1-1-2013

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

Cameron P. Wake
University of New Hampshire, cameron.wake@unh.edu

Steve Miller
Great Bay National Estuarine Research Reserve

Robert M. Roseen
University of New Hampshire

Ann Scholz
University of New Hampshire

Fay Rubin
University of New Hampshire

See next page for additional authors

Follow this and additional works at: https://scholars.unh.edu/stormwater

Recommended Citation

Authors

Cameron P. Wake, Steve Miller, Robert M. Roseen, Ann Scholz, Fay Rubin, Michael Simpson, Cliff Sinnott, Julia Peterson, and Lisa Townson

Assessing the Risk of 100-year Freshwater Floods in the Lamprey River Watershed of New Hampshire Resulting from Changes in Climate and Land Use
http://100yearfloods.org

A Final Report Submitted to
The NOAA/UNH Cooperative Institute for Coastal and Estuarine
Environmental Technology (CICEET)

Project Start Date: 1 Aug 2009

Compiled and Submitted by:

Cameron P. Wake
Earth Systems Research Center (ESRC)
Institute for the Study of Earth, Oceans, and Space (EOS)
University of New Hampshire, Durham, NH 03824

This final report includes contributions from project team members:
Steve Miller, Great Bay National Estuarine Research Reserve
Robert Roseen and Ann Scholz, UNH Stormwater Center
Fay Rubin, ESRC/EOS, UNH
Michael Simpson, Antioch University New England
Cliff Sinnott, Rockingham Planning Commission
Julia Peterson and Lisa Townson, UNH Cooperative Extension

January 2013

C I C E E T

UNIVERSITY of NEW HAMPSHIRE

Table of Contents

1. EXPANDED EXECUTIVE SUMMARY AND KEY FINDINGS

What is the coastal resource issue the project sought to address? Both the magnitude and frequency of freshwater flooding is on the rise in seacoast NH and around much of New England. In the Great Bay watershed, this is the result of two primary causes: 1) increases in impervious surface stemming from a three-to-four fold increase in developed land since 1962; and 2) changing rainfall patterns in part exemplified by a doubling in the frequency of extreme weather events that drop more than 4 inches of precipitation in less than 48 hours (Wake et al., 2011) over the same time period. Moreover, the size of the 100-year precipitation event in this region has increased 26% from 6.3 inches to 8.5 inches from the mid 1950's to 2010 (NRCC and NRCS, 2012). One consequence is the occurrence of three 100-year floods measured on the Lamprey River at Packers Falls since 1987, and a fourth if the three days of flooding in March of 2010 had occurred instead in two days (Figure 1). Flooding events are expected to continue to increase in magnitude and frequency as land in the watershed is further developed and climate continues to change in response to anthropogenic forcing (e.g., Hayhoe et el., 2007; IPCC, 2007; Karl et al., 2009). Land use management strategies, in particular low impact development (LID) zoning requirements, are one strategy that communities can employ for increased resiliency to flooding with the greatest influence in urban environments.
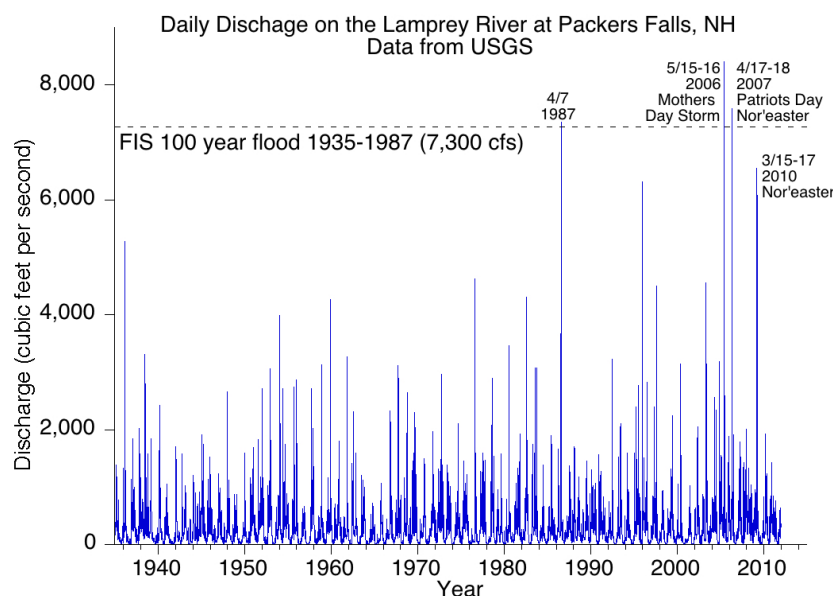
Figure 1. *Daily discharge measured on the Lamprey River at Packers Falls, NH. Data from USGS*

Describe the technology: We have developed a suite of products which enables visualization of possible flooding events in the future. We built upon existing FEMA guidelines (FEMA, 2009) to develop projections of potential future 100-year floodplains and peak flood discharge based on scenarios of land use and climate change within the Lamprey River watershed. Watershed modeling techniques were used to examine runoff storage characteristics for differing development strategies in combination with changes in precipitation depth. Future conditions are not currently included in FEMA evaluations of 100-year floodplains.

A rainfall-runoff model was developed to simulate current and future conditions with respect to water flow and areal extent of floodplains on the main stem of the Lamprey River. A

hydrological map was first generated for the 214 square mile watershed upstream of Macallen Dam for the Lamprey River using the Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS)(US Army Corp of Engineers [USACE] 2008) and HEC-GeoHMS (USACE 2008, 2009). A curve number reduction method was used to model LID and conventional development zoning scenarios (McCuen 1983, MDE 2008). Once the model calibration was complete, steady flow was simulated along the 36 mile reach of the Lamprey River and floodplain elevations and extents were quantified using HEC - River Analysis System (HEC-RAS)(USACE, 2001) and HEC-GeoRAS (USACE, 1999). The hydraulic model included 262 river cross sections: 115 sections from the original FIS dataset, 46 sections from recent field survey and other analyses, 101 additional sections and extended embankment elevations generated from 2011 LiDAR imagery (2-meter digital elevation model, 15- cm vertical root mean square error). In addition, standard GIS tools were utilized to prepare the data inputs required for the modeling, to conduct the build-out analysis, and to produce the final maps.

How does it address the problem? This project provides reliable maps of the 100-year floodplains and estimates of peak flood discharge in the Lamprey River for future development scenarios and climate conditions watershed up through the year 2100 and thereby provides decision relevant information for municipal representatives, emergency managers, resource mangers, planners, engineers, developers, and residents to better plan and prepare for future flooding events, and work towards building more resilient communities.

What is the geographic reach of the technology? The research was focused on the Lamprey River watershed in New Hampshire which drains into Great Bay in coastal NH.

Is it transferable to other locations? Our approach can be used in watersheds across New England and the entire country.

How is it an improvement over existing technologies? We project flooding conditions for land use, zoning, and climate scenarios in the Lamprey River watershed out to 2100. Currently FEMA only provides flood information based on past conditions. This provides a demonstration of current land use management decisions and the real impacts upon future flooding. In addition, revised analysis of current conditions are completed infrequently by FEMA.

What is the current stage of development (bench, lab, field, prototype)? The method is complete and has been applied to the main stem of the Lamprey River and products are now available online at the project web site ((http://100yearfloods.org) and on the NH GRANIT website (http://www.granit.unh.edu/MapLibrary/ProjectMaps).

Describe any technical and/or non-technical barriers to application. Watershed modeling efforts required access to high-resolution topographic LiDAR data, which is not currently available for many areas. Dissemination and use of the new floodplain maps would be improved if they were adopted as official maps by FEMA. However, this has not yet occurred.

Another issue raised by the Advisory Committee was the potential legal risks communities in the Lamprey River watershed may face as a result of adopting new flood management regulations and policies based on the new 100-year floodplain maps. Extensive analysis by the Vermont Law School – Land Use Clinic found that the risk of municipal liability is low, so long as municipalities follow sound planning principles.

Describe/name the intended users of the technology: We expect members of the Advisory Committee (listed in Table 2 of the report), and the groups that they represent (municipal officials including emergency managers, regional planners, watershed groups, state and federal representatives, and technical experts) to use the new 100-year floodplain maps and 100-year flood discharge model output. In addition, we expect the data and information will be of use to

developers, real estate representatives, and insurance companies. The data is also available to FEMA for incorporation in future flood map update activities.

Key Findings

The results of our research clearly show that the 100-year floodplain and associated peak flood water discharge, and flood water surface elevations have increased significantly between the production of the effective Flood Insurance Rate Maps (FIRMs; based on discharge data from 1935-1987) to current (2005) conditions, and will continue to increase in the future under the build-out scenarios developed as part of this research. Low impact development zoning was shown to have its greatest mitigation value in terms of resiliency in high impervious cover areas. Furthermore, the findings demonstrate the utility of scenario analyses as a powerful means to convey to the public the ramifications of different land use decisions. This is especially powerful as a means for motivation for change in development strategies and associated regulations and ordinances. This increase in the 100-year floodplain and 100-year flood discharge has important ramifications for natural resources, human well-being, emergency management, planning, and infrastructure. In addition, the risk of municipal legal liability associated with using the new 100-year floodplain maps is low, so long as municipalities follow sound planning principles.

Compare the performance of the technology or approach to existing methods in terms of:
Applicability to a priority coastal issue: Updated information is clearly required to prepare and adapt to current and future flooding conditions in New Hampshire's coastal watershed. Existing FEMA 100-year floodplain maps are not regularly updated to reflect current conditions and they do not project potential flooding conditions in the future. Our project used FEMA guidelines to update 100-year floodplain maps to current conditions and project future conditions based on land use and climate change scenarios.

Communities often do not connect their everyday land use decisions to flooding and resiliency. Scenario analyses are an effective way of communicating impacts of land use decisions for which municipalities have some control.

Cost: We have not completed a direct cost comparison with FEMA generated products.
Maintenance requirements: Not applicable.
Accuracy: We used FEMA guidelines for developing the updated 100 year floodplains. The extent of 100-year floodplains in the future are based on scenarios of land use and climate change. 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.

Speed: Not applicable.
Ease of use: The new 100-year floodplains were revised several times in response to comments from our Advisory Group and focus groups. Feedback from participants in our final workshop indicated that the maps were fairly easy to read, but that assistance is needed to make them easier to understand.

User capacity requirements (supplies, skills, hardware): Not applicable.

2. PROJECT DEVELOPMENT

2.1 Abstract:

The magnitude and frequency of freshwater flooding is on the rise in seacoast NH and around much of New England due to climate change (increases in extreme precipitation events) combined with increases in impervious cover resulting from land development. To facilitate effective planning and build community resiliency, decision-makers require information at a local scale that reflects current conditions and provides insights into the future hydrological implications of changing land use and changing climate.

The primary objective of this project was to develop a methodology for assessing flood risk associated with land use and climate change scenarios, implement the methodology for the 214 square mile Lamprey River watershed in southern NH, and produce decision relevant information for a range of stakeholders. An additional objective was to quantify the mitigation of flood risk by using low impact development (LID) instead of conventional development.

Technical methods included developing a rainfall-runoff model was developed to simulate current and future conditions with respect to water flow and areal extent of floodplains on the main stem of the Lamprey River using FEMA approved methods, developing scenarios of future climate and land use in the watershed out to the year 2100, and producing 100-year floodplain maps for current and potential future conditions. This project sought to integrate input from end users of the technical products to ensure that the products were high quality, relevant, and useful. Formative evaluation was conducted in conjunction with several engagement components of the project including the Advisory Committee, a series of focus group sessions, and a final public presentation of the project products. Collaboration among the project team was managed via quarterly team meetings. An Advisory Committee consisting of municipal officials, regional planners, watershed groups, state and federal representatives, and technical experts met semi-annually to guide the project, provide input on build-out scenarios and modeling efforts, advise on the interpretation of results, and shape the development and dissemination of the final products. In addition, questions of legal authority, measures, and consequences for communities using the new 100-year floodplain maps have been explored.

The results show that the 100-year floodplain and associated peak flood water discharge, have increased significantly between the production of the effective Flood Insurance Rate Maps (FIRMs; based on discharge data from 1935-1987) to current (2005) conditions, and will continue to increase in the future (Table 1). LID was shown to have its greatest mitigation value in high impervious cover areas. This increase flood risk has important ramifications for natural resources, human well-being, emergency management, planning, and infrastructure. In addition, the risk of municipal legal liability associated with using the new 100-year floodplain maps is low, so long as municipalities follow sound planning principles. All products from this project, including maps and reports are available online at the project web site: http://100yearfloods.org.

Table 1. Change in the 100-year water discharge and surface elevation at the Packers Falls gauging station, and in the 100-year floodplain area in the Lamprey River watershed.

Flood Studies	100-yr Packers Falls Discharge	100-yr Packers Falls Water Surface Elevation	100-yr Floodplain Area
FIS to 2005	56%	2.7 ft	20%
2005 to 2100	66%	4.4 ft	14%

2.2 Introduction

Southern New Hampshire is confronting the effects of rapid development and associated land use change and increases in impervious cover (IC) while also dealing with the serious impacts of a changing climate. Both factors influence the frequency and magnitude of flood events. Since 1990, the Great Bay watershed has undergone a 75% increase in impervious surface with a land conversion rate of nearly 1,500 acres per year (0.2% per year), with a total watershed IC increase from 4.3% in 1990 to 7.5% as of 2005. The Lamprey River has had an increased frequency of flood flow events; of the fifteen largest events since 1934, 8 have occurred in last 25 years, 5 have occurred in last 15 years, and 3 have occurred in last 5 years (Figure 1).   Recent flooding events, including major storms in New Hampshire in 2005, 2006, and 2007 (Comprehensive Flood Management Study Commission [CFMSC] 2008), in March 2010 (NRCC 2010), and hurricanes Katrina (2005), Irene (2011), and Sandy (2012) demonstrate a lack of resilience in municipalities and the resulting costs to society. They also reveal gaps in local decision-relevant flood risk information available to aid municipal officials and regional planners. Municipalities need information which details the results of land use decisions upon community resiliency to flooding. The use of green infrastructure systems that incorporate volume reduction are one strategy that can be used for flood mitigation. One of the many lessons learned from Hurricane Katrina and relevant to preparation for other natural disasters is the need to anticipate a changing climate and build in resiliency (ASCE 2007). Advance planning and investment in measures to adapt to climate change will typically result in less damage and lower overall costs to municipal and state governments (e.g., CLIMB 2004).

Coastal communities experience flood risks due to the hydrologic dynamics of oceanic, estuarine, and freshwater systems. To facilitate effective planning, decision-makers require information at a local scale that reflects current conditions and provides insights into the future hydrological implications of changing land use and changing climate. In freshwater systems, updated 100-year floodplain maps and flood risk information have been recognized both nationally (e.g., in the 2012 reauthorization of the National Flood Insurance Program; Grannis, 2012) and locally (CFMSC 2008) as critical for effective municipal decision-making and regional planning in the context of land use and climate change.

A new set of 100-year floodplain maps and 100-year flood discharge is needed because flood risk information and floodplain maps currently used by decision-makers are based on historic rainfall and peak discharge data that do not represent either: 1) current or future projected rainfall (Hayhoe et al., 2007; Wake et al., 2011; Madsen and Wilcox, 2012), or 2) development-driven land use changes that have expanded impervious surface coverage, resulting in an increase in runoff rates (e.g., Snover et al., 2007; CFMSC 2008; Stack et al., 2010; Roseen et al., 2011; PREP, 2013). In order to prepare for flooding events in the future and build more resilient communities, there is also the need for maps that project future flooding based on scenarios of future land use scenarios and future climate. These products can be used to inform the decisions made by communities that will influence their risk and vulnerability to climate.

2.3 Objectives

The objective of this project was to develop and refine a methodology for assessing flood risk associated with land use and climate change scenarios, implement the methodology for a coastal watershed, and demonstrate the use of associated products to support land use decision-

making in coastal communities. The project entailed collaborations among academic scientists, local decision-makers, and the Great Bay National Estuarine Research Reserve (GBNERR). GBNERR facilitated interactions among the technical experts and end-users to ensure that the research approach addressed local needs and that the final products are useful within municipal and regional decision-making contexts.

Through a pilot project in the Lamprey River watershed, the largest sub-watershed (214 square miles) of the Great Bay drainage in southeastern New Hampshire (Figure 2), we developed updated freshwater 100-year flood plain maps, updated 100-year discharge at specific cross-sections, and refined the assessment methodology and products based on end-user input.

We also quantified future 100-year floodplains and 100-year discharges resulting from changes in both climate and land use. The land use scenarios were based on a set of conventional (CON) and low-impact development (LID). The maps document current (updated) conditions and potential future changes to the floodplain elevation and areal extent. Thus, they address an immediate information need and provide a basis for assessing factors that can mitigate flood risk in ways that are germane to municipal decision-makers and regional planners. The project also draws clear connections between local government land use policies and communities' resilience to climate change. The products and associated outreach efforts emphasize that improved land use strategies can help communities mitigate the serious impacts that climate change poses to natural resources, human safety, private property, and municipal infrastructure, especially in urban centers with a high percentage of impervious surfaces. Further, they will aid municipal control over local development and land use practices by providing the sound scientific basis necessary for defensible policies and ordinances.
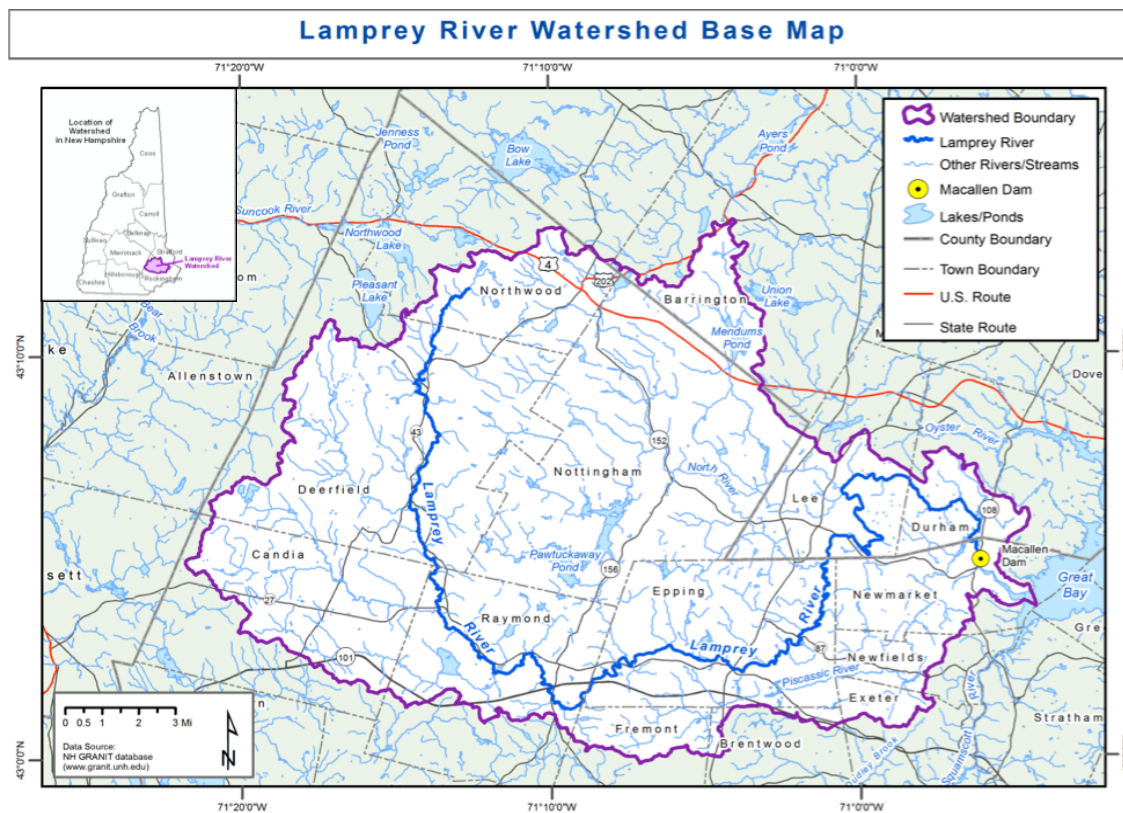

Figure 2. Lamprey River watershed in southeastern New Hampshire.

Development of useful and decision-relevant products has been guided by input from decision-makers throughout this project. An outreach and training program has disseminated results and demonstrated potential uses for the maps to ensure that decision-makers can interpret and effectively apply the new products and information. Outreach efforts have extended throughout the Great Bay watershed and the broader coastal management community so that similar efforts may be pursued in other areas. In addition, questions of legal authority, measures, and consequences for communities using the new 100-year floodplain maps have been explored.

2.4 Methods

Technical Methods

The technical methods are described for three areas of our research: (i) watershed hydrology and hydraulics, (ii) future land use and future climate, and (iii) production of 100-year floodplain maps for current and potential future conditions.

(i) Watershed Hydrology and Hydraulics

A rainfall-runoff model was developed to simulate current and future conditions with respect to water flow and areal extent of floodplains on the main stem of the Lamprey River. A rainfall-runoff hydrologic analysis is commonly used to assess changes in land use within the watershed and develop flood flows. Our model includes the Natural Resources Conservation Service (NRCS) Curve Number (CN) method. This is an acceptable approach according to FEMA's guidelines (FEMA, 2009). The CN method provides an estimate of runoff from any given tract of land based on precipitation, land cover, and soil type.

A watershed hydrologic model was generated for the 214 square mile watershed upstream of Macallen Dam for the Lamprey River using the Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS)(US Army Corp of Engineers [USACE] 2008) and Hydrologic Engineering Center - Geographic Hydrologic Modeling System (HEC-GeoHMS)(USACE 2008, 2009). The CN value represents the loss rate parameter for the hydrologic model. The sub basins in the watershed consist of several different land uses and hydrological soil groups (HSG). The area of each sub basin land use and respective HSG are weighted to establish a composite CN for the sub basin.

A curve number reduction method was used to model LID and conventional development zoning scenarios. The LID curve number analysis was applied using a method developed by McCuen (1983) and formalized in practice by the Maryland Department of the Environment (MDE 2008). It is a volume based approach developed by storing the increased runoff depth on the developed site by implementing LID. The method adjusts curve numbers based on the amount of storage designed using LID practices for the 1" water quality event. Because there are a limitless variety of applications of LID systems in a design context, the CN analysis performed here is based on providing a 1" WQV volume for all impervious surfaces. For the CN analysis, the practice type (i.e. bioretention, sandfilter, infiltration trench, etc) is unimportant, but rather the storage volume is critical.

This analysis applied the use of bioretention for all sites. One acre lot sizes and above incorporated the use of porous pavement which adds substantial additional storage. Commercial and industrial sites designs included parking (porous asphalt) and roads (standard asphalt and bioretention), and rooftop infiltration. In this instance, professional judgment was used as to

when and where porous pavements might be used. The common practice of limiting porous pavement usage to parking areas was applied.

The runoff curve number (CN) reduction is analyzed using the method outlined in the Environmental Site Design Sizing Criteria (MDE 2008) which is a modification of the TR-55 Method (NRCS 1986). This method applies an adjusted curve number based on the amount of storage built into the landscape using structural LID approaches that will result in runoff volume reduction by recharge. The goal is to achieve a condition equivalent to predevelopment; however the method is sensitive and can be used in conditions where both more or less than storage for a 1" WQV can be achieved. It may be desirable to oversize a system to compensate for locations where less storage is possible. For sites where equivalent storage for a 1" water quality event or more cannot be achieved then an additional design for the channel protection volume is required. The LID practices should be distributed uniformly throughout a drainage area.

The principle step in the curve number adjustment is the calculation of the rainfall amount captured. This is done by determination of the following parameters:

$$CN^* = \frac{200}{\left[(P+2Q+2)-\sqrt{5PQ+4Q^2}\right]}$$

Where:
CN* = the reduced CN used to reflect runoff volume stored by the infiltration practices
P = the design rainfall depth in inches
Q = the after development runoff depth minus the runoff depth retained by the infiltration practice (ΔQ) in inches

Following completion of the hydrologic model, calibration trials identified parameter value adjustments that matched simulated results with the observed hydrograph for specific flood events at the USGS gage at Packer's Falls Road near Newmarket. Real-time discharge and raw precipitation data were obtained from the USGS Instantaneous Data Archive for gage site 01073500, Lamprey River near Newmarket and the University of New Hampshire Weather Station, respectively. Baseflow was removed from the total runoff using a concave baseflow separation process in order to use a direct runoff hydrograph for the discharge time series data in HEC-HMS. Three major events were considered for the trials but ultimately calibrating the hydrologic model to the April 2007 historical flood incident produced the best fitting hydrologic model (Figure 3).

The final calibrated runoff parameters along with the rainfall depths were used to develop the historic, current, and future build-out hydrologic models. For a watershed of this size, the sensitivity of the rainfall input is decreased (McCuen, 2004) and this research evaluated the sensitivity of peak flow to changes in CN (Figure 4). A 5% increase or decrease in CN results in an equal percent increase or decrease in peak flow. A 10% decrease in CN adjusts the discharge similarly; however, a 10% increase in CN results in an increase in the discharge by more than 15%.
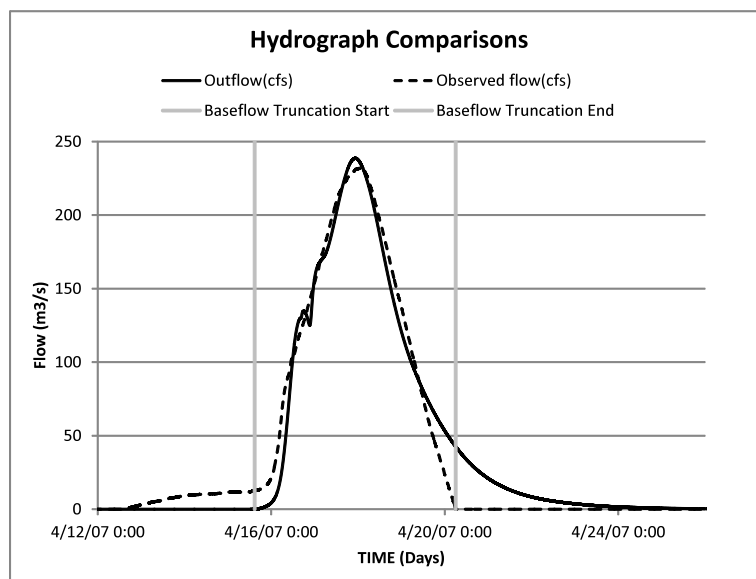
Figure 3. Simulated hydrograph compared to observed discharge measured at the Packers Falls gaging station on the Lamprey River for the April 2007 flood event. Note the close correspondence between the modeled and observed hydrographs.
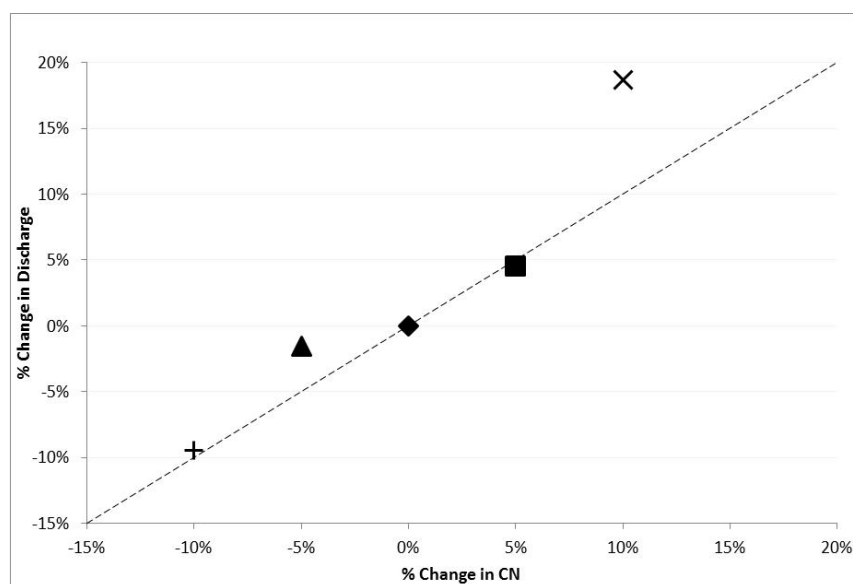
Figure 4. Sensitivity of discharge based on changes in curve number (CN).

Once the model calibration was complete, steady flow was simulated along the 36 mile reach of the Lamprey River and floodplain elevations and extents were quantified using Hydrologic Engineering Center - River Analysis System (HEC-RAS)(USACE 2001) and

Geographic River Analysis System (HEC-GeoRAS)(USACE 1999). The downstream boundary condition for this project is Macallen Dam in Newmarket, although additional analyses were also performed for Moonlight Brook (flowing through parts of downtown Newmarket and emptying directly into the tidal potion of the Lamprey River below the Macallen Dam).

The FEMA library data provided station and elevation records for over 100 cross sections. Additional sections added to the model came from previous hydraulic analysis performed by private consultants, and state and federal agencies. The hydraulic model included 262 river cross sections: 115 sections from the original FIS dataset, 46 sections from recent field survey and other analyses, 101 additional sections and extended embankment elevations generated from 2011 LiDAR imagery (2-meter digital elevation model, 15- cm vertical root mean square error). Reaches without surveyed cross-sections (Piscassic River and Moonlight Brook) used topography generated by LiDAR and assumed channel geometry. Flow for the Lamprey River was modeled as quasi steady using flow changes dictated by the HEC-HMS model. Following completion of the hydraulic model, calibration options were examined. Data collected by public works officials, the USGS, and local residents was used to validate the flood water surface elevations modeled in HEC-RAS.

The following calibration locations were examined for the hydraulic model: the USGS gage at Packers Falls, the Langford Lane bridge in Raymond, the Mill Street bridge crossing, the Durham Boat Club, and 220 Newmarket Road. All had high water marks during the April 2007 and March 2010 storm events. The USGS gage discharge curve was used in comparison with the rating curve developed for hydraulic model and were calibrated to the existing 100-year flow of 7300 cfs. Minor differences for flows less than 1,000 cfs may be attributed to the precision of the FIS geometry used for the cross section. During flows greater than 4,000 cfs more than 12% of the discharge begins to spread into the right overbank.

The April 2007 and March 2010 events provided historic high water and flooding. Following the event the USGS surveyed high water indicators (HWI) at the Langford Road bridge in Raymond. High water elevation at the Mill Street bridge in Epping was photographed and referenced to adjacent landmarks. The Durham Boat Club's interior walls provided the indication of high water marks and personnel have labeled and recorded most major flooding events. In using the recent NHDOT survey of RT108, the markings were converted to approximate elevations. Table 2 provides the obtained information and reference to the HEC-RAS model location.

Table 2: Observed high water elevations.

Location	River HEC-RAS Sta.	Event	WSE (NAVD29)	Indication
Langford Road, Raymond	Lamprey 167,900	April 2007	197.155	Wash line
			197.205	Wash line
			194.88	Seed line
Mill Street, Epping	Lamprey 106,389	April 2007	113.00	Observed HWI
Durham Boat Club, Newmarket	Beaudette 71	April 2007	34.1	HWI in building
		March 2010	33.3	HWI in building

Finally, the hydrologic and hydraulic models were run using the following boundary conditions (discussed in more detail below and summarized in Table 3):
   (1) updated (2005) land use and 8.5 inch 24-hr rainfall;
   (2) 2050 conventional and LID build-out and 8.5 inch 24-hr rainfall;
   (3) 2100 conventional and LID build-out and 11.4 inch 24-hr rainfall.

(ii) Future Land Use and Future Climate Scenarios
   A detailed description of the methods and results to estimate future land use and future climate are provided in the attached document titled "Review of Land Development (Build-out) and Climate Scenarios" (Wake et al., 2012). In brief, the final build-out (aka development) scenario we used was based on an exponential best fit to the historical 1962-2005 residential and non-residential developed land data and reflects the observed increase in the rate of land development in the Lamprey River watershed since 1962, even as the rate of increase in population had begun to decrease in 1990. In this exponential growth scenario, residential development will increase to 66,002 acres (48% of total area in watershed) by 2100. While this growth scenario projects commercial/industrial development activities to occur on 14,620 acres by 2100, we allocated 50% of this total activity to new development and 50% to redevelopment. Thus, the actual increase in commercial/industrial acreage was targeted to increase to 7,939 acres (6% of the watershed)
   Once the projected rate of land development was established, the next step was to determine potentially buildable areas. Once these areas were identified, the exponential residential land development scenario was used to map future residential acreage. This is followed by the application of the exponential growth rate for commercial/industrial uses based on two development scenarios – conventional (CON) and low impact development (LID)(Figure 5). The commercial industrial areas included a combination of new development (existing developable areas) and redevelopment. Redevelopment of existing commercial industrial is considered to be a powerful tool for the reduction of existing impacts impervious cover over long-term redevelopment process. Substantial redevelopment activities occur in the typically

11

limited commercial and industrially zoned areas. However, redevelopment in residential areas was not modeled, as it is rare for residential homes to be torn down and rebuilt.
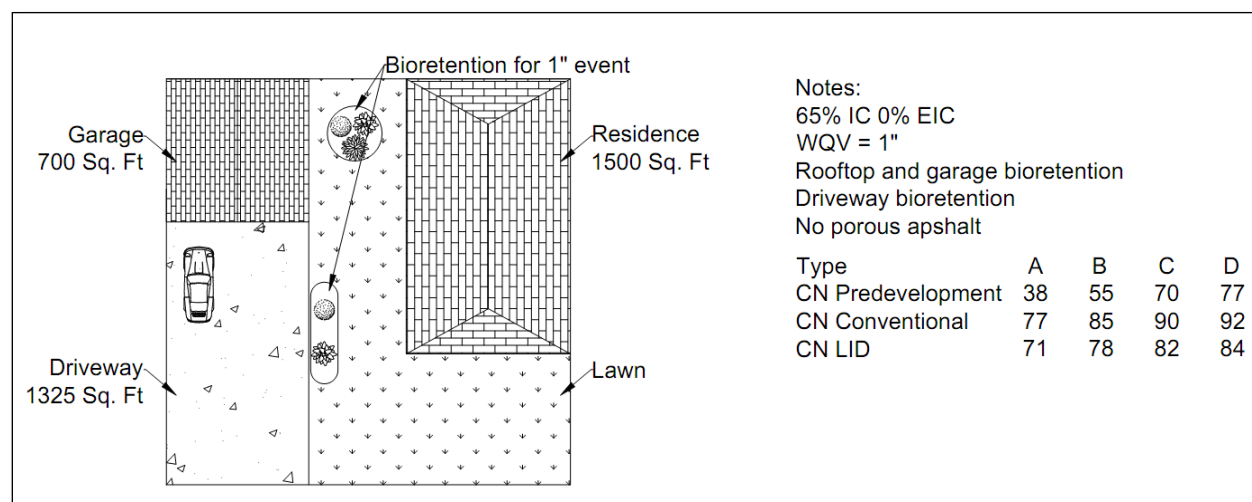

Figure 5: Illustration depicting a proto-typical LID new development for 1/3 acre residential zoning, impervious cover (IC), effective impervious cover (EIC), water quality capture depth, and curve number comparison.

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 to 1910. Recently, a collaboration between the NOAA Northeast Regional Climate Center (NRCC) and the USDA Natural Resources Conservation Service (NRCS) has produced an updated and comprehensive climatology of extreme precipitation in New York and New England through 2008 (NRCC and NRCS, 2012). The difference between the TP-40 and the more recent NRCC and NRCS (2012) estimates of the 24-hour 100-year rainfall depth are considerable (6.3 inches verses 8.5 inches; Table 3).

Atmosphere-ocean general circulation model (AOGCM) simulations driven by future emission scenarios were used to evaluate possible future changes in climate, including changes in precipitation. 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). 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 for the watershed from either the high or low emissions scenari . 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. 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. 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. Minor deviations between actual and targeted build-out acreages (e.g. residential build-out in 2050 and 2100) are a result of the proximity processing methodology utilized. Significant differences between actual and targeted acreages (e.g. commercial & industrial LID in 2050 and 2100) reflect the lack of buildable acreage in existing commercial/industrial zones.

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)

(iii) Production of 100-year Floodplain Maps for Current and Potential Future Conditions.

The output from the HEC-GeoHMS for four final conditions (existing FIRMs, updated [2005] land use and 8.5 inch 24-hr rainfall; 2100 conventional build-out and 11.4 inch 24-hr rainfall; and 2100 LID build-out and 11.4 inch 24-hr rainfall) provided the preliminary geospatial data sets. Minor editing was required to smooth the results and eliminate small data gaps. Final products from the effort included the geospatial data set (shapefile) for each condition, along with associated documentation.

A set of maps depicting past, current (2005), and potential future 100-year floodplains in the Lamprey River watershed was generated from the data sets. The maps incorporated floodplain boundaries, topographic models, aerial imagery, and standard base data (roads, town boundaries, surface water). Key reference features were also incorporated into the output products to assist communities in reading the maps.

Evaluation Methods

From its inception, this project sought to integrate input from likely end users of the technical products to ensure that the products were high quality, relevant, and useful to them. In addition, a comprehensive process of engagement with likely users was a project imperative. This engagement took the form of a project Advisory Committee, a series of focus group sessions, and a final public presentation of the project products. Formative evaluation was conducted in conjunction with each of these components to help assess product and process quality.

During the five Advisory Committee meetings, committee members were asked to provide the project team with their opinions concerning the overall project, technical analyses, map development and product relevance, and later about map quality and usability. Feedback from the committee members was then discussed at subsequent project team meetings and incorporated into the project.

Suggestions for focus group participants were gathered from project team and Advisory Committee members. The goal was to have representatives from three primary groups of potential map users – municipal officials, building and landscape design professionals, FIRE (finance, insurance and real estate) business representatives – respond to the most recent version of the maps. In May of 2012, a focus group of six participants and interview of one additional participant provided initial responses to the maps, commented on map attributes, offered suggestions for map uses and users and thoughts about what training might be needed for maps to be used.

The maps were presented at a Lamprey River Watershed Conference in June of 2012. Approximately 65 participants heard presentations, participated in discussions, and reviewed the maps located around the room. Approximately one-half of the participants completed a post session questionnaire about the day's events. Participants represented local governments; regional, state and federal agencies; universities; community and non-profit groups; the Advisory Committee, and the project team. The largest portion represented local governments. Participants responded (based on Lickert scale - strongly agree to strongly disagree) to various statements about changes in their familiarity, knowledge, ability, and comfort levels related to the maps and their usage. They were asked about likelihood of use, likely uses, and to comment on various aspects of the maps quality, relevance, and importance for various user groups. Participants were asked to record how they might apply what they learned, what obstacles they foresaw to applying the information, and what training might help overcome obstacles. They were also asked which component of the day's event was most useful and why.

Finally, a follow-up summative evaluation based on a formal survey will be sent to the project team and advisory committee members in the first half of 2013. An additional evaluation of select portions of this project was completed as part of a UNH Dissertation (Matso, 2012).

Collaboration Methods

Collaboration among the team members was managed via regular (at least quarterly) 1.5 – 2 hour team meetings organized by the Principal Investigator. Additional team meetings were held to prepare for the semi-annual meetings of the Advisory Committee. A sub-committee was also created to address the numerous technical issues associated with the build-out analysis and the hydrological and hydraulic modeling aspects of the project. This sub-committee met on several occasions as required to keep the technical analysis moving forward.

An Advisory Committee consisting of municipal officials, regional planners, watershed groups, state and federal representatives, and technical experts (Table 4) was chaired by Cliff Sinnott, Executive Director of the Rockingham Planning Commission. The Advisory Committee met semi-annually to guide the direction and focus of the project, provide input on build-out scenarios and modeling efforts, advise on the interpretation of results, and shape the development and dissemination of the final products.

Table 4. Members of the project Advisory Committee.

Municipal Representatives	
David Cedarholm	Durham Public Works
Diane Hardy	Newmarket Planning Dept.
Jennifer Perry	Exeter Public Works
Regional Representatives	
Cynthia Copeland	Strafford Regional Planning Commission
Jack Munn	Southern NH Planning Commission
Cliff Sinnott	Rockingham Planning Commission
Dawn Genes	Lamprey River Watershed Association
Sharon Meeker	Lamprey River Advisory Committee
State, New England, and Federal Representatives	
Joanne Cassulo	NH Office of Energy and Planning
Jen Gilbert	NH Office of Energy and Planning
David Knowles	FEMA Region 1
Ron Poltak	NEIWPCC
Keith Robinson	USGS (NH and Vermont)
Eric Williams	NH Dept. of Environmental Services

Knowledge Dissemination Methods

Knowledge about the project was disseminated in a variety of ways: presentations to the Advisory Committee, the focus groups, Strafford and Rockingham Regional Planning Commissions, and at professional conferences; via a site specific web site (http://100yearfloods.org) and the NH GRANIT website (New Hampshire's statewide GIS clearinghouse; http://www.granit.unh.edu/MapLibrary/ProjectMaps) (note all the new 100-year floodplain maps are posted on the NH GRANIT site); at an open workshop convened in collaboration with the Lamprey River Watershed Association and held in Raymond NH on 1 June 2012 (Agenda for the meeting provided in Appendix A); and via reports and peer-reviewed publications.

Target audiences include: municipal officials, emergency managers, regional planners, watershed groups, state planners, NH Dept. of Environmental Services, NEIWPCC, FEMA, and USGS representatives, engineering firms, floodplain managers, FIRE representatives and concerned citizens.

2.5 Results Discussion

Technical Results

The primary products generated by this project are the models and maps of past, current, and potential future 100-year floodplains in the Lamprey River watershed. Information in the

maps can be used for municipal and regional planning, emergency management, zoning, master plan updates, and infrastructure projects. We also produced a companion document to the maps that provides 100-year water surface elevation and 100-year flood discharge at Flood Insurance Study (FIS) Cross Sections for past, current (2005), and potential future 100-year flood conditions (Scholz et al., 2012).

A series of floodplain maps depicts the extent of 100 year floods for the following conditions:

    Past conditions (these are the existing FEMA Flood Insurance Rate Maps [FIRMs])
    Updated (2005) Conditions (2005 land use and 100 year, 24 hour precipitation of 8.5")
    2100 Conditions (for both Conventional and Low Impact Design build-out scenarios, 24 hour precipitation of 11.4")

These maps are available for download from the New Hampshire GRANIT website (http://www.granit.unh.edu/Projects/Details?project_id=244) for the following regions within the watershed and conditions:

    Watershed Map - FIRM, 2005 Conditions, 2100 Conventional Build-out
    Watershed Map - FIRM, 2005 Conditions, 2100 Conventional Build-out with Aerial Photo Base
    Watershed Map - FIRM, 2005 Conditions, 2100 LID Build-out
    Durham - FIRM, 2005 Conditions, 2100 Conventional Build-out
    Durham - FIRM, 2005 Conditions, 2100 LID Build-out
    Epping - FIRM, 2005 Conditions, 2100 Conventional Build-out
    Epping - FIRM, 2005 Conditions, 2100 LID Build-out
    Lee - FIRM, 2005 Conditions, 2100 Conventional Build-out
    Lee - FIRM, 2005 Conditions, 2100 LID Build-out
    Newmarket - FIRM, 2005 Conditions, 2100 Conventional Build-out
    Newmarket - FIRM, 2005 Conditions, 2100 LID Build-out
    Raymond - FIRM, 2005 Conditions, 2100 Conventional Build-out
    Raymond FIRM, 2005 Conditions, 2100 LID Build-out

Figures 6 and 7 provide examples of the watershed format and the large-scale local format, respectively.
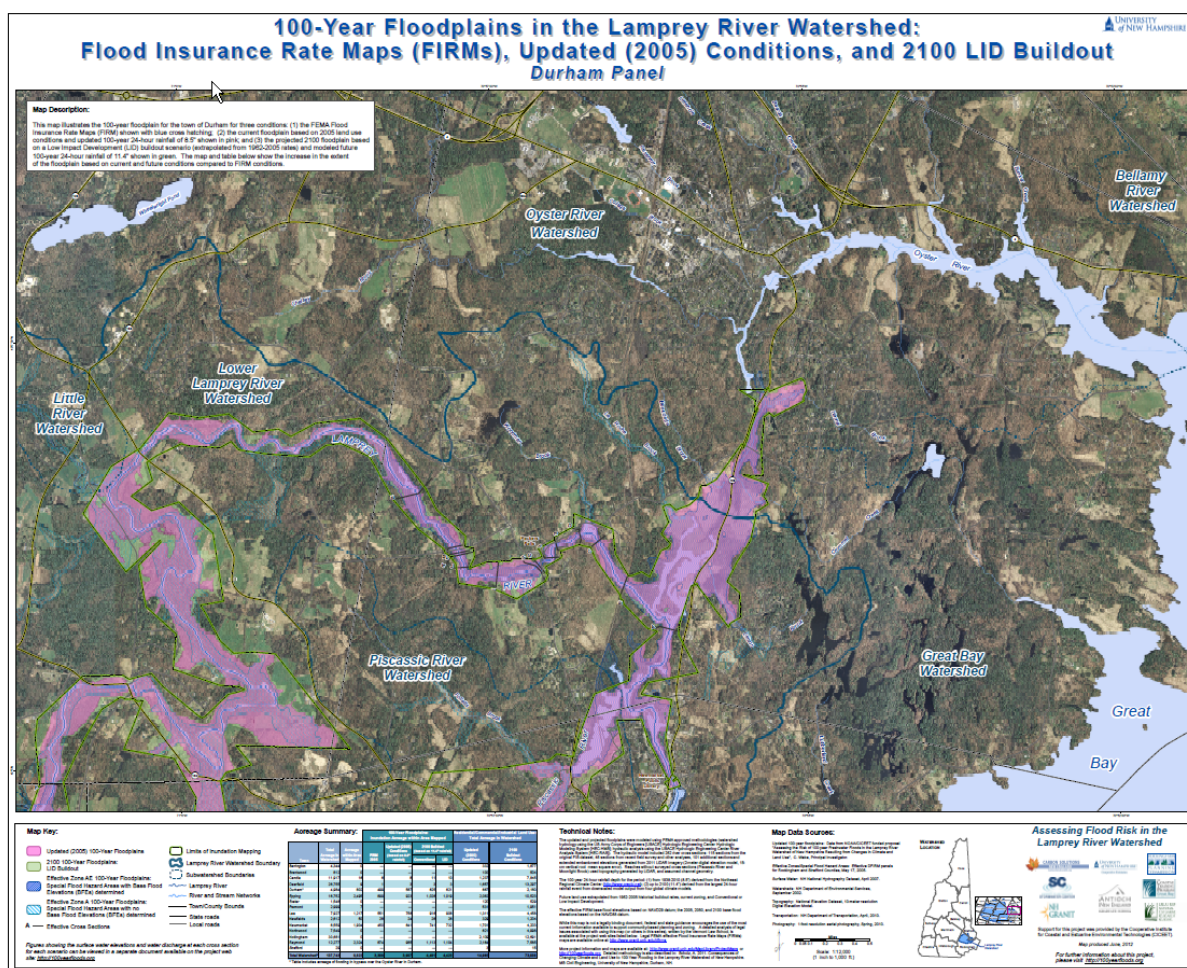
Figure 6. Lamprey River watershed map illustrating FIRM, updated 2005 conditions, and 2100 conditions under the conventional buildout scenario.

Figure 7. Large-scale map for section of Durham, NH, showing FIRM, updated 2005 conditions, and 2100 conditions under the LID buildout scenario.

A summary of the areal extent of the 100-year floodplains by town for the four conditions (FIRM, current [2005], conventional build-out [2100] and LID build-out [2100]) is provided in Table 5. Changes in the water surface elevation and discharge for 100-year flood for the four conditions for 60 cross sections on the Lamprey River are detailed in a project report (Scholz et al., 2012) and are summarized for the Packers Falls cross section in Table 6. Additional results are discussed in detail in a masters thesis (Scholz, 2011) and a second project report on the build-out and climate scenarios (Wake et al., 2012).

Table 5. Summary of changes in acres flooded under different land use and climate scenarios.

Town	Total Acreage in Watershed	Acreage within Area Mapped	FIRM** (based on 6.3" rainfall)	Updated (2005) Conditions (based on 8.5" rainfall)	2100 Buildout (based on 11.4" rainfall)		Residential, Commercial & Industrial Land Use: Total Acreage in Watershed	
					CON***	LID***	Updated (2005) Conditions	2100 Buildout Conditions
Barrington	4,344	0	---	---	---	---	332	1,877
Brentwood	812	0	---	---	---	---	100	504
Candia	11,917	16	6	8	11	10	1,237	7,845
Deerfield	26,755	9	1	3	3	3	1,657	13,297
Durham*	4,984	802	499	567	625	621	667	2,160
Epping	16,752	2,495	899	923	1,026	1,019	2,082	10,523
Exeter	1,546	0	---	---	---	---	120	529
Fremont	2,999	7	---	---	---	---	531	1,951
Lee	7,927	1,217	551	756	916	906	1,311	4,458
Newfields	2,612	50	28	24	26	26	329	1,204
Newmarket	6,559	1,904	450	641	741	732	1,701	4,203
Northwood	7,549	0	---	---	---	---	621	4,998
Nottingham	30,681	0	---	---	---	---	2,109	12,691
Raymond	12,277	2,324	874	985	1,113	1,104	2,164	7,585
Strafford	29	0	---	---	---	---	3	15
Total Watershed*	**137,743**	**8,822**	**3,309**	**3,907**	**4,461**	**4,423**	**14,965**	**73,838**

* Table includes acreage of flooding in bypass over the Oyster River in Durham.
** FIRM: Flood Insurance Rate Maps, based on dischage data from 1935-1987.
*** CON: Conventional development; LID: Low impact development

Table 6. Changes in water surface elevation and discharge at Packers Falls under different land use and climate scenarios.

Parameter	FIS	Updated 2005	2100 CON	2100 LID
WSE (feet)	38.80	41.45	45.86	45.50
Discharge (cfs)	7,300	10,636	17,609	16,959

The maps, Tables 5 and 6, and report (Scholz et al, 2012) clearly show that the 100-year floodplain area, 100-yea water surface elevation, and 100-year flood water discharge, have increased significantly between the production of the FIRMs (based on discharge data from 1935-1987) to current (2005) conditions, and will continue to increase in the future under the buildout scenarios developed as part of this research. This increase in areal extent, water surface elevation, and discharge has important ramifications for natural resources, human well-being, emergency management, planning, and infrastructure (buildings, roads, dams) in the watershed.

The key floodplain and discharge results we have modeled for the four conditions (Table 2) are discussed briefly below:

Flood Insurance Study (FIS) and Flood Insurance Rate Maps (FIRMs): At the USGS gaging station at Packer's Falls upstream of Newmarket, the FIS 100-year discharge for the 183

square mile watershed upstream is 7,300 cubic feet per second (cfs) with a water surface elevation of 38.30 feet (relative to NAVD 1988) (FEMA 2005). This effective flood flow is based on the annual peak discharges for the years 1935 through 1987. The rainfall-runoff model we developed generated a flood flow of 6,828 cfs at the gaging station using historic TP-40 rainfall depth (6.3 in). Under these conditions, the area of the 100-year floodplain within the region mapped for the FIRMs (essentially the area around the main stem of the Lamprey River) is 3,309 acres (Table 5).

2005 Current Conditions: Using the 2005 land use conditions and the NRCC and NRCS (2012) rainfall depth of 8.5 inches, our model predicts flood flow at Packers Falls to be 10,636 cfs, an increase of 56% over FIS conditions; water surface elevations increase by 2.7 feet (Table 6). The overall average increase in discharge across the watershed is 48% and average water surface elevation increases an average of 1.9 ft along the 36 mile reach of the Lamprey River studied. The area of the 100 year floodplain within the mapped region under these land use and climate conditions increased to 3,907 acres (18%). Furthermore, during major events, flows from the Lamprey River bypass under and over a one mile stretch of Route 108 to Hamel Brook which is within the Oyster River watershed. The updated flood flow and hydraulic model for the Oyster River bypass generated a base flood elevation increase of 3.3 feet along the Longmarsh Brook to Hamel Brook reach.

2100 Conventional Build-out Conditions: The 2100 build-out condition of the watershed based on continued exponential growth and projected maximum 24-hour rainfall depth of 11.4 inches increased flood flows to 17,609 (an increase of 66% above 2005 conditions) and water surface elevations by 4.4 feet at Packers Falls (Table 6) compared to updated 2005 conditions. The area of the 100-year floodplain within the mapped area under these land use and climate conditions increased to 4,461 acres, an increase of 14% from 2005 conditions.

2100 LID Build-out Conditions: Implementation of LID decreased the flood flow an average of 3.4% from the conventional build-out, and 3.8% at Packers Falls (Table 6). Water surface elevation at Packers Falls with LID development decreased by 0.67 feet (Figure 8). While 0.67 feet is small in contrast to the overall change in flood elevation, it is very significant in terms of flood depth and mitigation. It represents an 11.5% reduction in water surface elevation increase that could theoretically be due to long-term increases in impervious cover in the largely undeveloped watershed. For standard development, any increase to the 100-yr flood elevation greater than 0.01 ft requires filing of a letter of map revision and approval by FEMA. The degree of flood mitigation was observed to be greatest for areas with increasing impervious cover. The Lamprey River watershed has a low overall IC presently, so the impact is minimal. However, the reductions are significant in smaller urban sub basins with high impervious cover. Future increases in runoff depth (R) were reduced by as much as 7.5% to 9.1% (Table 7).
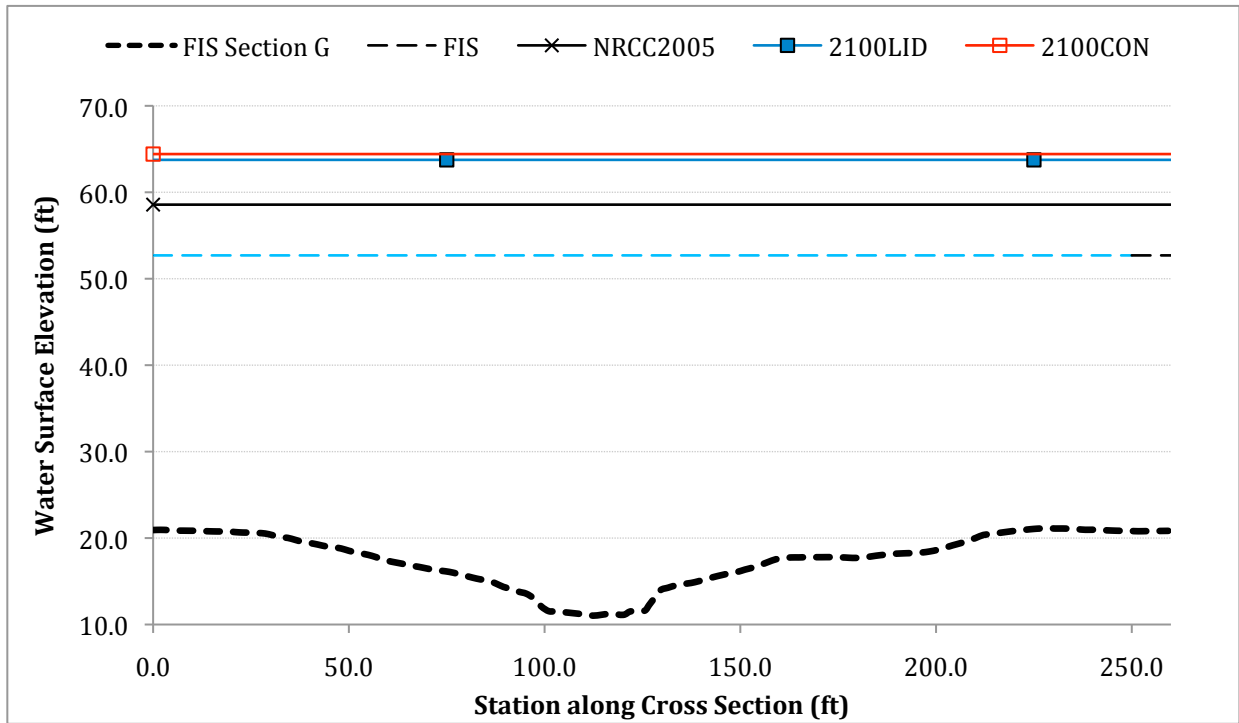
Figure 8: Water Surface Elevations at Packers Falls for 5 Conditions: Existing FIS, 2005, and 2100 LID and Conventional Build-Out , Newmarket New Hampshire

Table 7. Differences between conventional (CON) and low impact development (LID) on urban watershed curve numbers (CN), and runoff depth (R).

Sub basin	Area (sq. miles)	2005 CN	2100 CON CN	2100 LID CN	ΔCN CON-LID	2005 R (in)	2100 CON R (in)	2100 LID R (in)	ΔR CON-LID (in)
Moonlight Brook	0.9	68.5	74.0	70.9	3.1	4.5	8.1	7.8	0.27
Raymond Intermittent	0.9	65.9	73.9	71.3	2.6	4.4	8.4	8.0	0.36
Epping Intermittent	1.2	70.0	76.9	72.1	4.8	4.9	8.6	8.3	0.29

The analysis showed that the modeled LID practices began to show minimal hydrologic benefit below about 3% to 7% impervious cover and increasing benefit, in terms of CN reduction, is obtained with increasing impervious cover and for poor quality soils. Because there are a limitless variety of applications of LID systems in a design context, the CN analysis performed here is based on providing a 1" water quality volume (WQV) for all impervious surfaces. CN values would be adjusted for less or more WQV designs.   For the CN analysis, the

practice type (i.e. bioretention, sandfilter, infiltration trench, etc) is unimportant, but rather the volume reduction. This analysis applied the use of LID for all developed and redeveloped sites. One (1) acre lot sizes and above incorporated the use of porous pavement which adds substantial additional volume reduction. Commercial and industrial site designs included parking (porous asphalt) and roads (standard asphalt and bioretention), and rooftop infiltration. The common practice of limiting porous pavement usage to parking areas was applied.

Evaluation Results

Advisory Committee

      The first Advisory Committee meeting focused on what the advisors considered reasonable build-out conditions and low impact development scenarios. They were also asked their perceptions about anticipated uses of the maps and possible barriers to use based on the fact that the maps would not be "legal" floodplain maps. From observation and meeting notes, it was evident that committee members freely offered their opinions and a number of considerations for the mapping team. The mapping team responded accordingly. In fact, a technical sub-committee was established to discuss build-out scenarios when the mapping team was not able to easily incorporate the range of scenarios the advisory committee members deemed optimum.

      The Advisory Committee members also played a very important role in responding to initial map products in February of 2011. They were asked to comment on several aspects of the first draft of the maps - initial reactions, modifications to improve them, ideas about perceived uses and potential users, and potential barriers to use. The members offered suggestions on map format, content, presentation and scale. They provided very specific feedback about map text and features (e.g., change terminology). They also offered ideas about suggested uses (e.g. discussion starter, hazard mitigation planning and motivating communities to adopt higher standards); users (e.g. municipal planners, city engineers, departments of public works, developers and insurance companies) and barriers to use (e.g. accessibility and concerns about insurance costs). One critical aspect that ended up driving the project in a new direction emerged at this time – the initial maps did not include significant, known flooding trouble spots within the 100-year floodplain. This issue drove the mapping team to consider redelineating 100-year floodplains using new LiDAR topographic data as soon as it became available to provide more accurate representation of areas susceptible to flooding. It was essential to improve the mapping accuracy and subsequently products' credibility in the user community. And while this development delayed the project completion, the mapping team once again took the feedback from the Advisory Committee members to incorporate into the next version of the data, and ultimately the project maps.

Focus Groups

      Comments about map attributes were interesting in that there was a fairly wide range of reactions to specific features (e.g. cross sections), however responses to questions about map uses and training needed were more unanimous. Members of the focus group commented that the maps would be useful for planning, especially hazard mitigation and master planning. There were also some suggestions about the use of the maps to guide land conservation efforts (i.e. flood storage). The need for training to be offered to map users was discussed and strongly supported by focus group participants. They suggested training be offered to planning boards,

site review boards, emergency management personnel, select boards, road agents and department of public works.

Results from Questionnaire Following the Final Project Workshop (1 June 2012)
        The event increased the participant's familiarity with the new 100-year floodplain maps, their ability to access them, their comfort with using them, and the legal aspects of using them. Close to 90% of respondents anticipated using the maps - in order of most common to least common selection - to inform or motivate others, for planning and zoning, for promoting low impact development, for developing policies or regulations, to reuse the data and analysis, for emergency management, to change development and building practices, and to change lending and insurance practices. Respondents predominantly agreed that the maps were high quality and relevant for protecting people, property, and infrastructure. Over 90% of respondents thought the maps were most important for local, state, and federal leaders, and scientists and academics. Respondents indicated that the maps were fairly easy to read, but that assistance was needed to make them easier to understand. Respondents consider using the maps for community and municipal decision-making as well as for the technical information (i.e. rainfall and precipitation) contained. Obstacles to use fall into two primary categories – acceptance/skepticism (e.g. public acceptance) as well as feasibility (e.g. funding). Suggestions were offered for training, many of which included face-to-face presentations for municipal officials. "Most" useful components of the day's event included discussion (e.g. local stories, background information, ability to discuss and network, low impact development as a management tool) as well as the actual maps (e.g. current and projected data, revised curve numbers, legal review).
        Overall, there is evidence that the project resulted in high quality, relevant products that are anticipated to be useful for decision making, especially at the local level. That said, the need for training to be offered in conjunction with the maps appears to be a critical element to facilitate their use. Other strengths of the maps appear to be for their technical merits based on the data and analysis for use by other scientists and technical experts.
        While a formal survey of project team and Advisory Committee members has yet to be conducted, the sheer number and substance of methodology and map revisions undertaken by the mapping team based on the input of the Advisory Committee members and focus groups point to the development of a much better product and process than would have occurred without a focus on user-community engagement.

Collaboration Results

        Team meetings were a critical component of the project and were necessary to discuss key issues and keep the project moving forward. The PI organized all team meetings, including developing agendas that were closely followed. Review and input from the Advisory Committee served to significantly improve the overall results of the project (as detailed in the evaluation section above). We expect to further investigate the value of the project team and Advisory Committee meetings and input after we collect responses to the formal survey will be distributed in 2013.
        One issue raised by the Advisory Committee early on in the project focused on the potential legal risks communities in the Lamprey River Watershed may face as a result of adopting new flood management regulations and policies based on the new 100 year floodplain

maps. As a result, Julia Peterson and Cameron Wake worked with lawyers from the Vermont Law School – Land Use Clinic to secure a $25,000 grant from the NOAA National Sea Grant Law Center to investigate questions of legal authority, measures, and consequences for communities using the new floodplain maps. To assess potential legal risks, they investigated four potential legal challenges related to: municipal liability, enabling authority, the use of the new floodplain maps as evidence, and takings.

In brief, they found that the risk of municipal liability is low, so long as municipalities follow sound planning principles. Not only is the level of risk low, the federal government *encourages* communities to enact certain types of regulations designed to reduce flood hazards. This encouragement provides states and municipalities an additional layer of assurance with respect to adopting and defending revised or new flood regulations. Under federal floodplain guidelines, states and municipalities are encouraged to establish more stringent regulations above and beyond minimum federal requirements. The results of their research are detailed in a 124 page report (Vermont Law School, 2012) that is available on the project web site.

Knowledge Dissemination

All of the new floodplain maps are available for download from the New Hampshire GRANIT website (http://www.granit.unh.edu/Projects/Details?project_id=244). Reports and other supporting documentation are available on the project web site (http://100yearfloods.org). In addition, paper copies of all of the new 100-year floodplain maps were hand delivered to all municipalities within the watershed and to the Rockingham, Strafford, and Southern New Hampshire Regional Planning Commissions; and postcards (Appendix B) with information on how and where to access the new 100-year floodplain maps were sent to over 400 stakeholders.

One masters thesis focused on the hydrologic and hydraulic modeling was produced (Scholz, 2011) and the project team produced two reports: one report on the build-out and climate scenarios developed for this project (Wake et al., 2012) and a second on water surface elevation and flood flows at the Flood Insurance Study (FIS) cross sections (Scholz et al., 2012). Lawyers and interns from the Vermont Law School also wrote a comprehensive report on legal aspects of using the new 100 year floodplain maps (Vermont Law School, 2012). The project team is also currently writing two papers for submission to peer reviewed journals (Roseen et al., in prep; Peterson et al., in prep).

Team members have made over 15 presentations at professional conferences and regional planning committee meetings. The dates and location of these presentations are listed below and electronic copies of these presentations are available on the project website.

11 January 2013 The Good, the Bad, and Ugly: Lessons Learned from Engaging Stakeholders in an Assessment of Flood Risks in the Lamprey River Watershed. Presented at the 6th Annual Lamprey River Symposium, Durham, NH.

27 Sept 2012 Changing Climate and Land Use: 100-Year Flood Maps in the Lamprey River Watershed of New Hampshire. Presented at the Water, Weather, Climate and Community Workshop 5: What Does Adaptation Look Like, Greenland, NH.

1 June 2012 Past, Present, and Potential Future 100-Year Floods in the Lamprey River Watershed. Presented at the Floodplains of the Lamprey River Workshop, Raymond, NH.

1 June 2012 Questions of Legal Authority, Measures, and Consequences. Presented at the Floodplains of the Lamprey River Workshop, Raymond, NH.

16 May 2012. Mapping and Legal Implications of Future Flooding in the Lamprey River
    Watershed of New Hampshire due to Changes in Land Use and Climate. NEIWPCC 23rd
    Annual Nonpoint Source Pollution Conference, Portsmouth, NH.
23 March 2012 Mapping and Legal Implications of Future Flooding in the Lamprey River
    Watershed of New Hampshire Due to Changes in Land Use and Climate. Presented at the
    NH Water and Watershed Conference, Plymouth State University, NH
21 March 2012 Climate and Land Use Consequences to 100-Year Flooding. Presented at the
    Nebraska Post-Construction Stormwater Workshop, Lincoln, Nebraska.
6 January 2012 Consequences of Changing Climate and Land Use to 100-Year Flooding.
    Presented at the 5th Annual Lamprey River Symposium, Durham, NH.
23 May 2011 Climate and Land Consequences to 100-Year Flooding. Presented at the World
    Environmental and Water Resources Congress.
18 May 2011 Changing Climate and Land Use: Consequences for 100-Year Flooding in the
    Lamprey River Watershed of New Hampshire. Presented at the Association for State
    Floodplain Managers, Louisville, KY.
24 February 2011 Assessing the Risk of 100-year Freshwater Floods in the Lamprey River
    Watershed of New Hampshire Resulting from Changes in Climate and Land Use. Presented
    to the Lamprey River Advisory Committee, Newmarket, NH.
17 November 2010 Assessing Flood Risk in the Lamprey River Watershed. Presented at the NH
    Local Government Center's 69th Annual Conference, Concord, NH.
28 January 2010 Assessing the Risk of 100-year Freshwater Floods in the Lamprey River
    Watershed of New Hampshire Resulting from Changes in Climate and Land Use. Presented
    to the Strafford Regional Planning Commission.
8 January 2010 Assessing the Risk of 100-year Freshwater Floods in the Lamprey River
    Watershed of New Hampshire Resulting from Changes in Climate and Land Use. Presented
    at the 3rd Annual Lamprey River Symposium.
9 September 2009 Assessing the Risk of 100-year Freshwater Floods in the Lamprey River
    Watershed of New Hampshire Resulting from Changes in Climate and Land Use. Presented
    to the Rockingham Planning Commission.

3. STATE OF THE TECHNOLOGY

The technical methods used in this study followed those defined by FEMA guidelines
(FEMA, 2009) and were reviewed by FEMA personnel on several occasions (David Knowles,
FEMA Region 1, pers. comm.). This project added an analysis of future land use and climate
conditions, an analysis that is not currently included in FEMA evaluations of floodplains. The
information is an effective visualization tool for communities to understand the long-term
impacts of zoning and land use decisions.   The maps and report quantifying changes in the area
of the 100-year floodplain, flood discharge, and flood water surface elevations were developed to
provide decision relevant information for planners, zoning boards, conservation commissions,
developers, and insurance agents and are available to the public on our web site
(http://100yearfloods.org). We did not pursue any patents, copyrights, licensing agreements or
partnerships.
The recent floods in the Lamprey River watershed have provided a real world verification
of the ongoing changes in 100-year floods. For example, many of the 100-year floodplains

depicted on the current (2005) conditions maps flooded during recent flooding events (e.g., 2006, 2007, 2010). This real-world demonstration of an expansion of the 100-year floodplains resulting from a combination of change in land-use and climate serves as a powerful example for a wide range of stakeholders, and has certainly helped focus their attention on the extent of potential future flooding events.

The potential users of the technology are represented by the members of our Advisory Committee and include representatives from municipalities, regional planning commissions and watershed groups and state, New England, and federal institutions. Additional users we were unable to bring into the project were developers, insurance agents, and real estate brokers, but we expect the information we produce will be of use to them.

Contact information for the individuals on our Advisory Committee is provided below:

Name	Organization	Tel.	E-mail
Municipal Representatives			
David Cedarholm	Durham Public Works	603-868-5578	dcedarholm@ci.durham.nh.us
Diane Hardy	Newmarket Planning Dept.	603-659-8501	dhardy@newmarketnh.gov
Jennifer Perry	Exeter Public Works	603-773-6157	jperry@exeternh.org
Regional Representatives			
Cynthia Copeland	Strafford Regional Planning Commission	603-742-2523	cjc@strafford.org
Jack Munn	Southern NH Planning Commission	603-669-4664	jmunn@snhpc.org
Cliff Sinnott	Rockingham Planning Commission	603-778-0885	csinnott@rpc-nh.org
Dawn Genes	Lamprey River Watershed Association	603-659-9363	dawn.genes@lrwa-nh.org
Sharon Meeker	Lamprey River Advisory Committee		s-meeker@comcast.net
State, New England, and Federal Representatives			
Joanne Cassulo	NH Office of Energy and Planning	603-271-1755	joanne.cassulo@nh.gov
Jen Gilbert	NH Office of Energy and Planning	603 271-2155	jennifer.gilbert@nh.gov
David Knowles	FEMA Region 1		David.Knowles@fema.dhs.gov
Ron Poltak	NEIWPCC	978-323-7929	rpoltak@neiwpcc.org
Keith Robinson	USGS (NH and Vermont)	603-226-7807	kwrobins@usgs.gov
Eric Williams	NH Dept. of Environmental Services	603-271-2358	eric.williams@des.nh.gov

4. NEXT STEPS

In addition to encouraging a wide range of potential users regarding the products of our research as described above, we have identified at least five additional next steps.

(1) During the first half of 2013 we plan to complete a follow-up summative evaluation based on a formal survey sent to the project team and Advisory Committee members. The information will be added to a paper currently being developed for submission to a peer-reviewed journal (Peterson et al., in prep.) that describes the collaborative aspects of the project.

(2) Complete and submit a paper for publication in a peer-reviewed journal describing primarily the technical methods and technical results of the project (Roseen et al., in prep).

(3) Collaborate with representatives from NH Office of Energy and Planning to revise the results so they can be adopted by FEMA. This however requires additional funding which we have not yet been able to secure.

(4) Share the detailed modeling results with municipal and regional representatives as they plan and design new infrastructure projects (this is already occurring with Durham and Newmarket).

(5) Build upon the methods developed in this project to develop 100-year floodplain maps and flood discharge flows for future conditions in other watersheds around Great Bay and across New England. As above, this will require additional funding.

(6) Incorporate the following changes into future methods:
- a focus upon ultra urban, high impervious cover areas. These areas have demonstrated the greatest mitigation value for low impact development zoning.
- Review a range of storm depths in addition to the 100-year flood plain to assess the range of mitigation benefits for more frequent floods.
- Perform a damage and cost assessment using the FEMA HAZUS. Average annualized losses avoidance is an extremely powerful tool and logical next step for this work product.

5. LITERATURE CITED

ASCE (American Society of Civil Engineers). 2007. The New Orleans hurricane protection system: what went wrong and why. American Society of Civil Engineers Hurricane Katrina External Review Panel, Reston, Virginia.

CFMSC (New Hampshire Comprehensive Flood Management Study Commission). 2008. HB 648 Comprehensive Flood Management Final Report, September 2008. http://gencourt.state.nh.us/statstudcomm/reports/1853.pdf

CLIMB (Climate's Long-term Impacts on Metro Boston)(2004). Final Report. Civil and Environmental Engineering Department, Tufts University. EPA Grant No. R.827450-01.

FEMA 2005. Flood Insurance Study for Rockingham County, NH.

FEMA 2009. Appendix C: Guidance for Riverine Flooding Analysis and Mapping.

Grannis, J (2012) Analysis of How the Flood Insurance Reform Act of 2012 (H.R. 4348) May Affect State and Local Adaptation Efforts. Georgetown Climate Center Report. http://www.georgetownclimate.org

Hayhoe, K, CP Wake, TG Huntington, L Luo, MD.Swartz, J.Sheffield, E Wood, B Anderson, J Bradbury, A DeGaetano, TJ Troy, and D.Wolfe (2007) Past and future changes in climate and hydrological indicators in the U.S. Northeast. *Climate Dynamics* 28, 381-407.

Hershfield, DM (1961) Rainfall Frequency Atlas of the United States. U.S. Dept of Commerce – Weather Bureau Technical Paper No. 40. http://www.nws.noaa.gov/oh/hdsc/PF_documents/TechnicalPaper_No40.pdf

Karl, TR, JM Melillo, and TC Peterson, (eds.) 2009. Global Climate Change Impacts in the United States, Cambridge University Press. http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts

Matso, K (2012) Producing Science that Actually Gets Used By Coastal Communities: What Funders Should Do to Link More Knowledge with Action. Ph.D. Dissertation, University of New Hampshire, Durham, NH.

Madsen T and N Wilcox 2012. When It Rains, It Pours: Global Warming and the Increase in Extreme Precipitation from 1948 to 2011. Environment America Research & Policy Center, Boston, MA. http://www.environmentamerica.org/reports/ame/when-it-rains-it-pours.

McCuen, R. (1983). "Changes in Runoff Curve Number Method." Maryland Department of Environment.

MDE. (2008). "Maryland Stormwater Design Manual, Supplement No. 1.", Maryland Department of Environment.

McCuen, R (2004) Hydrologic Analysis and Design (3rd Edition).

NRCC (Northeast Regional Climate Center) (2010) Northeast Overview – March 2010 Monthly Summary. http://www.nrcc.cornell.edu/impacts/Impacts_03-10.html

NRCC and NRCS (Northeast Regional Climate Center and Natural Resource Conservation Service) 2008. Extreme precipitation in New York and New England. http://precip.eas.cornell.edu.

Peterson, J, C Wake, S Miller (in prep.) The Good, the Bad, and Ugly: Lessons Learned from Engaging Stakeholders in an Assessment of Flood Risks in the Lamprey River Watershed.

PREP (Piscataqua Reginoal Estuaries Project) 2013. State of the Estuaries 2013. http://www.prep.unh.edu/resources/pdf/2013 SOOE/SOOE_2013_FA2.pdf

Roseen R, Jananski T, Houle J, Simpson M and J Gunderson, 2011. Forging the Link: Linking Economic Benefits of Low Impact Development and Community Decisions. UNH Stormwater Center Report. http://www.unh.edu/unhsc/forgingthelink

Roseen R, A Scholz, C Wake, F Rubin, S Miller, T Ballestero, M Simpson, C Sinnott, J Peterson (in prep) Assessing the Impacts of Changes in Climate and Land Use on 100-Year Floods in the Lamprey River Watershed

Scholz A (2011) Consequences of Changing Climate and Land Use to 100-Year Flooding in The Lamprey River Watershed of New Hampshire. M. Sc. (Civil Engineering) Thesis, University of New Hampshire, Durham, NH.

Scholz,A, R Roseen, and C Wake (2012) Water Surface Elevation and Flood Flows at Flood Insurance Study (FIS) Cross Sections for Four Conditions. Project Report available online at: http://100yearfloods.org/resources/#Reports

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds). 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge University Press, Cambridge, UK. http://www.ipcc.ch/ publications_and_data/ar4/wg1/en/contents.htmlUSACE (U.S. Army Corps of Engineers) (1999) HEC-GeoRAS: GIS Tools for Support of HEC-RAS using ArcGIS, User's Manual.

Snover AK, Binder, LCW, Kay J, Sims R, Lopez J, Willmott E. 2007. Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments. Climate Impacts Group, King County, WA, ICLEI - Local Governments for Sustainability.

Stack, L, Simpson M.H. Crosslin T, Roseen R., Sowers D. and C. Lawson (2010). Oyster River Culvert Analysis. Final Project Report funded under a US EPA Climate Ready Estuaries Grant: http://www.prep.unh.edu/resources/pdf/oyster_river_culvert-prep-10.pdf

USACE (U.S. Army Corps of Engineers) (2001) HEC-RAS: River Analysis System, User's manual.

USACE (U.S. Army Corps of Engineers) (2008) HEC-HMS: Hydrologic Modeling System, User's Manual

USACE (U.S. Army Corps of Engineers) (2009) HEC-GeoHMS Geospatial; Hydrologic Modeling Extension User's Manual.

Vermont Law School (2012) New Floodplain Maps for a Coastal New Hampshire Watershed and Questions of Legal Authority, Measures and Consequences. Vermont Law School Land Use Clinic Report submitted to the NOAA National Sea Grant Law Center. Project Report available online at: http://100yearfloods.org/resources/#Reports

Wake CP, E Burakowski, E Kelsey, K Hayhoe, A Stoner, C Watson, E Douglas (2011) Climate Change in the Piscataqua/Great Bay Region: Past, Present, and Future. Carbon Solutions New England Report for the Great Bay (New Hampshire) Stewards. http://www.carbonsolutionsne.org/

Wake, C, F Rubin, R Roseen, A Sholz, M Simpson, and C Sinnott (2012) Review of Land Development (Build-out) and Climate Scenarios. Project Report available online at: http://100yearfloods.org/resources/#Reports

APPENDIX A:

Agenda for the final open workshop convened in collaboration with the Lamprey River Watershed Association

Floodplains of the Lamprey River

Friday June 1, 2012
Raymond Baptist Church**,** 145 Route 27, Raymond, NH

AGENDA

8:00 – 8:30 AM	Registration, Coffee, Danish
8:30 – 8:40 AM	Introductions & Welcome, Dawn Genes, Lamprey River Watershed Assoc.
8:40 – 9:10 AM	Sustaining Watersheds: An Integrated Sustainability Perspective
	Dr. Tom Kelly, Chief Sustainability Officer, UNH
9:10 – 9:20 AM	Local Flood Impact Story #1
9:20 – 9:50 AM	Past, Present, & Potential Future 100-year Floods in the Lamprey River
	Watershed, Dr. Cameron Wake, EOS, UNH
9:50 – 10:40 AM	Poster Session: Review of New 100-year Floodplain maps
10:40 -10:50 AM	Local Flood Impact Story #2
10:50 -11:20 AM	Questions of Legal Authority, Measures, and Consequences
	Tom Broderick, Vermont Law School
11:20 – 11:50 AM	Land Use, Low Impact Development, and Community Resiliency
	Dr. Robert Roseen, Director, Stormwater Center, UNH
11:50 – Noon	Wrap Up
Noon	Lunch and Evaluations
1:00 PM	Adjourn

New 100 year flood maps and additional information available online by 25 June 2012 at:
**http://100yearfloods.org   and   http://www.granit.unh.edu**

Sponsored by:

Lamprey River Main Stem Communities: Northwood, Deerfield, Raymond, Epping, Lee, Durham, Newmarket
Tributary Communities: Candia, Nottingham, Fremont, Brentwood, Exeter, Newfields

APPENDIX B:

Image of postcard (front and back) sent to over 400 stakeholders in the Lamprey River watershed, New Hampshire, and New England providing informaiton on where the project products are available online.

FRONT:

Assessing Flood Risk in the Lamprey River Watershed
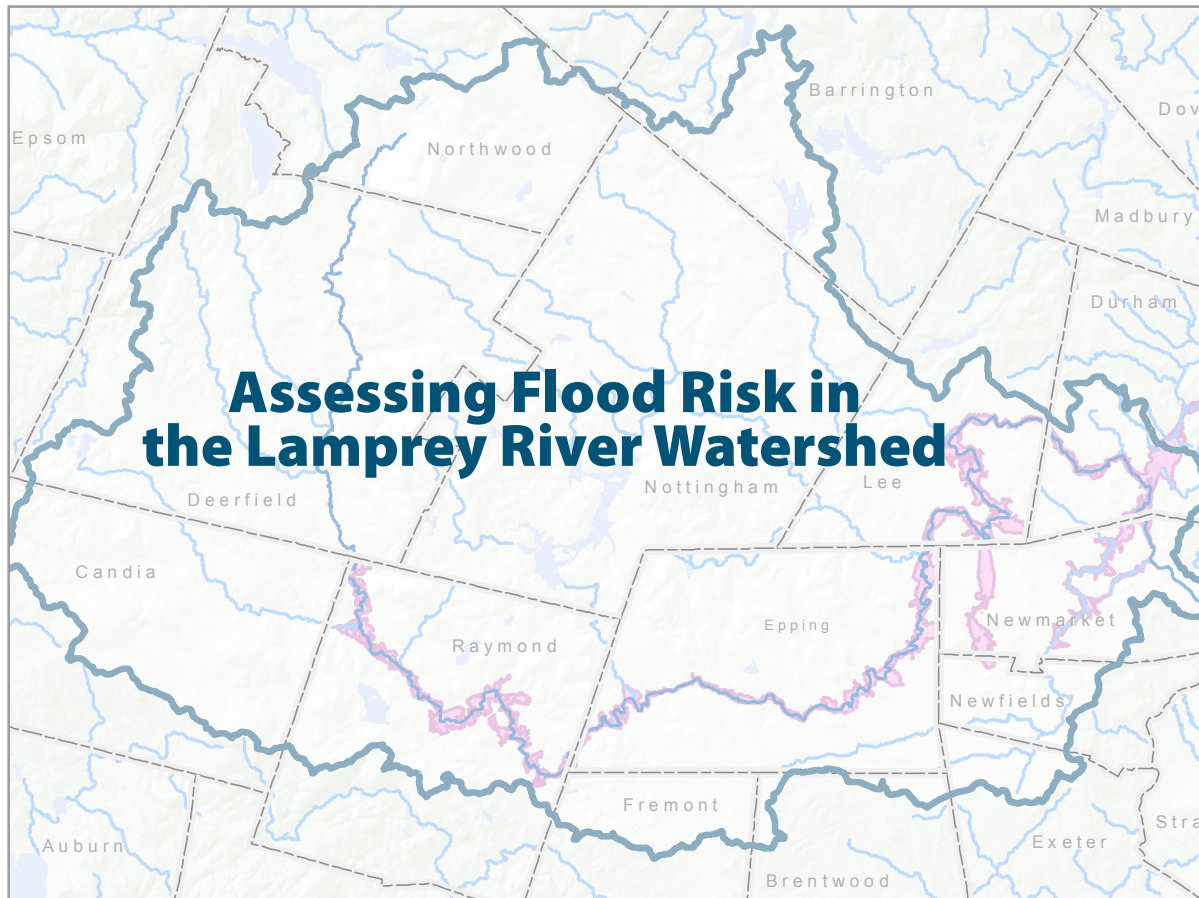
BACK:

A UNH led project has modeled existing and potential future 100-year floodplains in Lamprey River Watershed. Products (100-year floodplain maps, flood heights at cross-sections, and legal analysis) are online at **http://100yearfloods.org** or **http://www.granit.edu**.

Information in the maps and cross sections can be used for municipal and regional planning, emergency management, zoning, master plan updates, and infrastructure projects. The legal analysis may be useful for drafting ordinances or facing legal challenges to flood management ordinances.

Regards, Cameron Wake
UNH Institute for the Study of Earth, Oceans, and Space , 8 College Road, Durham, NH 03824

For more info. contact Steve Miller (Great Bay National Estuarine Research Reserve) 603-778-0015 ext. 305