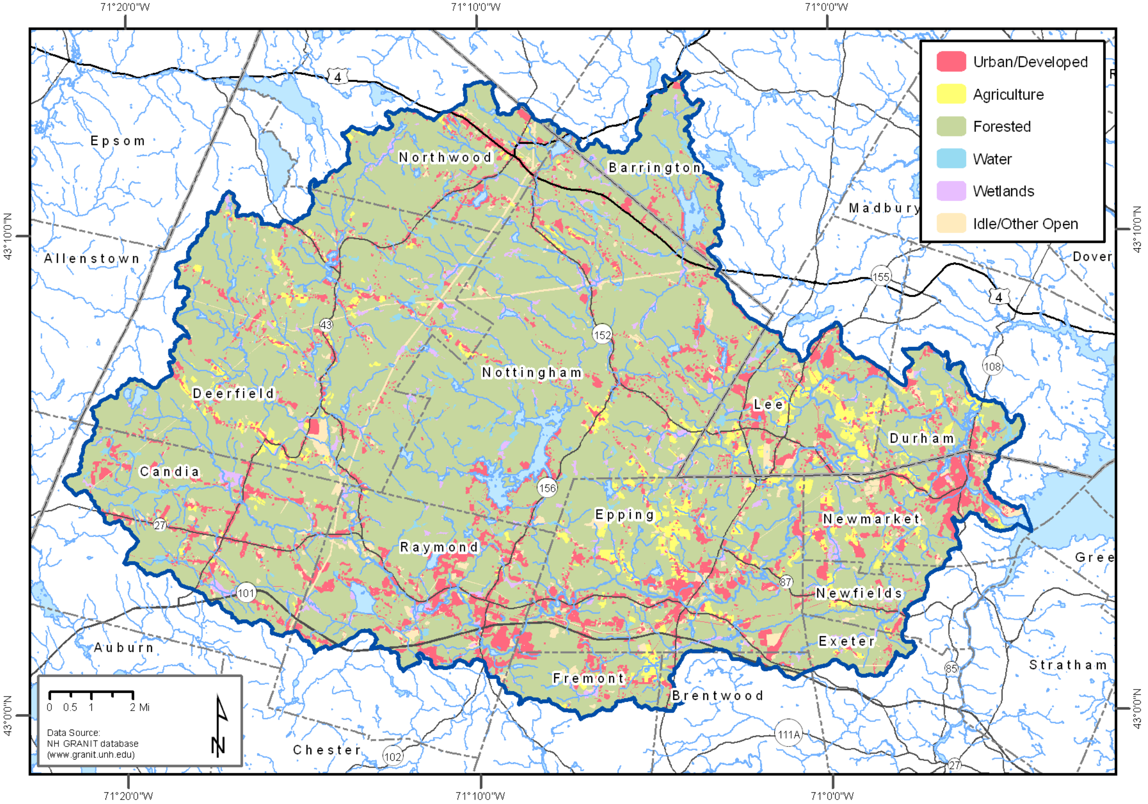
Lamprey River Watershed Generalized Land Use - 1962



Lamprey River Watershed Generalized Land Use - 1974

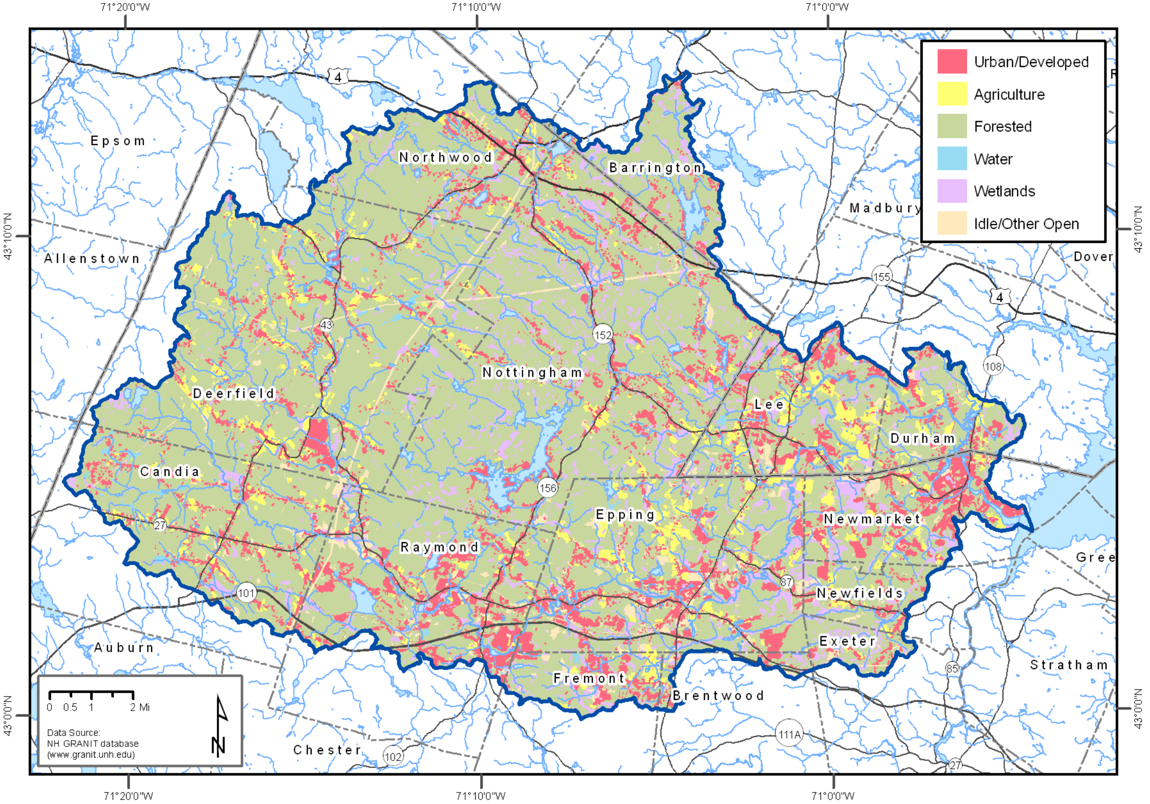


Lamprey River Watershed Generalized Land Use - 1998



Data Source:
NH GRANIT database
(www.granit.unh.edu)

Lamprey River Watershed Generalized Land Use - 2005



Data Source:
NH GRANIT database
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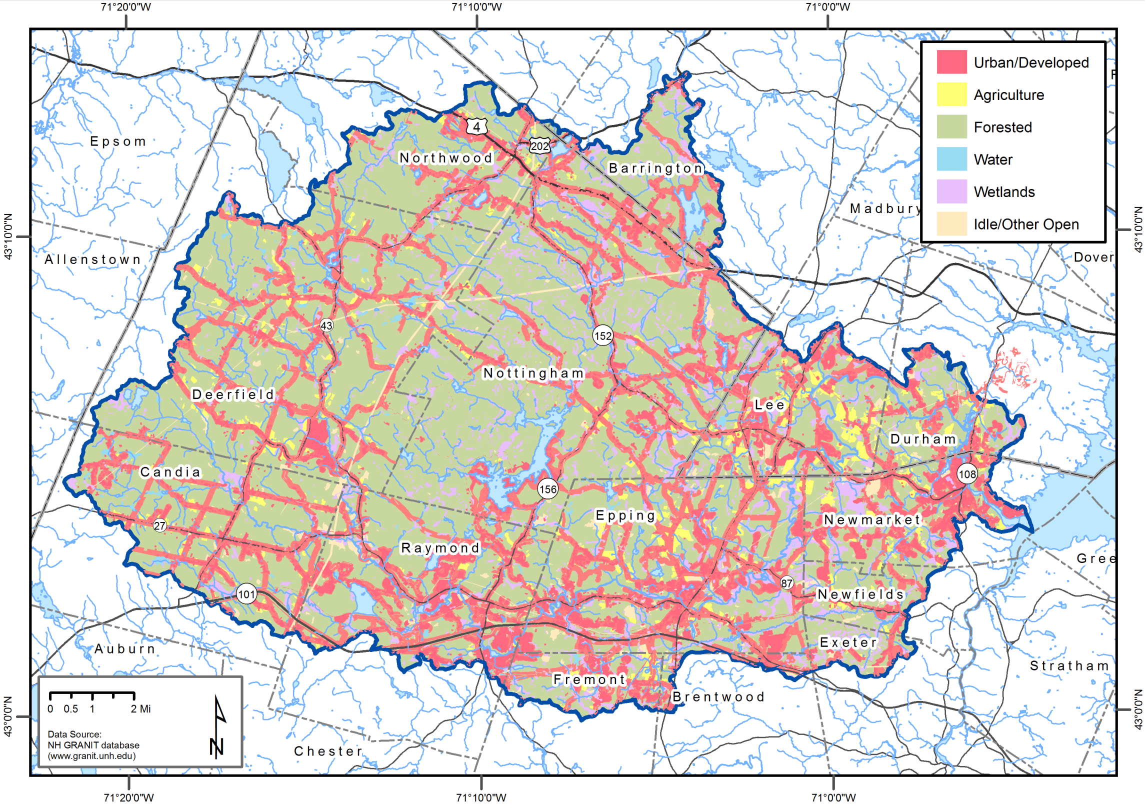
Lamprey River Watershed Generalized Land Use - 2050



Lamprey River Watershed Generalized Land Use - 2100