DRAFT

8 31 15

12 20 15 – Land Use Appendix added in

Appendices (note: not all in Times Roman 12 so that formats do not get changed)

Appendix AS1

HSPF Calibration and Verification

Discharge. HSFP requires as input hourly precipitation (P), temperature (T), potential evapotranspiration (PET), cloud cover, dewpoint temperature, solar radiation, and wind speed.

For the respective calibration and verification periods of 1996 to 2006 and 2006 to 2014, hourly P and T values were used from Epping meteorological station. PET was calculated by the Hamon method (described in http://naldc.nal.usda.gov/download/7287/PDF). The hourly values of cloud cover, dewpoint temperature, solar radiation, and wind were taken from Durham NH meteorological station. During calibration, model parameters were adjusted to achieve the best fit. During verification, model parameters were not adjusted.

The calibration was carried out for the Haigh Road USGS gauge on the Exeter River, which has daily discharge data from June 1996 to the present and is the gage closest to Exeter in the basin. The drainage area of the gage is 63.5 square miles. The results of this are in Figures 1 and 2. As can be seen, the calibrated model strongly captures high and low daily flows. This is confirmed in the verification plots in Figure 3 and 4. In addition, flows at Great Dam were estimated from the measured water depths at the dam (measured since 2005 by Exeter) and then converted to flows using the spillway and gate rating curves. HSPF assumes all flow passes over the dam. A comparison for approximately 1.5 years is in Figure 5. As can be seen, again, the verification is strong.

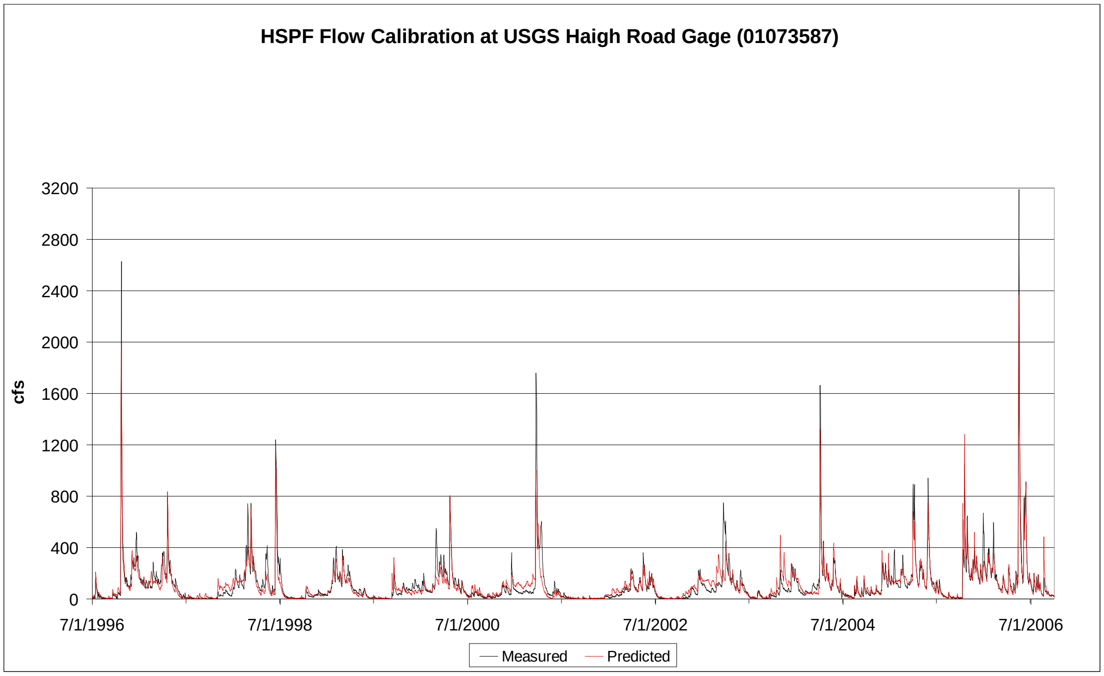

Figure 1. HSPF Flow Calibration at Haigh Road

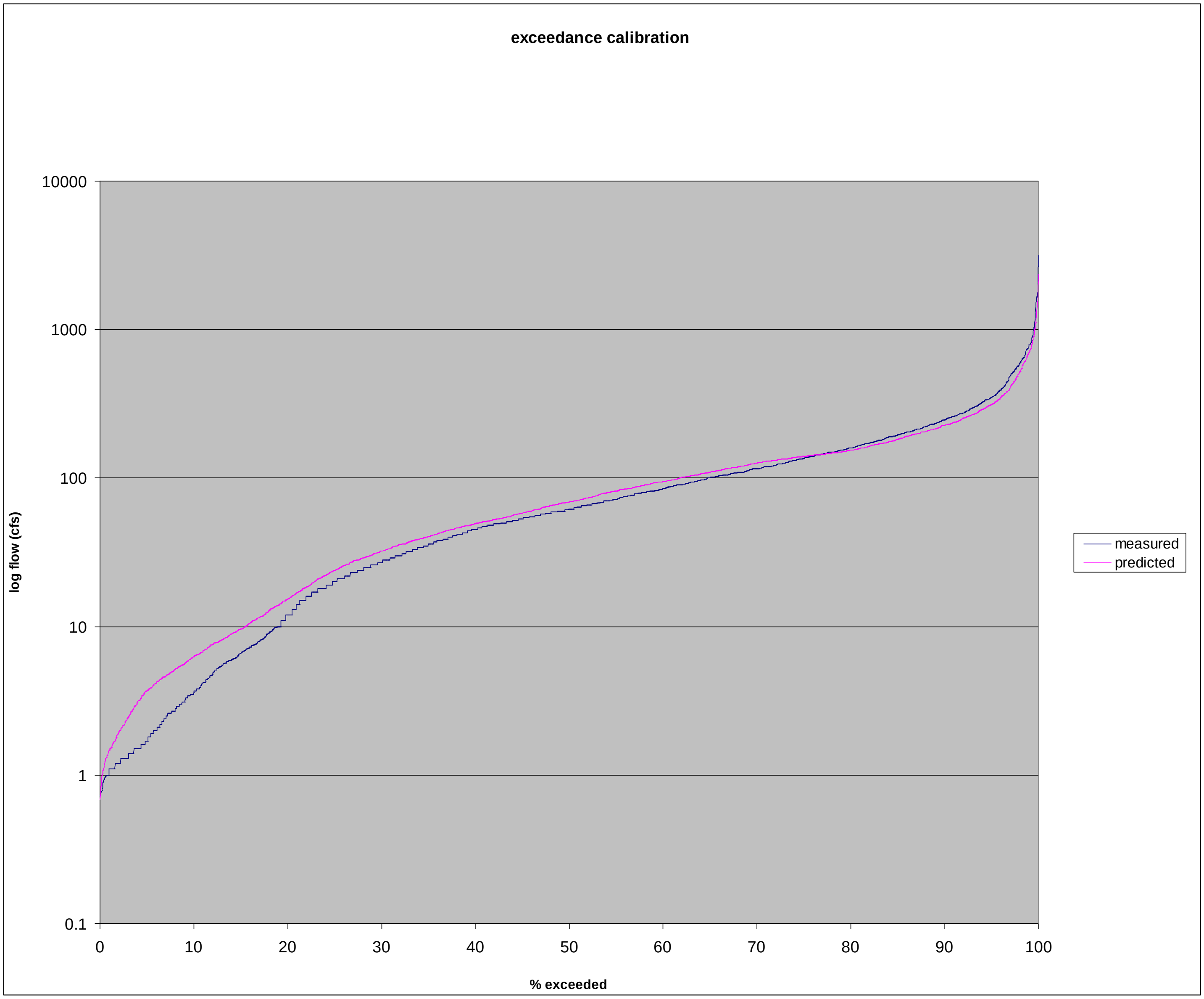

Figure 2. HSPF Flow Calibration at Haigh Road

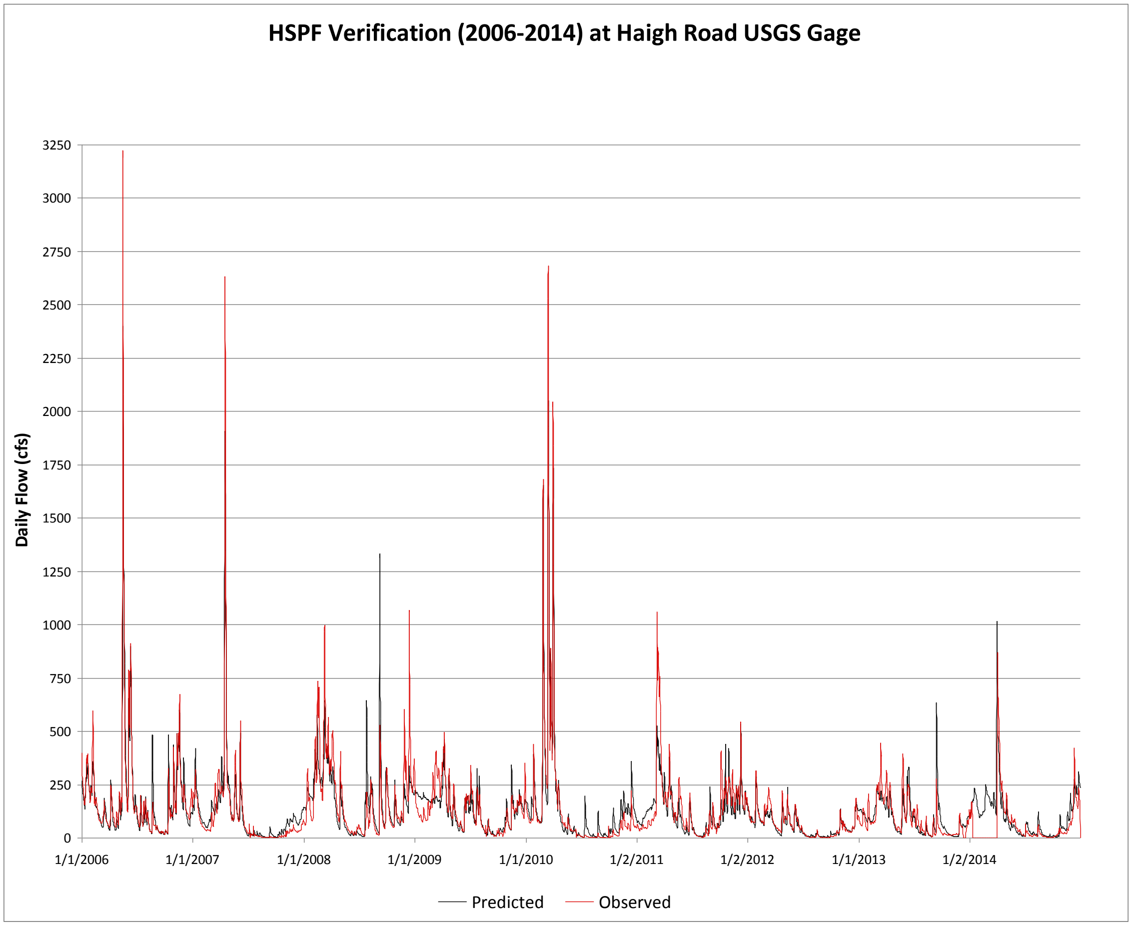

Figure 3. HSPF Flow Verification at Haigh Road

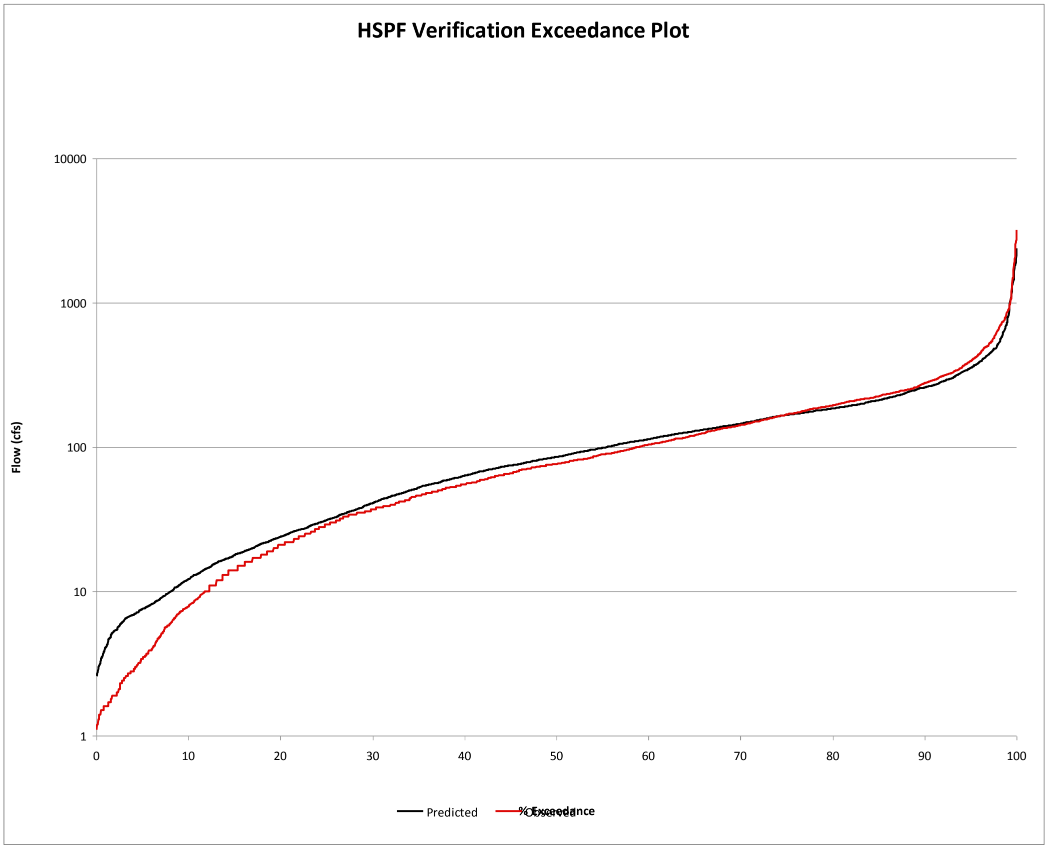

Figure 4. HSPF Flow Verification at Haigh Road

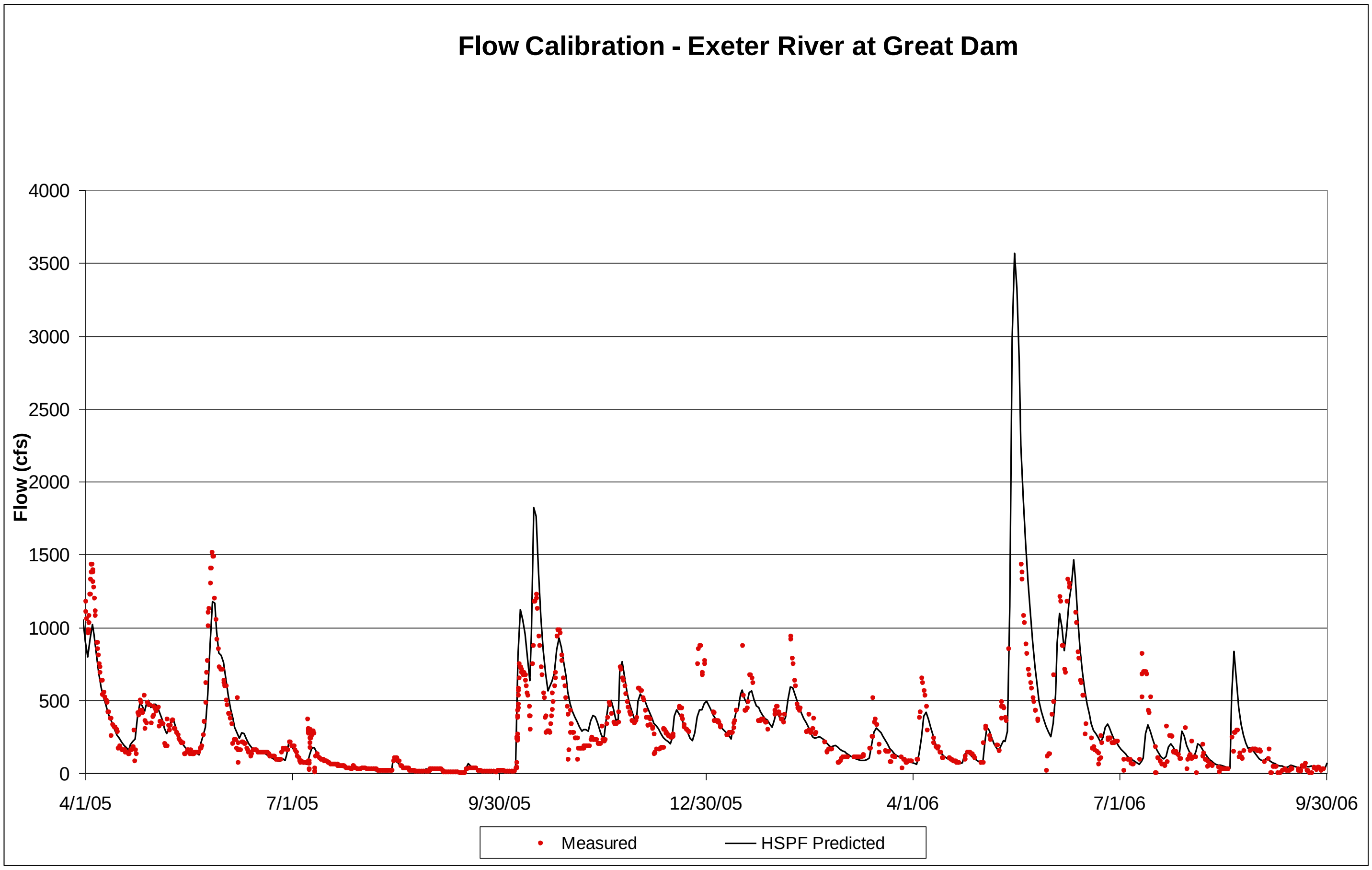

Figure 5. HSPF Flow Verification at Great Dam

Water Quality. Following the calibration and validation of the linked HSPF hydrologic and stream hydraulic models of the Exeter River, an HSPF water quality sub-model was developed to estimate buildup, wet weather wash-off and groundwater base flow inputs of total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN) from 14 land uses located within each of the 60 tributary sub-watersheds. Parameters and rate constants use to define water quality processes within each land use were adapted, with only minor adjustments, from a recent TMDL model of the Upper and Middle Charles River (USEPA, 2012). HSPF was also used to simulate downstream transport, settling and other gains/losses of these parameters, due to biogeochemical processes occurring within the Exeter River, upstream of Great Dam.

A literature search was conducted for historical water quality data available for the Exeter River. However, only one year of monthly monitoring data at the Great Dam (NHDES, 2010) was found. Due to the small amount of monitoring data available at only one stream location, a full WQ calibration was precluded. However, as a WQ model check, daily HSPF predictions for TSS, TP and TN concentrations at Great Dam were averaged over 2010 and compared to the average of the 2010 monthly monitoring data at the same location (March through December). During 2010, the average observed TSS, TP and TN concentrations at Great Dam were found to be 2.19, 0.026 and 0.534 mg/l, respectively. On an annual basis in 2010, the daily HSPF WQ predictions at Great Dam for TSS, TP and TN were found to be 2.43, 0.032 and 0.405 mg/l, respectively. These results suggest relative error values of 11% for TSS, 23% for TP and -24% for TN. These error levels are within guidelines given for HSPF stream water quality models in Donigian (2002) and are deemed acceptable for the current HSPF application for assessment of relative water quality impacts of climate change scenarios.

REFERENCES:

A.S. Donigian, 2002. WATERSHED MODEL CALIBRATION AND VALIDATION: THE HSPF EXPERIENCE, Aqua Terra Consultants, Mountain View, CA.

MADEP and USEPA Region 1, 2007. Final Total Maximum Daily Load for Nutrients In the Lower Charles River Basin, Massachusetts. Massachusetts Department of Environmental Protection, Worcester, MA.

NHDES, 2010. Water Quality Monitoring Data at Great Dam.

Appendix AS2

Land Use Change in the Watershed

(Note: even though labeled Draft, this is final version)

Geosyntec consultants

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Memorandum

Date: 5 February, 2014

To: Paul Kirshen

From: Robert Roseen, Renee Bourdeau, Chad Yaindl, Julia Ryan, Geosyntec Consultants

Subject: Build-out Analysis Methodology and Results

The purpose of this memorandum is to summarize the methodology and results of the build-out analysis for the Exeter River watershed. The goal of a build-out analysis is to determine 1) how much land in a town or watershed is available for development, 2) what type of development will be permitted on that land, and 3) how much development there will ultimately be. Goals 1 and 2 are met by analyzing trends in developed land and goal 3 is met by analyzing population trends and existing regional build-out and master plans.

Historic and future developable land was calculated from land use layers provided by New Hampshire GRANIT. Population trends were analyzed based on data from the US Census Bureau. The trends were projected forward to years 2030, 2050, and 2070 to determine an expected amount of future development. Fuzzy analysis techniques in GIS were used to create "development potential" coverage maps to predict where future development may occur.

DEVELOPED LAND TRENDS AND PROJECTIONS

Historic land use maps from New Hampshire GRANIT were used to determine the amount of developed land in 1964, 1974, 1998 and 2005. The land use maps were classified into three types of developed land: residential, industrial/commercial, and roads. The acreage of each developed land use class, using zonal statistics in GIS, was calculated for each of the four years. In 1962, approximately 86% of the developed land in the watershed was zoned residential, 87% in 1974, 90% in 1998 and 89% in 2005; whereas, industrial and commercial land represented 14% in 1962, 13% in 1974, 10% in 1998 and 10% in 2005, as presented in Table 1. In 1962, the ratio of residential development to commercial development was 6 acres to 1 acre. In 1974, the ratio was 7:1 (residential acres to commercial acres) and 9:1 in both 1998 and 2005.

Table 1. Historic Acreage of Residential and Industrial/Commercial Developed Land

Year	Total Developed Land (acres)	Total Residential Land (acres)	Total Industrial/ Commercial Land (acres)
1962	3759	3221	538
1974	5579	4876	703
1998	12105	10879	1226
2005	13662	12275	1386

For each of the developed land uses, the acreage over time was plotted and a linear trend was fit to the data (Figure 1). That trend was then used to project estimated developed land for the years 2030, 2050, and 2070. Figure 1 shows the results of the projections for the three land use classes, along with the calculated trend and the associated R^2 value.

In order to predict where projected development will occur, the three developed land use classes must be related to zoning classifications. A zoning class does not exist for roads and is typically a function of developed land, the amount of road development needs to be allocated between residential and industrial/commercial land use. Based on the projected trends of residential and industrial/commercial development, the ratio between the two classes is approximately 10 residential acres for every 1 industrial/commercial. Therefore, the acres of projected road development is divided among residential and industrial/commercial based on the 10:1 ratio.

Using the development trends from Figure 1, the projected acreage of developed residential and industrial/commercial was calculated and is presented in Table 2. The average rate of residential development from 1974 to 1998 was 250 acres per year, and trends show a decrease to 199 acres per year between 1998 and 2005. Based on the development trends, the projected average residential development between 2005 and 2070 is 209 acres per year. For industrial/commercial development, between 1974 and 1998, 22 acres per year was added and stayed consistent through 2005. Projected development trends show a decrease in the industrial/commercial development to 20 acres per year on average between 2005 and 2070.

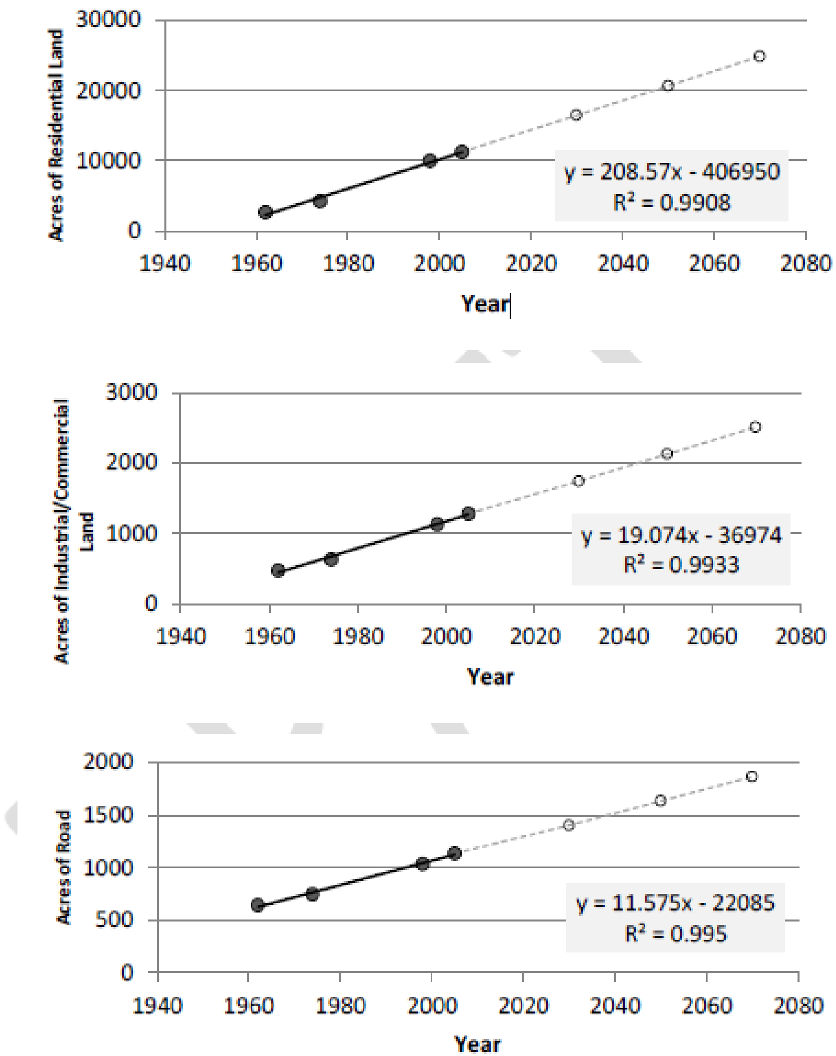


Figure 1. Trends and projections for the acreage of residential, industrial/commercial, and road land uses. Historic data indicated by solid line, solid circles, projected data indicated by dashed line/open circles.

Table 2. Historic and Projected Acreage of Residential and Industrial/Commercial Developed Land

Year	Total Developed Land (acres)	Total Residential Land (acres)	Total Industrial/ Commercial Land (acres)	Projected Additional Residential Land (since 2005) (acres)	Projected Additional Ind./Com. Land (since 2005) (acres)
1962	3759	3221	538	-	-
1974	5579	4876	703	-	-
1998	12105	10879	1226	-	-
2005	13662	12275	1386	-	-
2030	19595	17723	1872	5448	486
2050	24380	22105	2275	9830	888
2070	29164	26487	2677	14212	1291

DEVELOPMENT POTENTIAL MAP

In order to translate the build-out projection numbers to spatial data, a map of development potential was created. The development potential map assigns a score to each point within the watershed according to several factors that dictate how likely that point is to experience development. Beginning with the highest scores, areas of progressively lower score are selected for development until the total projected developed area has been attained.

Table 3 lists the factors included in the development potential analysis. Each of these factors was represented by a GIS shapefile or coverage. Each factor was rasterized and then transformed to a "fuzzy analysis" factor. Fuzzy analysis is a GIS Spatial Analyst tool which allows one to overlay rasters that represent weighting of individual factors, to produce an overall weighting raster. Each individual factor ranges from 0-1, and the resulting weight raster also ranges 0-1. The individual factors are multiplied at each raster cell, meaning that if any individual factor is 0 (e.g., a location that is already developed, or within a wetland, etc.), the overall resulting weight will be 0. Table 4 describes how each individual factor was weighted.

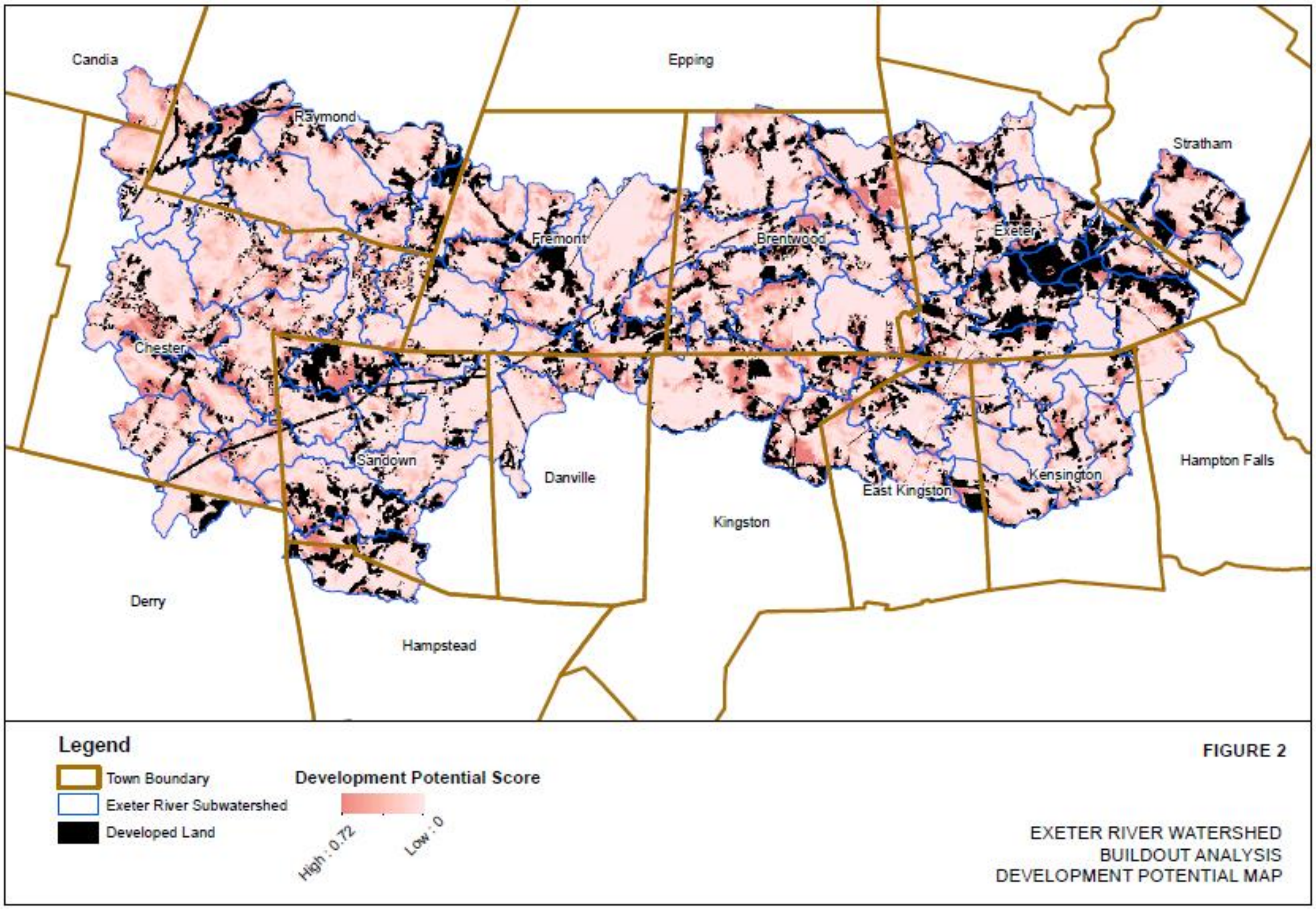
Table 3. Factors and Methods used to calculate development potential.

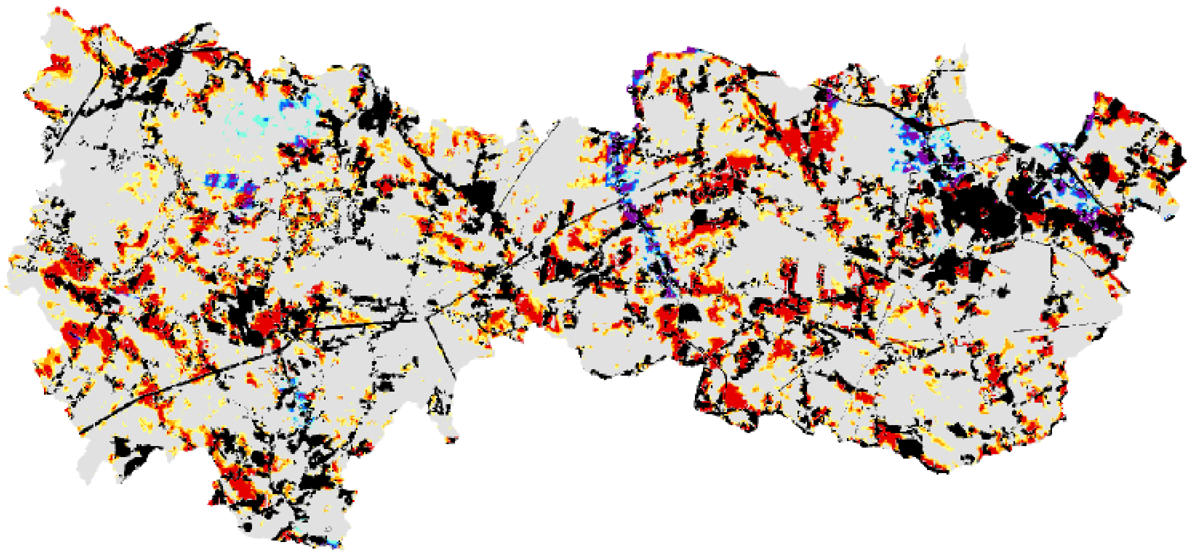
Data Layer	Source	Fuzzy Membership
Currently Developed Land	Land Use. NH GRANIT	Binary (0 if developed, 1 if undeveloped)
Proximity to Developed Land	Land Use. NH GRANIT	MSSmall (Transitions from 1 at small values to 0 at large values)
Conservation Easement	New Hampshire Conservation/Public Lands. NH GRANIT	Binary (0 if inside polygon, 1 if outside)
Distance to Major Road	NH Public Roads. NH GRANIT	MSSmall (Transitions from 1 at small values to 0 at large values)
Distance to Wetlands	New Hampshire Wetlands Base Map. NHDES	MSLarge (Transitions from 0 inside or at small distances to 1 at large values)
Distance to Stream/River	National Hydrography Dataset. USGS.	MSLarge (Transitions from 0 inside or at small distances to 1 at large values)
Topographic Slope	Digital Elevation Model. USGS.	MSSmall (Transitions from 1 at small values to 0 at large values)

Figure 2 shows the resulting fuzzy analysis "development potential" weighting raster. The total acreage associated with each score for each zoning type was calculated and plotted in Figure 3. From Figure 3, an estimated development potential score can be estimated for each projection of additional residential and industrial/commercial land.

By selecting all areas with development potential scores greater than the target scores shown on Figure 3, the locations of the projected development can be plotted spatially, as shown in Figure 4.

The total projected development expected in each of the Exeter River Subwatersheds has been summarized in tables included with this memorandum as Attachment 1. These tables are intended to be used to update the existing HSPF and SWMM models to reflect buildout conditions.


Candia
Epping
Raymond
Stratham
Fremont
Brentwood
Exeter
Chester
Sandown
Danville
Kingston
East Kingston
Kensington
Hampton Falls
Derry
Hampstead
Legend
Town Boundary
Exeter River Subwatershed
Developed Land
Development Potential Score
High : 0.72
Low : 0
FIGURE 2
EXETER RIVER WATERSHED
BUILDOUT ANALYSIS
DEVELOPMENT POTENTIAL MAP



Legend

- Developed Land (2005)
- Projected Residential (2030)
- Projected Residential (2050)
- Projected Residential (2070)
- Projected Industrial/Commercial (2030)
- Projected Industrial/Commercial (2050)
- Projected Industrial/Commercial (2070)

FIGURE 4

EXETER RIVER WATERSHED
BUILDOUT ANALYSIS

LOCATION OF PROJECTED RESIDENTIAL
AND INDUSTRIAL/COMMERCIAL DEVELOPMENT
FOR 2030, 2050, AND 2070

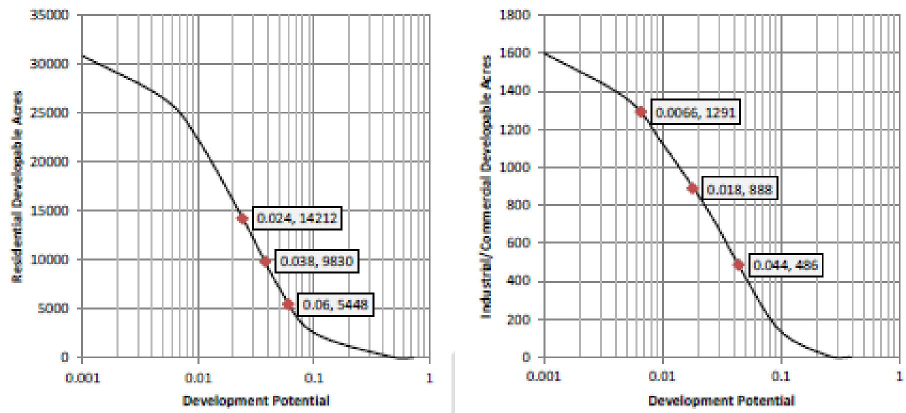


Figure 3. Total area above given development potential score for residential (left) and industrial/commercial (right) land uses. Target development potential scores and projected acreages for the three projected years (2030, 2050, 2070) are indicated by the diamond markers.

POPULATION TRENDS AND PROJECTIONS

In 2010, approximately 113,982 lived in the Exeter River Watershed. Table 4 shows the population of the towns intersecting the Exeter River watershed from 1960 through 2010. Data was obtained from the US Census Bureau and the New Hampshire Office of Energy and Planning. The following formula was used to determine the annual percent growth rate for each decade:

$$r = \left(\frac{P_t}{P_0}\right)^{1/t} - 1$$

where r is the annual percent growth rate, P_t is the population at time t, and P_0 is the population at the previous time step. Table 5 shows the computed annual percent growth rates for each census decade. The growth rate has decreased considerably since its peak between 1970-1980. For this reason, we will not use an average growth rate, but instead will project the most recent growth rate (2000-2010, 0.59%/yr) forward. The predicted population in 2030 is 128,077 persons.

Table 4. US Census Bureau Population of towns intersecting Exeter River watershed.

TOWN	1960	1970	1980	1990	2000	2010
Candia	1490	1997	2989	3557	3911	3909
Raymond	1867	3003	5453	8713	9674	10138
Chester	1053	1382	2006	2691	3792	4768
Derry	6987	11712	18875	29603	34021	33109
Hampstead	1261	2401	3785	6732	8297	8523
Sandown	366	741	2057	4060	5143	5986
Fremont	783	993	1333	2576	3510	4283
Danville	605	924	1318	2534	4023	4387
Kingston	1672	2882	4111	5591	5862	6025
Brentwood	1072	1468	2004	2590	3197	4486
East Kingston	574	838	1135	1352	1784	2357
Kensington	708	1044	1322	1631	1893	2124
Exeter	7243	8892	11024	12481	14058	14306
Hampton Falls	885	1254	1372	1503	1880	2236
Stratham	1033	1512	2507	4955	6355	7255
TOTAL	27,599	41,043	61,291	90,569	107,400	113,892

Table 5. Annual percentage population change

	Total Population	% Change per Year
1960	27,599	-
1970	41,043	4.05%
1980	61,291	4.09%
1990	90,569	3.98%
2000	107,400	1.72%
2010	113,892	0.59%

* * * * *

ATTACHMENT 1. Summary Tables of Expected Increases in Development since current (2005) levels.

Subwatershed ID	Projected Additional Residential Acres 2030	2050	2070	Subwatershed ID	Projected Additional Residential Acres 2030	2050	2070
BB1	38.54	81.58	138.10	ET7	12.53	52.50	112.08
BB2	292.98	398.44	459.22	ET8	43.98	78.27	120.12
BLR1	265.55	404.36	554.27	FB1	95.77	168.36	232.21
BLR2	214.95	308.11	410.50	FB2	105.46	150.86	198.63
BLR3	256.33	384.49	505.80	FB3	149.21	280.21	421.62
DB1	166.00	279.27	394.66	GB1	54.15	88.20	112.56
DB2	129.58	272.88	424.22	GB2	70.23	122.96	201.94
DB3	91.04	165.53	226.06	GB3	16.55	45.40	96.24
DBB1	46.35	85.84	124.14	GB4	57.93	103.34	154.88
ER1	24.12	28.14	30.50	GB5	58.64	95.53	149.21
ER10	195.56	303.15	398.44	HB1	13.01	30.98	59.12
ER11	25.54	61.72	126.51	LR1	80.40	130.29	168.13
ER12	5.20	28.14	61.24	LR2	19.86	46.82	76.85
ER13	34.05	74.49	126.51	MB1	98.84	179.00	250.42
ER14	67.87	126.98	212.35	MB2	83.71	149.21	205.25
ER15	204.07	314.74	452.59	NB1	36.18	62.19	90.09
ER2	132.18	196.27	266.73	PM1	10.40	18.44	29.56
ER3	93.40	141.17	193.90	PM2	147.55	224.88	290.14
ER4	280.45	421.62	572.25	PP1	106.65	204.31	306.93
ER5	150.39	213.53	273.12	PP2	124.38	198.87	261.06
ER6	107.12	216.84	329.40	SQ1	30.98	51.31	78.51
ER7	81.11	153.70	245.21	SQ2	10.40	11.11	12.06
ER8	78.03	218.49	362.50	SS1	67.16	155.59	282.10
ER9	58.41	115.87	186.81	TB1	221.33	412.16	575.32
ET1	86.78	146.84	213.53	TB2	257.51	376.93	528.50
ET2	65.03	148.03	228.19	WB1	146.37	289.43	512.42
ET3	34.76	86.07	161.98	WLB1	35.47	86.55	182.79
ET4	30.50	87.26	187.52	WLB2	100.26	199.81	310.24
ET5	12.30	43.98	109.48	WW1	3.55	3.78	4.73
ET6	12.06	43.98	103.57	YB1	105.23	165.05	222.99

Climate Adaptation Plan for Exeter (CAPE)
5 February 2014
Page 12

	Projected Additional Industrial/Commercial Acres				Projected Additional Industrial/Commercial Acres		
Subwatershed ID	2030	2050	2070	Subwatershed ID	2030	2050	2070
BB1	29.56	66.45	88.91	ET7	1.18	13.48	32.16
BB2	17.50	22.23	24.12	ET8	0.00	0.00	0.00
BLR1	6.86	11.11	13.71	FB1	17.73	41.38	105.94
BLR2	0.00	0.00	0.00	FB2	0.00	0.00	0.00
BLR3	13.24	18.92	21.52	FB3	0.00	0.00	0.00
DB1	0.00	0.00	0.00	GB1	0.00	0.00	0.00
DB2	53.44	70.70	75.43	GB2	0.00	0.00	0.00
DB3	49.42	97.90	124.62	GB3	0.00	0.00	0.00
DBB1	48.71	98.84	124.62	GB4	0.00	0.00	0.00
ER1	0.00	0.00	0.00	GB5	0.00	0.00	0.00
ER10	0.00	0.00	0.00	HB1	0.00	0.00	0.00
ER11	0.00	0.00	0.00	LR1	0.71	5.44	12.30
ER12	0.00	0.00	0.00	LR2	34.76	67.16	96.24
ER13	5.20	14.19	23.88	MB1	0.00	0.00	0.00
ER14	0.00	0.00	0.00	MB2	0.00	0.00	0.00
ER15	5.91	7.33	7.33	NB1	24.59	48.48	86.78
ER2	0.00	0.00	0.00	PM1	13.24	28.38	46.11
ER3	0.00	0.00	0.00	PM2	17.97	19.63	19.86
ER4	42.80	68.34	85.60	PP1	0.00	1.42	2.36
ER5	0.00	0.00	0.00	PP2	3.07	8.51	18.92
ER6	0.00	0.00	0.00	SQ1	0.00	0.00	0.00
ER7	0.00	0.00	0.00	SQ2	0.24	0.24	0.24
ER8	0.00	0.00	0.00	SS1	13.71	19.86	21.05
ER9	1.89	1.89	2.36	TB1	0.71	1.89	2.13
ET1	8.99	9.46	9.93	TB2	6.15	7.09	8.04
ET2	0.00	0.00	0.00	WB1	25.07	39.73	46.11
ET3	4.73	22.46	60.06	WLB1	0.00	0.00	0.00
ET4	31.69	65.50	104.52	WLB2	0.24	0.24	0.24
ET5	0.00	0.00	0.00	WW1	5.44	10.88	17.50
ET6	0.00	0.00	0.00	YB1	0.00	0.00	0.00

Appendix AS3

Climate Change Values for HSPF

As described in Appendix AS1, HSPF requires hourly values of meteorological information. Measured values were available for all for the calibration and verification runs. To develop scenarios of future possible values, we relied upon monthly projections of temperature (T) and precipitation (P) from 8 General Circulation Models (GCM) and other non-GCM methods to obtain the other values.

P and T Projections. GCMs are detailed models of the inter-related atmosphere, land, and ocean systems that are driven by emission scenarios of greenhouse gas emissions. Different models from different organizations are used because of uncertainties in our understanding of the systems; no one model can be considered to be most representative of the systems. Because the GCMs have relatively large grid sizes (perhaps order of 100s of miles by 100s of miles), their projections have to be "downscaled" to smaller geographical areas before they can used in watershed modeling, We initially chose 8 GCMs for the Exeter watershed based upon past analysis of these being most representative of present and future climates in the area (Hayhoe, personal communication). These are listed in Table 1 and are the most recent available output from these models; the so-called CMIP5 runs. For each model, we considered two GHG emission scenarios over the 21st century, so-called RCP4.5 and RCP 8.5. The former is a moderate emission scenario, the latter the highest emission scenario. The monthly GCM projections were then obtained from the "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections" archived at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/, a joint project of the US Army Corps of Engineers, NCAR, USGS, Santa Clara University, Bureau of Reclamation, and others. They were obtained for the years 1970 – 2000 to represent present climate, 2025-2055 to represent 2040 and 2055-2085 to represent 2070; a climate period is generally represented by 30 year period to minimize impacts of shorter-term variations in meteorological conditions. These values were "downscaled" values for the Exeter watershed.

GCM #	GCM Name:
1	ccsm4.1.rcp45
2	cnrm-cm5.1.rcp45
3	csiro-mk3-6-0.1.rcp45
4	inmcm4.1.rcp45
5	ipsl-cm5a-lr.1.rcp45
6	miroc5.1.rcp45
7	mpi-esm-lr.1.rcp45
8	mri-cgcm3.1.rcp45

Table 1. GCMs

The 30 year moving averages of each GCM for each RCP were plotted in Figures 1 and 2. Six sets from the 16 scenarios were then chosen to be used in the HSPF simulation runs based upon their P and T values covering the widest ranges of possible P and T combinations. The final scenarios chosen are in Table 2. Those runs were then re-numbered and correspond to the flow values for the climate change scenarios in the main HSPF text.

30 year moving average 4.5 emission scenario

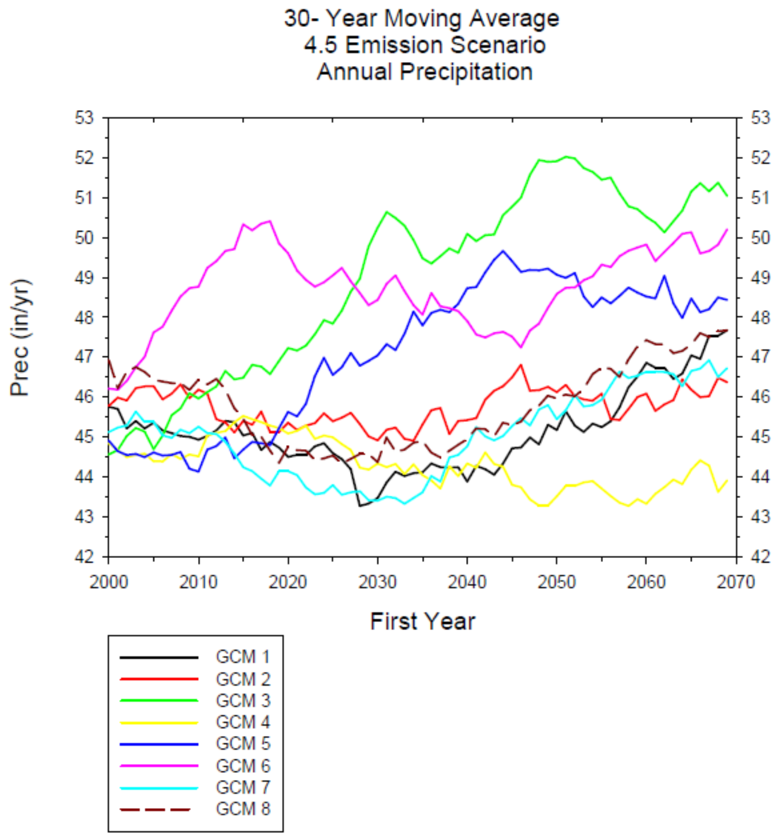


Figure 1. RCP 4.5 Emission Scenario

30 year moving average 8.5 emission scenario

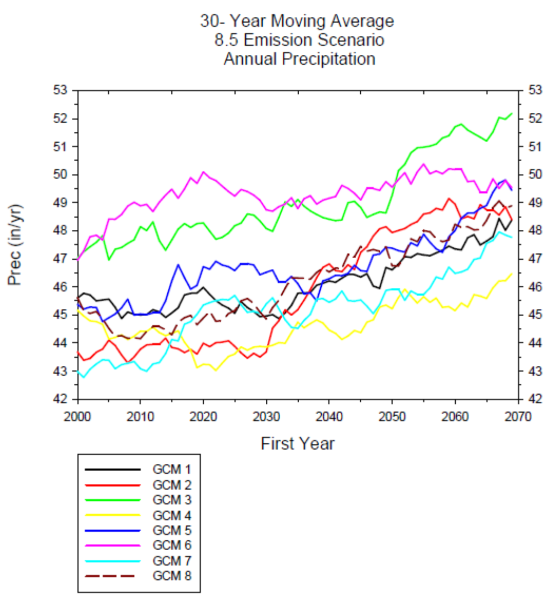


Figure 2. RCP 8.5 Emission Scenario

GCM Name and Scenario	GCM Run Number
ccsm4.1.rcp45	1
csiro-mk3-6-0.1.rcp85	2
inmcm4.1.rcp45	3
miroc5.1.rcp85	4
mpi-esm-lr.1.rcp85	5
csiro-mk3-6-0.1.rcp45	6

Table 2. Final GCM and RCP Scenarios and New Assigned Numbering

Because, however, hourly values of P and T were needed, we temporally downscaled the monthly P and T values using the methods described in the **Downscaling** section.

Downscaling of P, T and PET

We used the delta method as described in Johnson et al (2011) and used by many to develop the downscaled GCM projections for the watershed. We developed monthly scaling factors for each climate parameter (daily T average) and P) by examining the change in the future climate scenario GCM climate parameter compared to the baseline (1970-2000) GCM climate parameter.

The two future climate periods considered were: 2025-2055 (mid-century) and 2055-2085 (late century). For example, Change 1 for P by month is that month's E[GCM P for 2025-2055] divided by E[GCM P for 1970-2000]. Similarly, Change 2 for T is that month's E[GCM T for 1970-2000] subtracted from that month's E[GCM T for 2055-2085]. To develop the future scenario hourly climate data time series required by HSPF, we multiplied the 1970-2000 observed hourly P by the monthly specific GCM climate parameter Change 1. We added Change 2 to the 1970-2000 observed hourly T for that month.

To generate the present hourly PET distribution for the Hamon PET using historical daily Tave for each day, the historical hourly PET for each day is multiplied by the ratio of the daily PET from Hamon to the daily PET for that day.

To determine future hourly PET, we used the ratio of the projected monthly PET from Hamon using T GCM 2025-2055 to PET Hamon using T GCM1970-2000, then multiplied the daily PET Harmon for historical T by the ratio. Similarly, it was done for the period 2055-2085.

Johnson, T., Butcher, J., Parker, A., and Weaver, C., Investigating the Sensitivity of US Streamflow and Water Quality to Climate Change: The US EPA Global Change Research Program’s “20 Watershed” Project, JWRPM, on line, July 14, 2011.

Downscaling of Other Meteorological Parameters. Besides P, T and PET, HSPF also requires cloud cover, dewpoint temperature, solar radiation, and wind speed. While these may probably change under climate change, projections of them were not readily available. We could have estimated a dew point temperature change assuming the relative humidity remains the same as present, but decided not after determining that even with a 10% increase in dew point temperatures, the daily flows are essentially identical to those found using the measured dew point temperatures. Therefore for the climate change analyses with HSPF, we assumed the historic values of these parameters over the 30 year periods in the future remained the same as over the period 1970-2000. Thus, we assume the values in 2025 were the same as the values in 1970, values in 2026 same as 1971, etc and similarly for 2055 to 2085.

Appendix AS4

Calibration and Verification of HEC-HMS

This is summarized from Walker, A., Climate Change Flood Analysis in Exeter, NH, Department of Earth Science MS Research Project, University of New Hampshire, 2014.

Overview

Computer models of natural processes such as runoff generation or river flow among others are quite useful in their ability to simulate and evaluate conditions or events of interest that cannot be created or recreated in the field. However, in order for the results of such model simulations to have value, the model must be calibrated and verified. The process of calibrating a model of natural processes consists of recreating several historically observed events or datasets, adjusting model parameters as necessary to maximize similarities between observed and simulated data. Ideally, the range of calibration events should approximate the range of events over which the model will be utilized. Upon successful calibration, a model is subjected to verification, in which the model is used to recreate a final historical event that was not used during calibration. This verification process ideally ensures that no event-specific biases affected the model's calibration and that the model can be used to produce reliable output under a variety of input conditions. In the case of the Exeter/Squamscott River watershed rainfall-runoff model, the HEC-HMS model was calibrated against three historically observed events and verified against a fourth event, all of which occurred during the period 2000-2013.

Calibration

The rainfall-runoff model was calibrated against three historical events, the Mother's Day event of May 2006, which approximated the 100-year flood, the Patriot's Day event of April 2007, which approximated the 50-year flood, and the April Fool's event of April 2004 event, which approximated the 5-year flood. While larger events, such as the 100-year flood under various future climate scenarios, and possibly smaller events, such as the 2-year or bankfull event, are expected to be simulated, the three calibration events represent a suitable range. The model could not be calibrated to larger events in particular as there are simply no historically observed datasets against which to calibrate; the Mother's Day event is the largest event on record in the Exeter/Squamscott River watershed. Together, these three calibration events adequately bracket the range of flood events that the HEC-HMS model will be expected to represent for the CAPE Project.

During the calibration process, the rainfall-runoff model used rainfall data observed during the three events at a meteorological gage located at the University of New Hampshire (UNH). The University is not located within the Exeter/Squamscott River watershed, but instead in the immediately adjacent Oyster River watershed. Ideally the historical rainfall data would have been observed within the modeled watershed, but unfortunately no rainfall data were recorded within the Exeter/Squamscott River watershed with sufficient temporal resolution to be useful during the calibration process. The UNH rainfall data, recorded at 1-minute intervals was used to drive the three calibration simulations. The resulting runoff hydrograph was compared against 15-minute streamflow data recorded at USGS gage

#01073587, the Exeter River at Haigh Road in Brentwood ("Haigh Road gage" or "USGS gage"). In addition, the simulated water levels in the Great Dam impoundment during the calibration events were compared against observed irregularly spaced water level readings taken at Great Dam during those three historical events.

Model Adjustments

Based on the process of calibrating the rainfall-runoff model, I made several adjustments or modifications to the initial rainfall-runoff model to maximize the correlation between observed and simulated conditions. In general, calibration simulations revealed that the initial model was failing to accurately recreate historical events in two ways – 1) not enough total runoff was occurring, and 2) peak runoff was occurring too high and too soon.

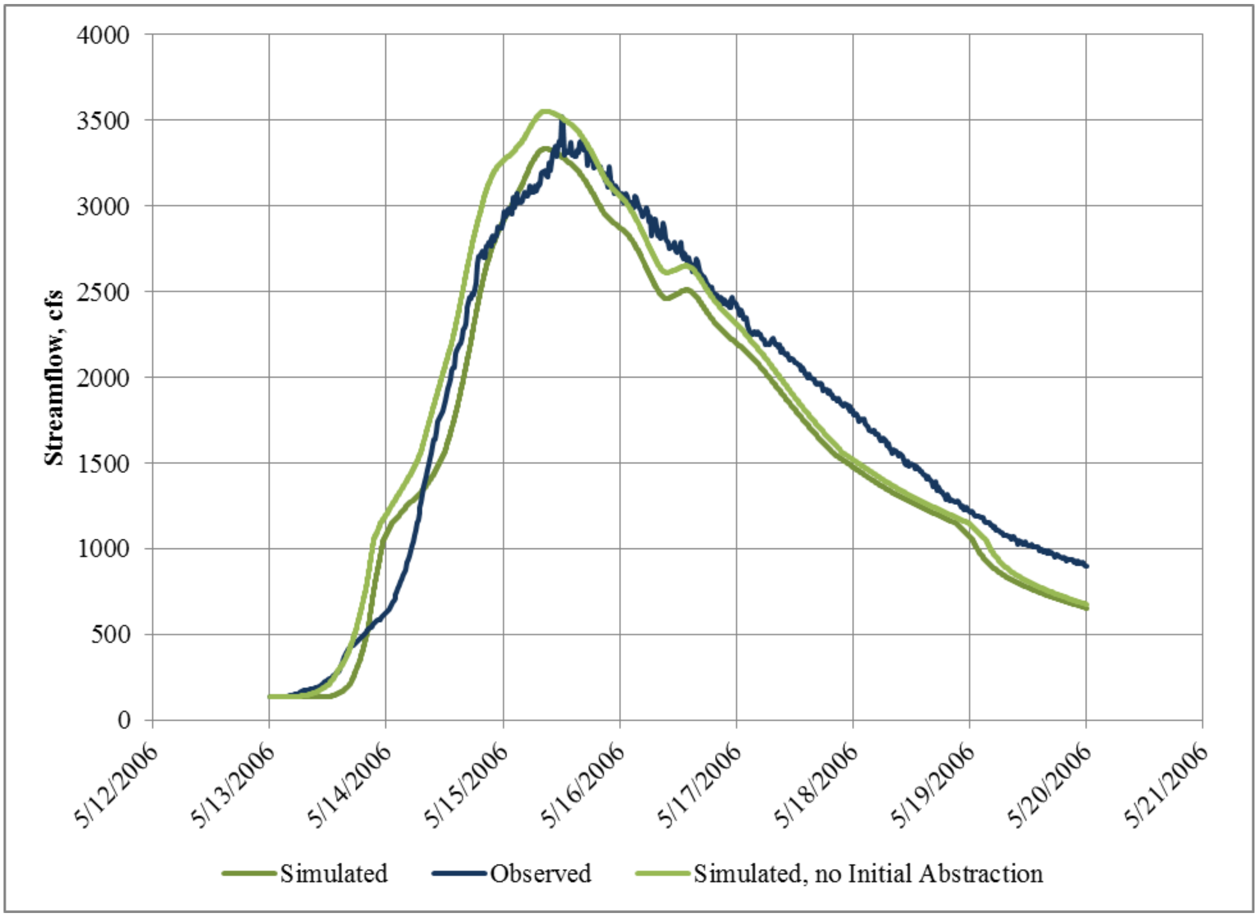
The first issue, insufficient total runoff, was addressed by increasing the CN of all 56 modeled sub-basins by 10%. The estimation of the initial curve numbers is documented in detail in the full report of Walker. As described in that section, initial curve numbers were developed based on geospatial datasets of soil type and land cover type consistent with the TR-20 methodology. While this methodology is routinely used to approximate a sub-basin's tendency to absorb rain vs. generate runoff, it is relatively simplistic based on its use of only three input variables. Certainly, an error of at least 10% could be expected. In this case, based on initial results from all three calibration simulations in which the Exeter/Squamscott River watershed was generating too little total runoff, the CNs of all 56 sub-basins were increased accordingly.

The second issue, peak runoff occurring too early and too high, was addressed through a number of adjustments. In general, this type of pattern suggests that the runoff is being allowed to move down-watershed too rapidly. The rate of lag between the occurrence of excess water accumulating on a soil surface and the arrival of that water downstream is a function of several parameters in a HEC-HMS model, including the lag time within each sub-basin, but also lag time in the reaches that connect sub-basin mouths and in the lag time associated with impoundments or reservoirs. To improve model performance regarding the timing and magnitude of peak runoff, I increased the lag times associated with all three lag types: sub-basin, reach, and reservoir routing. I adjusted the stage-storage-discharge relationships of modeled reservoirs to impound more water and to discharge it slower. I increased the Manning's value used to simulate floodplain friction in modeled reaches. I also increased the Time of Concentration in each sub-basin. Time of Concentration was originally estimated using the Mockus Lag Equation. However, other methods of estimating T_c are routinely used, including the NRCS TR-55 methodology. The TR-55 methodology estimates T_c in a more detailing manner, breaking up a flowpath through a sub-basin into separate components depending on the type of flow that is likely occurring. Developing an estimate of a sub-basin's T_c in this manner resulted in alternative T_c values, ranging from a 56% reduction to a 594% increase. On average, T_c throughout the Exeter/Squamscott River watershed slightly more than doubled, increasing by 135%. This combination of adjustments, increasing lag time within sub-basins, in river reaches, and in reservoir routing, resulted in significantly better correlation between observed and simulated peak runoff values and peak runoff timing. That improved correlation is clearly visible in the final calibration results presented in the following section.

Calibration Results

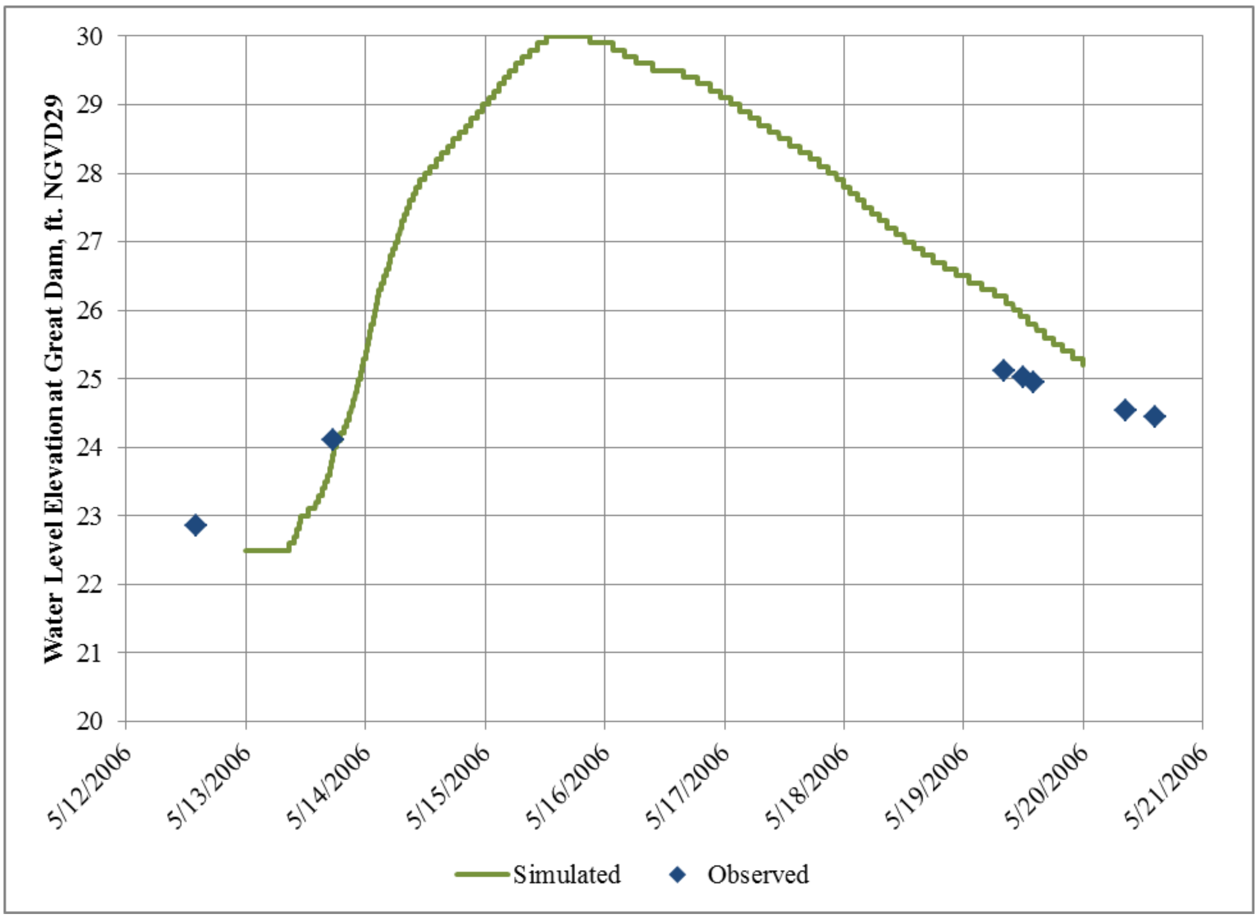
The Mother's Day Flood, approximating the 100-year flood, occurred for roughly seven days in the Exeter/Squamscott River watershed, beginning on May 13th, 2006 and receding by May 20th. The event, which continues to stand as the flood of record in the Exeter/Squamscott River watershed, saw a peak streamflow of 3,520 cubic feet per second (cfs) at the Haigh Road gage and a total of approximately 1.09 billion cubic feet of water over the length of the 7-day event. The observed USGS gage data is represented as the blue line in Figure 1 below.

Figure 1: Observed vs. Simulated Streamflow during the Mother's Day Flood



During the calibration process, this event was recreated with and without initial abstraction. Initial abstraction is the depth of rainfall that would be expected to be absorbed into the ground rather than contribute to runoff. The simulation of initial abstraction assumes that the ground is not already saturated. That may or may not have been the case during the Mother's Day flood event. More than an inch of precipitation had occurred in the week leading up to the event; the precise capacity of the ground to initially absorb the event's rainfall is unclear. For that reason, the calibration event was simulated both with and without initial abstraction as shown in Figure 1 with a dark green and light green line, respectively. The simulation with initial abstraction indicates a peak runoff rate at the Haigh Road gage location of 3,335 cfs, only 5.3% less than the observed peak rate. The total simulated runoff with initial abstraction incorporated was 1.00 billion cubic feet over seven days, only 8.3% less than observed. The simulation without initial abstraction indicates both a higher peak runoff rate of 3,553 or 0.1% more than observed, and a higher total runoff volume of 1.09 billion cubic feet, matching observed conditions. Whether or not any initial abstraction occurred during the historical event, it is clear that the HEC-HMS model quite accurately recreates historical runoff rates.

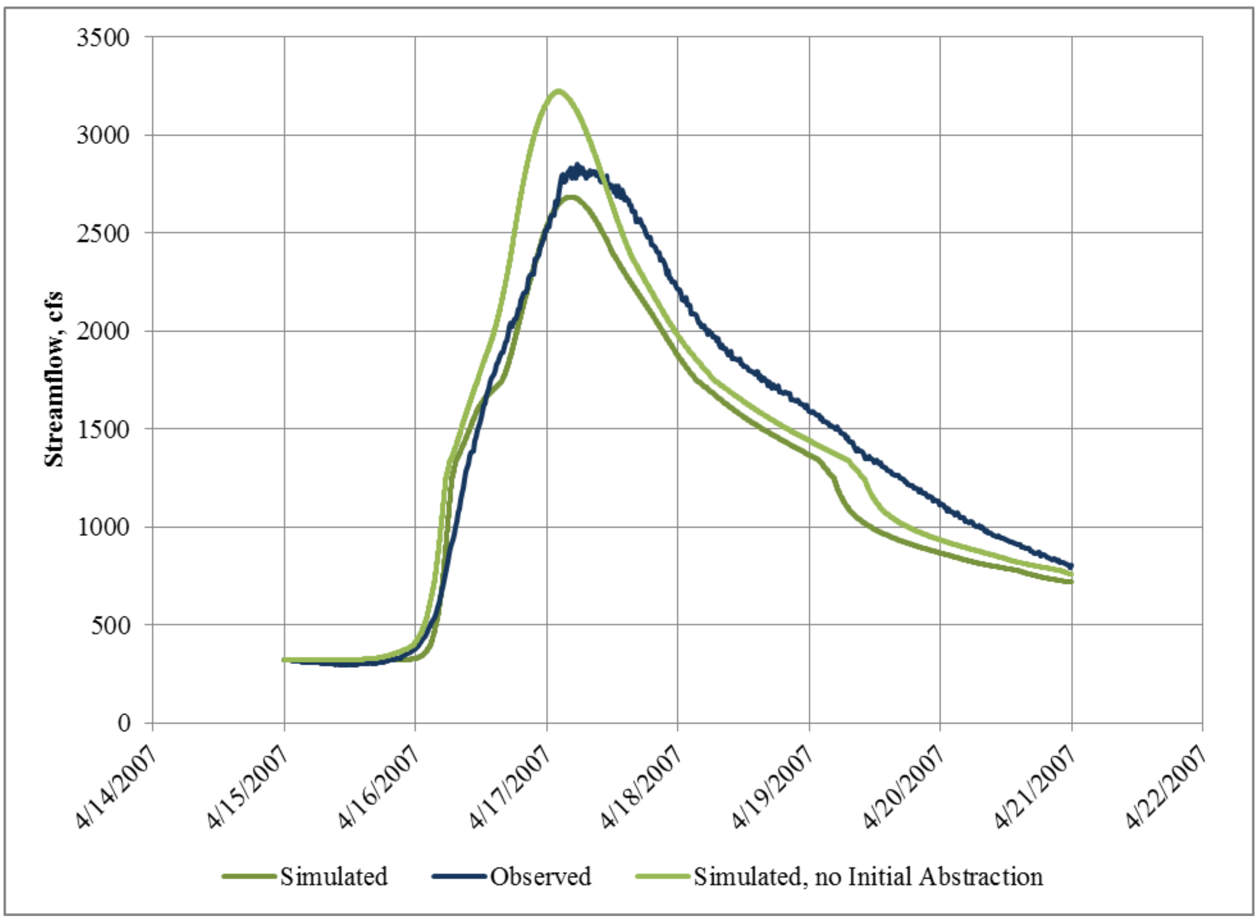
Figure 2: Observed vs. Simulated Water Level at Great Dam during the Mother's Day Flood



The simulated and observed water levels at Great Dam during the Mother's Day Flood were also compared during the calibration process, as shown in Figure 2. Unfortunately, given the severity of the flood, Town personnel were not able to access the water level gage at the dam's primary spillway during the event. However, based on the limited observed water levels at the beginning and end of the event, it appears that the model adequately captures the response of the Great Dam impoundment, generally to within one foot of observed conditions.

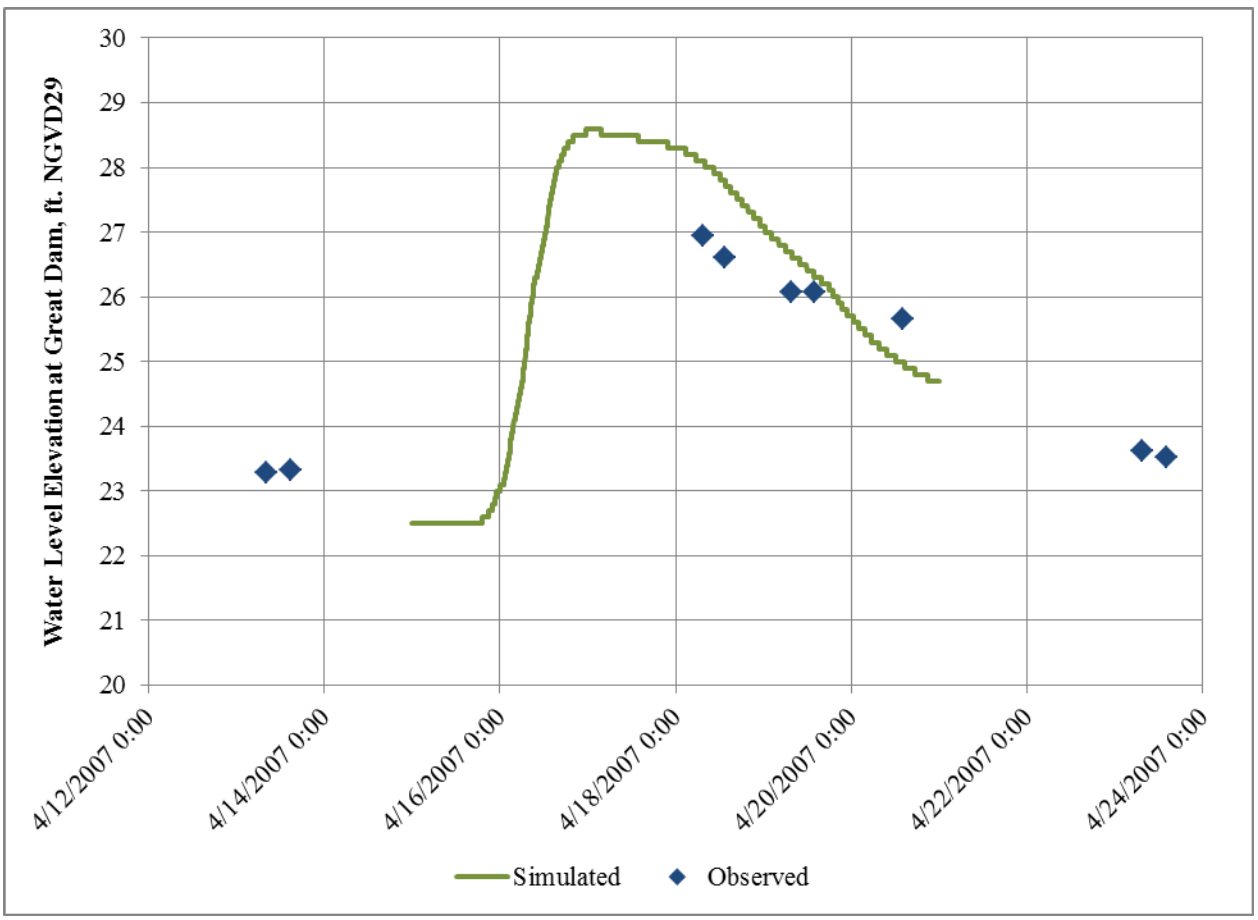
The Patriot's Day Flood, approximating the 50-year flood, occurred for roughly five days in the Exeter/Squamscott River watershed, beginning on April 16th, 2007 and receding by April 21st. The event saw a peak streamflow of 2,850 cfs at the Haigh Road gage and a total of approximately 711 cubic feet of water over the length of the 5-day event. The observed USGS gage data is represented as the blue line in Figure 3 below.

Figure 3: Observed vs. Simulated Streamflow during the Patriot's Day Flood



During the calibration process, this event was recreated with and without initial abstraction. As with the Mother's Day Flood of the following year, more than an inch of precipitation had occurred in the week leading up to the event and there was snow cover at the onset of the rainfall event; therefore, the precise capacity of the ground to initially absorb the event's rainfall is unclear. For that reason, the calibration event was simulated both with and without initial abstraction as shown in Figure 3 with a dark green and light green line, respectively. The simulation with initial abstraction indicates a peak runoff rate at the Haigh Road gage location of 2,684 cfs, only 5.3% less than the observed peak rate. The total simulated runoff with initial abstraction incorporated was 627 million cubic feet over five days, 11.8% less than observed. The simulation without initial abstraction indicates both a higher peak runoff rate of 3,223 or 13.1% more than observed, and a total runoff volume of 703 million cubic feet, only 1.1% less than observed conditions. Whether any initial abstraction occurred during the historical event, it is clear the HEC-HMS model quite reliably recreates the event's historical runoff rates.

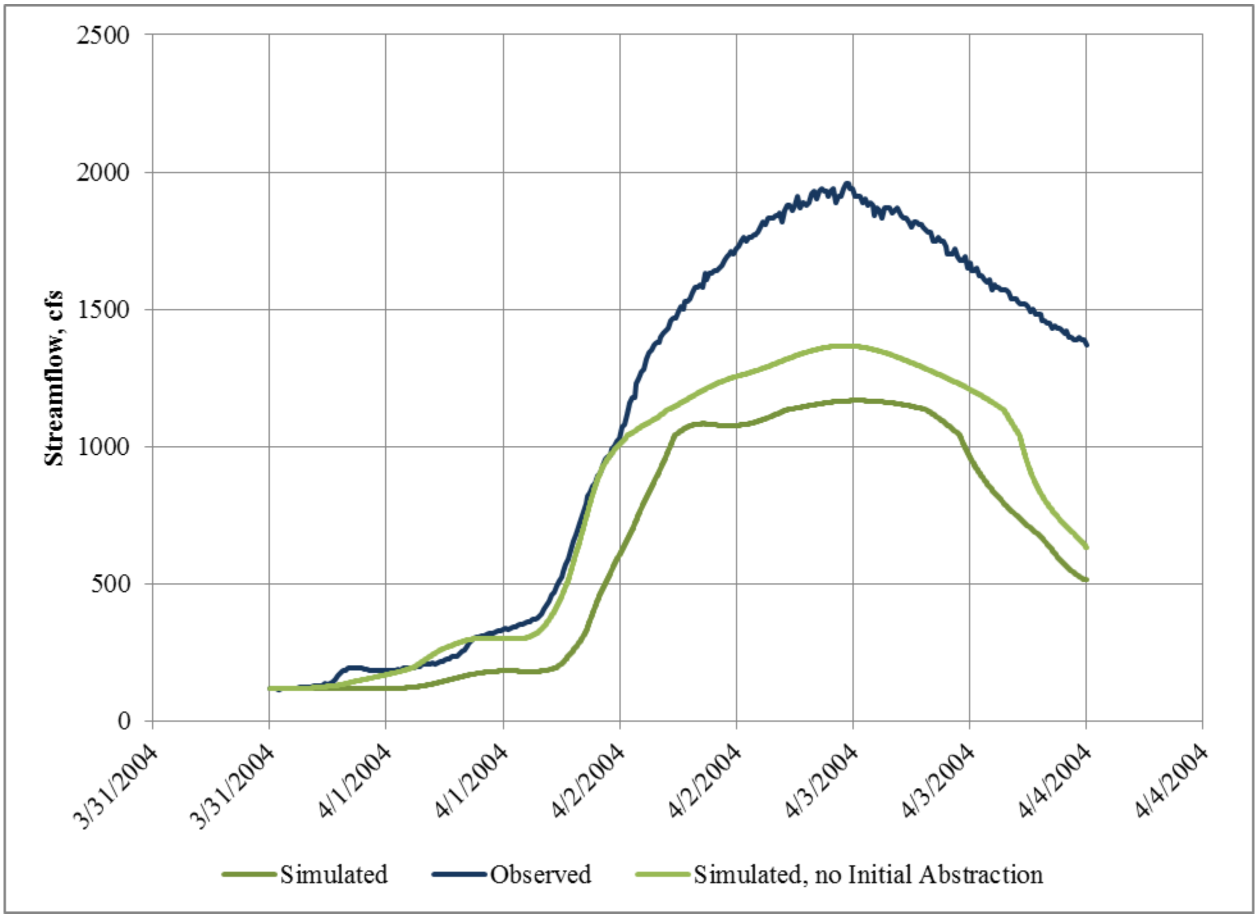
Figure 4: Observed vs. Simulated Water Level at Great Dam during the Patriot's Day Flood



The simulated and observed water levels at Great Dam during the Patriot's Day Flood were also compared during the calibration process, as shown in Figure 4. Unfortunately, as with the Mother's Day Flood, given the severity of the flood, Town personnel were not able to access the water level gage at the dam's primary spillway during the event. However, based on the limited observed water levels at the beginning and end of the event, it appears that the model adequately captures the response of the Great Dam impoundment, though perhaps slightly overestimating the peak water level.

The April Fool's Flood, approximating the 5-year flood, occurred over roughly three days in the Exeter/Squamscott River watershed, beginning on April 1st, 2004 and receding by April 4th. The event saw a peak streamflow of 1,960 cfs at the Haigh Road gage and a total of approximately 322 million cubic feet of water over the length of the 3-day event. The observed USGS gage data is represented as the blue line in Figure 5 below.

Figure 5: Observed vs. Simulated Streamflow during the April Fool's Day Flood



During the calibration process, this event was recreated with and without initial abstraction. More than an inch of precipitation had occurred in the preceding week, and there was snow cover at the onset of the rainfall event; therefore, the precise capacity of the ground to initially absorb the event's rainfall is unclear. For that reason, the calibration event was simulated both with and without initial abstraction as shown in Figure 5 with a dark green and light green line, respectively. The simulation with initial abstraction indicates a peak runoff rate at the Haigh Road gage location of 1,167 cfs, 40.4% less than the observed peak rate. The total simulated runoff with initial abstraction incorporated was 188 million cubic feet over five days, 41.6% less than observed. The simulation without initial abstraction indicates both a higher peak runoff rate of 1,367 or 30.3% less than observed, and a total runoff volume of 238 million cubic feet, 26.1% less than observed conditions. Unfortunately no water level observations were available for this event as the Town only began recording water levels consistently in 2005.

However, from Figure 5, it is clear that unlike the much larger Mother's Day and Patriot's day calibration events, the April Fool's model simulation does not capture the peak runoff hydrology of the Exeter/Squamscott River watershed particularly well. The rising limb of the simulated event matches quite well, particularly without incorporating initial abstraction, however the peak of the runoff event is not well recreated. This issue does not appear to be specific to this event, but rather an issue for the majority of smaller flood events. A review of other model outputs not portrayed in Figure 5 shed no light on the issue. In all likelihood, the issue is caused by the TR-20 methodology itself. TR-20 was not developed to recreate historical events and has been shown to do a relatively poor job under certain circumstances (Hodgkins et al., 2007). It appears that in the case of the Squamscott River, the TR-20 methodology at the heart of the rainfall-runoff model developed in support of this pilot project, performs admirably for large events on the order of the 50- to the 100-year flood, but is not particularly reliable for smaller events, such as the 5-year flood.

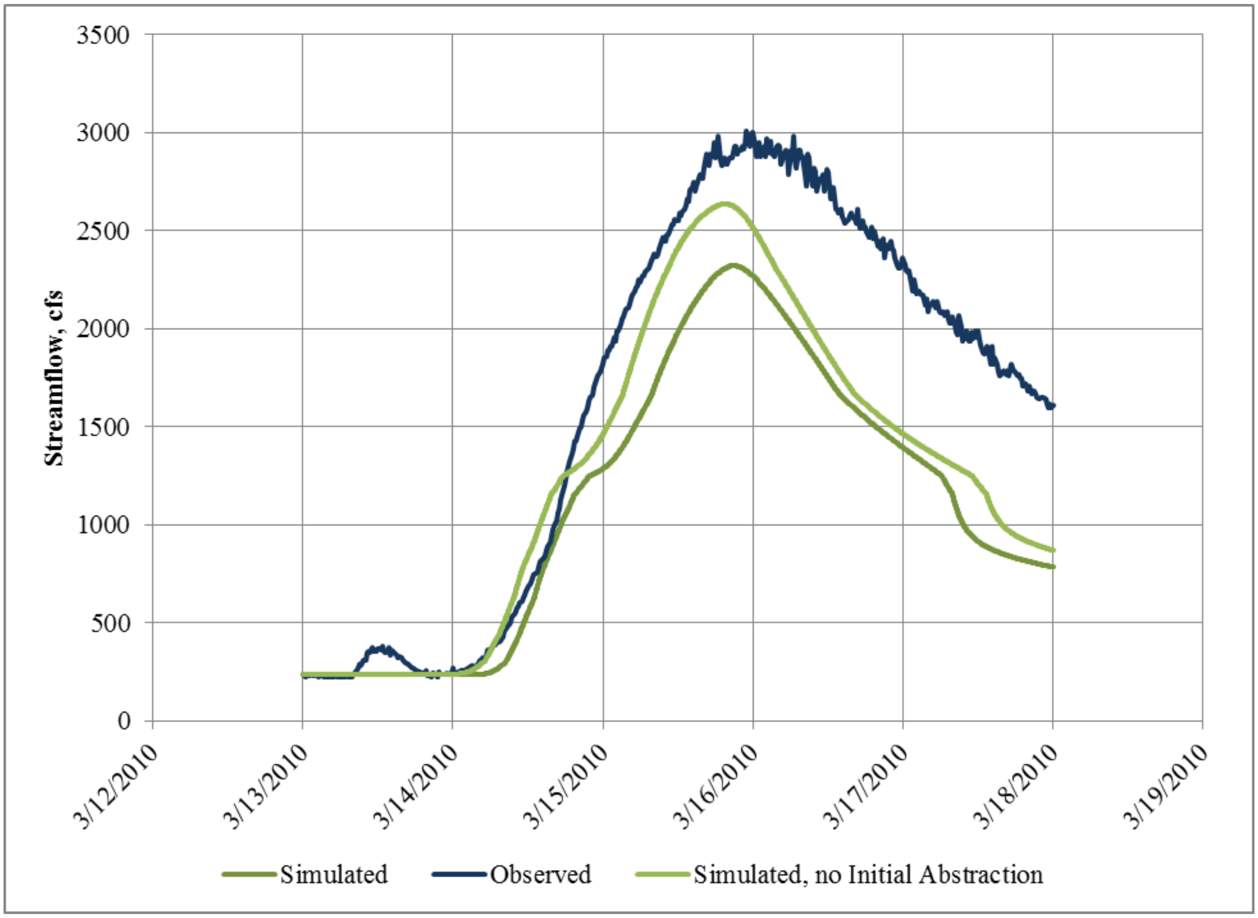
Verification

The calibrated rainfall-runoff model was then *verified* to ensure that no event-specific biases affected the model's calibration and that the model can be used to produce reliable output under a variety of input conditions. No additional modifications were made to the HEC-HMS model during this verification process. The verification run was conducted in much the same way as the three calibration runs, by simulating observed 1-minute rainfall data recorded at the University of New Hampshire gage and comparing model output against streamflow data observed at the Haigh Road gage.

The selected verification event, approximating a 20-year flood, occurred over a roughly 4-day period beginning on March 14th, 2010 and ending on March 17th. The event saw a peak streamflow of 3,010 cfs at the Haigh Road gage and a total of approximately 686 million cubic feet of water over the length of the 4-day event. The observed USGS gage data is represented as the blue line in Figure 6 below.

During the verification process, this event was recreated with and without initial abstraction. Several inches of rain had fallen during the two weeks leading up to the event, and it is highly likely that the ground was fully or near fully saturated at the onset of the rainfall event. While the verification event was simulated both with and without initial abstraction as shown in Figure 6 with a dark green and light green line, respectively, it is highly likely that the "no initial abstraction" conditions most closely represent the observed conditions. The simulation with initial abstraction indicates a peak runoff rate at the Haigh Road gage location of 2,322 cfs, 22.9% less than the observed peak rate. The total simulated runoff with initial abstraction incorporated was 463 million cubic feet over four days, 32.5% less than observed. The simulation without initial abstraction, highly likely to be more representative of actual conditions, indicates both a higher peak runoff rate of 2,637 or 12.4% less than observed, and a total runoff volume of 531 million cubic feet, 22.6% less than observed conditions.

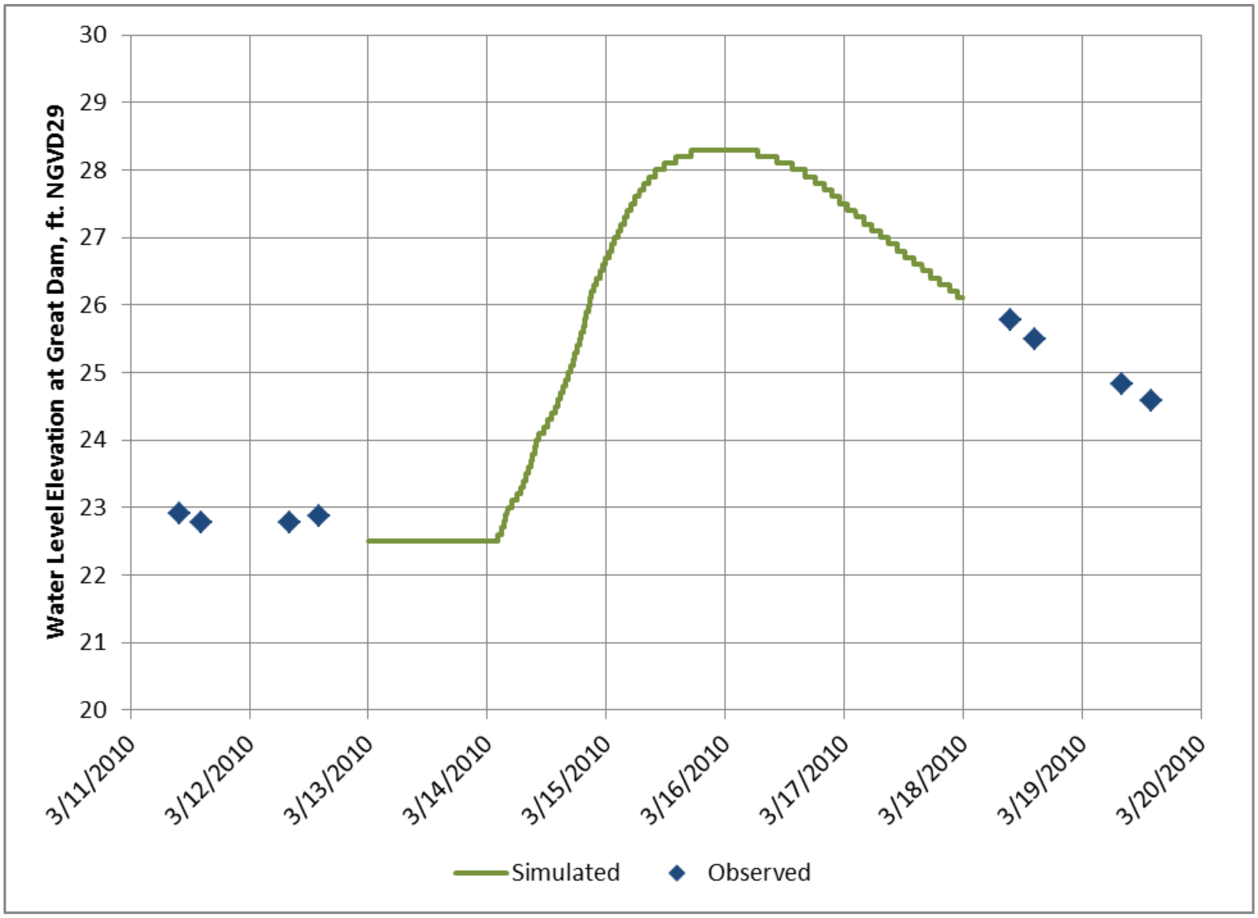
Figure 6: Observed vs. Simulated Streamflow during the March 2010 Flood



The simulated and observed water levels at Great Dam during the March 2010 flood were also compared during the verification process, as shown in Figure 7. Unfortunately, as with the Mother's Day and Patriot's Day Floods, given the severity of the flood, Town personnel were not able to access the water level gage at the dam's primary spillway during the event. However, based on the limited observed water levels at the beginning and end of the event, it appears that the model admirably captures the response of the Great Dam impoundment, generally to within half a foot.

The results of this verification run, shown in Figures 6 and 7, confirm the conclusions drawn from the calibration event, namely that the HEC-HMS rainfall-runoff model rather accurately captures the hydrology of the Exeter/Squamscott River watershed during large flood events, greater than the 25-year flood, but is less reliable during those flood events less than the 25-year flood.

Figure 7: Observed vs. Simulated Water Level at Great Dam during the March 2010 Flood



Appendix AS5

Calibration and Verification of HEC-RAS

As with the rainfall-runoff model, the HEC-RAS hydraulic river model was calibrated during the Removal Feasibility Study, but changes to the model during this pilot program and a broader range of simulated conditions required that the river model be recalibrated. Calibration of a HEC-RAS model ensures that simulated flood levels and other outputs are accurate and reliable under a variety of flow conditions. As with the rainfall-runoff model, calibration is achieved by recreating historically observed outputs by simulating historically observed inputs.

In this case, as the HEC-RAS model is to be used to evaluate the social and financial impacts of flooding in the Town of Exeter, it was important to ensure that the model reliably represents those outputs, particularly in the downtown area where such impacts are greatest. Water levels in that area are controlled primarily by Great Dam and the High Street bridge. For that reason, the HEC-RAS model was calibrated by recreating historically observed water levels at Great Dam under a variety of hydrologic conditions. Since 2005, the Town of Exeter has been maintaining a record of daily or sub-daily measurements of the depth of water over the primary Spillway of Great Dam. This dataset was readily converted to a record of water surface elevations so that they may compared to HEC-RAS model output.

In order to recreate these historically observed water levels, the HEC-RAS model needed to be driven by known inflow conditions. Streamflow data recorded by the USGS gage at Haigh Road in Brentwood served this purpose. Unfortunately, that dataset represents only approximately half of inflow to the Great Dam impoundment, the other half coming from the Little River, Great Brook, Mill Brook, Drinkwater Brook, and other smaller tributaries to the Exeter River downstream of the USGS gage. As no flow records exist for these tributaries, their inflow was approximated by extrapolating the USGS flow data based on their respective drainage areas in relation to that of the USGS gage. In this manner, the HEC-RAS model was calibrated by simulating historically observed inflow conditions and comparing the simulated water level to historically observed water levels at Great Dam.

There are many ways to execute that calibration process. One method would be to identify several flood events of various magnitudes, as was done with the rainfall-runoff model, and attempt to recreate historical observations at the dam. Unfortunately, during many large flood events, Town personnel cannot safely make observations of water level. Further, during smaller flood events, the storage capacity of the impoundment may result in lower peak water levels than would be simulated by constant flow rate HEC-RAS simulations. Instead, the HEC-RAS model was calibrated by attempting to recreate several "events" in which the water level recorded at Great Dam remained nearly constant over an extended period of time. Ultimately, 22 such events were identified over a range of hydrologic conditions, as discussed in the following section. The use of quasi-steady state events was also valuable because the backwater condtions were estimated for steady state conditions given the peak flood flows estimated in HEC-HMS.

Results

The HEC-RAS model was calibrated by attempting to recreate 22 individual "events" in which water levels at Great Dam remained nearly constant over an extended period of time. Those "events" span a wide range of water levels, ranging from 1.8 inches to 42.5 inches of flow over the dam's primary spillway. Three events were selected for each 5-inch range beginning with 0-5 inches and ending with 30-35 inches. Water levels beyond that depth are indicative of a significant flood event, and given the limited duration of the dataset (2005-present) and site access issues during large floods, there are relatively little water levels recorded beyond 35 inches, even fewer over a sustained period. Only one sustained "event" was identified beyond 35 inches, in which water levels remained at or near 42.5 inches for more than 24 hours. The inflow conditions used to drive the 22 calibration simulations were determined by taking the average of the daily streamflow rates observed at the upstream USGS gage over the course of each event. The water level, duration, and average inflow condition observed at the USGS gage for all 22 calibration events are presented in Table 3.

Table 3: HEC-RAS Model Calibration Targets

Water Level Range, in.	Avg. Water Level, in.	Start Date	End Date	Avg. Streamflow @ USGS gage, cfs
0-5	2.5	7/28/05	8/14/05	35
	1.8	8/18/05	9/15/05	14
	1.9	9/16/05	10/7/05	11
5-10	8.7	4/13/05	4/22/05	119
	8.3	5/11/05	5/22/05	104
	7.7	6/10/05	6/26/05	95
10-15	13.1	4/8/05	4/10/05	298
	14.5	10/10/05	10/12/05	352
	12.3	3/26/07	3/30/07	304
15-20	15.6	5/30/05	5/31/05	489
	16.5	6/5/07	6/6/07	429
	19.0	3/10/11	3/11/11	749
20-25	22.9	4/1/05	4/2/05	613
	21.4	10/26/05	10/27/05	651
	21.5	3/11/11	3/14/11	839
25-30	*28.2*	4/3/05	4/3/05	747
	28.3	4/4/05	4/5/05	866
	26.4	10/16/05	10/16/05	997

30-35	32.2	3/29/05	3/31/05	873
	30.3	4/3/05	4/4/05	889
	31.5	5/26/05	5/27/05	914
35-40	*No data available*			
40-45	42.5	4/19/07	4/19/07	1350
45-50	*No data available*			
50+	*No data available*			

The results of the 22 calibration simulations, including the simulated and observed water levels at the Great Dam spillway are presented in Table 4.

Table 4: HEC-RAS Model Calibration Results

Range	Observed Flow Depth, ft.	Simulated Flow Depth, ft.	Deviation	Avg. Deviation
	0.21	**0.42**	102%	
0-5	0.15	**0.22**	49%	57%
	0.16	**0.19**	20%	
	0.73	**0.94**	30%	
5-10	0.69	**0.86**	25%	27%
	0.64	**0.81**	27%	
	1.09	**1.09**	0%	
10-15	1.21	**1.16**	-4%	-5%
	1.02	**0.92**	-10%	
	1.30	**1.73**	33%	
15-20	1.38	**1.50**	9%	36%
	1.58	**2.62**	66%	
	1.91	**2.16**	13%	
20-25	1.78	**2.30**	29%	34%
	1.79	**2.89**	61%	
	2.35	**2.59**	10%	
25-30	2.36	**2.95**	25%	29%
	2.20	**3.33**	51%	
	2.68	**2.97**	11%	
30-35	2.53	**3.01**	19%	16%
	2.63	**3.08**	17%	
40-45	3.54	**4.16**	17%	17%
Average			27%	
Median			22%	

As indicated by Table 4, the model generally simulates water levels that are somewhat higher than those that were historically observed. Of the 22 calibration events, 19 overestimate the depth of flow at Great Dam; one matched historical observations to within 0.01 feet; and two underestimated flow depths. The HEC-RAS model's tendency to overestimate flow depths is likely due to a combination of two factors - 1) the inflows used to drive the calibration simulations are likely too high, and 2) HEC-RAS is only capable of simulating a single discharge coefficient for the dam though in reality that coefficient changes as the head over the spillway changes.

The first factor contributing to an overestimation of flow depths is the likelihood that the inflows used to drive the calibration simulations are also overestimated. As discussed in the preceding section, inflows used to represent the major tributaries to the Great Dam impoundment were estimated by extrapolating the USGS flow data based on their respective drainage areas in relation to that of the USGS gage. Developing the calibration inflows in this manner assumes that all tributaries are experiencing the same flow condition. When water levels at Great Dam are in excess of approximately 1-1.5 feet over the spillway, there is generally a flood ongoing or recently passed within the watershed.

So for many of the 22 calibration events, the average streamflow at the Haigh Road gage over the event duration generally represents only some portion of a flood hydrograph.

As revealed by the rainfall-runoff model, the Exeter River headwaters that discharges to the USGS gage generally experiences peak runoff rates significantly later over the course of a flood than the Little River, Great Brook, Mill Brook, and other smaller tributaries to the Great Dam impoundment. That pattern is likely due to the numerous small dams, large wetland presence, shallower watershed slopes, and longer flowpaths in that drainage than in other parts of the larger Exeter/Squamscott River watershed. So when the peak runoff rate is occurring at the USGS gage, flooding in most of the other tributaries has already started to recede. However, extrapolating inflow rates for those smaller tributaries from the USGS streamflow data assumes that all tributaries are peaking at the same time. So for those calibration events occurring during a flood, generally those with more than 1-1.5 feet of flow over the dam, the inflow used to drive those simulations is generally overestimated, resulting in overestimated flow depths as well. Unfortunately, there are no other streamflow datasets with which to calibrate the HEC-RAS model. The method used, while imperfect, represents the only meaningful way to calibrate the model. The results presented in Table 4 must instead be interpreted qualitatively against this inflow overestimation factor.

The second factor contributing to an overestimation of flow depths is the fact that HEC-RAS is only capable of simulating a single discharge coefficient for the dam though in reality that coefficient changes as the head over the spillway changes. Typically, flow over a dam's spillway and/or abutments, can be approximated by representing those structures as a weir as the HEC-RAS software is designed. Flow over a weir is calculated as a function of flow depth, weir length, and a coefficient of discharge, which reflects the relative impact of friction over the weir surface. In practice, that coefficient of discharge varies with flow depth; when flow depth is shallow, that coefficient is relatively high, but as flow depth increases, the influence of the weir surface decreases and the coefficient decreases accordingly. Unfortunately, HEC-RAS is not capable of capturing that dynamic pattern and instead uses a single coefficient of discharge.

Instead, a single discharge coefficient was selected that maximized the calibration results without representing the Great Dam inappropriately. HEC-RAS simulations, not presented in Table 4, indicate that a discharge coefficient of 3.6 would be required to reduce the average model error to 0%, although significant deviations between observed and simulated conditions would persist. Unfortunately, for a weir breadth of 3 feet such as with the Great Dam primary spillway, discharge coefficients are generally between 2.6 and 3.0 until flow depths exceed 4 feet. A discharge coefficient is simply not representative of real world conditions. For that reason, a discharge coefficient of 2.7 was ultimately selected, as it represented a reasonable representation of real world conditions under a significant portion of the hydrologic conditions for which the HEC-RAS model was intended for use. Note that the results presented in Table 4 were determined with a discharge coefficient of 2.7.

In addition to this calibration, the model was previously calibrated to 10, 50, 10 and 50 year events using FEMA discharge and water surface profiles in VHB (2013).

Appendix AS6

Flood Methods

MODELS

Two models were used in developing flood analyses for the CAPE project; one hydrologic (HEC-HMS) and one hydraulic/open-channel (HEC-RAS). Hydrologic and hydraulic (H&H) models are an approximation of a natural environment. Such models are based on dozens of assumptions as well as empirical averaging. In hydrologic modeling (rainfall-runoff, HEC-HMS), hypothetical storms with statistical precipitation depths, defined durations, and mathematical distributions (i.e., 6.0-inches of rainfall in 24-hours) are fictitious. Runoff depths generated from hypothetical storms are also a result of assumed and approximated values such as antecedent moisture conditions. No modeled storm or runoff will ever match the assumptions that define any specific model but do represent a reasonable estimation of stochastic events.

Hydraulic or open-channel modeling (HEC-RAS) used for this project is based on the flow input from the hypothetical HEC-HMS modeling. The input flow data is based on a modeled snapshot at the exact same time as the peak flow at Great Dam. Geometry is built from multiple sources, all with some level of accepted error. In addition to the any potential accumulated error from the hydrologic model, geometry, or other estimated/approximated parameters, it is important to understand that this hydraulic model is both one-dimensional and static (no cross-channel variations or time component). The model is based on a singular flow condition (from HEC-HMS results) and does not vary with time. Flooding results are instantaneous and do not evaluate duration of flooding or conditions beyond the model assumptions or spatial limits.

<u>HEC-HMS Models</u>

Only the 'COMPUTE' for FREQUENCY-STORMS (10, 25, 100) models as developed up by A.Walker (AW) were run by L.Mather. Please refer to AW documentation for specifics regarding HEC-HMS model development.
Four separate models were created for the CAPE project; one each for 2010 and 2040, and two for 2070 'low' and 'high'. The two 2070 models bound the upper and lower potential future conditions for both rainfall depth and future build-out analyses where 2070 Low applies a 2040 build-out condition and 2070 High uses a full 2070 build-out.
The HEC-HMS model folders (*2010_Conditions, 2040_Conditions, 2070_Conditions, 2070Rain_2040Land)* can be found in: *C:\Users\lfc24.WILDCAT\Desktop\CAPE\CAPE Flood Models\HEC-HMS Models.*
Output from computed HEC-HMS models was exported into Microsoft Excel (Excel) and organized for input into HEC-RAS models. Extracted data needed for input into HEC-RAS included:

- Peak Inflow and Outflow at Great Dam;
- Time of Peak Inflow and Outflow at Great Dam;
- Outflow at Pickpocket Dam (PP DAM) at the time of Great Dam peak inflow;
- Outflow at Great Cove confluence with the Exeter River (J-GB1) at the time of Great Dam peak inflow;
- Outflow at Little River confluence with the Exeter River (J-LR1) at the time of Great Dam peak inflow;
- Outflow at Colcord Pond Dam (CP DAM) at the time of Great Dam peak inflow; and
- Outflow at Wheelwright Brook (WC) at the time of Great Dam peak outflow.

This data transfer work can be found in the path and file *C:\Users\lfc24.WILDCAT\Desktop\CAPE\CAPE Flood Models\HMS-RAS Transfer.xlsx* on the '*For Model – Freq Distr HMS v4.0*' tab.
Work also developed in the *HMS-RAS Transfer.xlsx* file includes tabs:

- '*Model Extensions*' – compiled data to increase the stage storage curves to accommodate the higher 2040 and 2070 runoff values.
- '*For Model – HMS v3.4 Compare*' – compared HEC-HMS v3.4 and v4.0 to be sure there was no output difference between software versions.
- '*For PK-HMS Freq 14.10.09*' – comparisons of SCS versus Frequency storm output, and discharge approximations the High Road gage on the Exeter River. Since the model was not developed with a junction or way-point directly at the Haigh Road gage, the flows for the two immediate subcatchments, upstream and downstream (BH DAM and ER4, as can be seen in *HaighRd-HMS-GIS.pdf*), were sampled for each scenario per PK request.

<u>HEC-HMS Data Sources:</u>

Hydrologic rainfall-runoff models run on HEC-HMS software v 4.0 as developed and distributed by the US Army Corps of Engineers, Hydrologic Engineering Center (HEC).
HEC-HMS models as developed and documented by Andrew Walker of Weston & Samson Engineers, Portsmouth NH.

HEC-RAS Models

The original/base model was developed by AW of Weston & Samson Engineers (W&S) for the Great Dam Removal Study (not the CAPE Project). Specifics related to the original/base model development are documented by W&S.
In September/October of 2014, the frequency-storm outputs from the HEC-HMS models (described above) were input as upstream boundaries and lateral inflow locations for all scenarios/profiles in the base HEC-RAS model, replacing the previously applied SCS storm runoff flows. In addition to the revised flow data, downstream boundary tidal data was also updated per P.Kirshen of UNH.
In December 2014 through January 2015, forty-two (42) HEC-RAS cross-section (XS) were evaluated and revised for the upper flood plain areas only; no revisions were made to the channel or immediate channel bank areas. These XSs had originally used approximated upper floodplains above the maximum computed water surface elevation (WSEL) profiles. As the HEC-RAS model was originally developed for the study of the Great Dam removal, these original XSs were more than sufficient. However, with increased flows in future climate change (CC) scenarios, WSELs increased into these approximated floodplains. It was discussed and decided that these 42 XSs needed to be enhanced with more accurate LiDAR data at the ends of each XS. This process also involved revising the cutline links between the model and GIS to match.
XSs were evaluated to check the accuracy of the data points including the upper floodplain delineation with respect to the new (CC scenarios and frequency-storm flows) WSELs. XSs where the new WSELs were now within approximated upper floodplains were flagged for revision. For most XSs the horizontal (latitude, longitude) endpoints of the XS were held. Additionally, the adjacent floodplain areas at the confluence of the Exeter and Little Rivers were evaluated and marked for extension/revision as the original XSs did not sufficiently describe this area for the increased future flows. For these XSs, the cutline endpoints were spatially extended and in some instances the XS was slightly adjusted to better define the confluence-floodplain area, however, maintaining the locations of the original XSs was given the highest priority, and XSs were only adjusted if determined to be critically necessary.
XS revisions were compiled into an Excel file by using the 3D Analyst tools in the ESRI ArcGIS software and local LiDAR mapping. This LiDAR was the same as used in the original XS development. New and original XS data was graphed and overlaid in Excel to determine the extent, if any, of the revisions needed. In the process of comparing the XSs, a vertical datum shift of + 0.76115 feet was added to the LiDAR elevation points. This datum shift was computed by planar coordinates at Great Dam using *NOAA VERTCON* utility (*http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl*) showing a shift of 0.233 meters (0.76115 feet) between NAD 88 and NGVD 29 vertical datum.
Revisions were carefully matched manually to blend the updated upper floodplain data with the baseline XSs. Only the most upper limits of the floodplain were revised in the selected XSs. <u>No channel or immediate bank data was revised.</u> Plots of the original (grey), GIS (orange), and final revised (yellow) XSs are plotted in the working Excel file (*XS-Revisions 2015-01.xlsx*).

The development work for the XS revisions is found in the path and file: *C:\Users\lfc24.WILDCAT\Desktop\CAPE\CAPE Flood Models\HEC-RAS Model\XS-Revisions 2015-01.xlsx*.
The development work for the cutline revisions is found in the path and file:
C:\Users\lfc24.WILDCAT\Desktop\CAPE\CAPE Flood Models\HEC-RAS Model\XS-Revisions Prep 2014-12.xlsx on the '*Cutline Points – REVISED*' tab.
A steady-state (static) HEC-RAS model requires three external sub-files to define the model environment: a geometry file that defines the physical conditions of the study area including XSs and man-made structures (bridges and dams, etc.); a flow file that provides the instantaneous (static) flows at the upstream and downstream boundary conditions (Pickpocket Dam and tidal elevations downstream of Great Dam, respectively) and lateral inflows; and a plan file which identifies which combination of geometry and flow data sets to use together.
Geometry data included either 'Dam In' or 'Dam out' scenarios, and were coded for this project as either 1 or 2, respectively. Geometry files included 99 channel XSs, 12 bridges/culvert crossings definitions, and 5 dam (Dam In) or 3 dam (Dam Out) definitions. The difference between geometry files 1 and 2 is limited to the elimination of the structure definitions for Great Dam, and the Fish Weir immediately downstream of Great Dam, in the Dam Out condition.
Flow data included 'Mean High High Water' (MHHW) or 'MHHW with Storm Surge' (Surge) and were coded as A or B, respectively. Each flow file includes 9 flow profiles: 3 storm events (10-year, 25-year, and 100-year), for each time period; 2010, 2040, and 2070 Low (MHHW-A flow file) or 2070 High (Surge-B flow file).
Therefore, with these components (2 geometry and 2 flow files), four plans were compiled and run in HEC-RAS; 1A (Dam In, MHHW), 2A (Dam Out, MHHW), 1B (Dam In, Surge), and 2B (Dam Out, Surge).
HEC-RAS model results were exported using the "*Export GIS Data…*" tool under the '*Files'* pulldown menu in the HEC-RAS software. This tool writes the WSEL data in the proper format to be imported into GIS software.

Data Sources:

Hydraulic channel flow models run on HEC-RAS software v 4.1.0 as developed and distributed by the US Army Corps of Engineers (US ACOE), Hydrologic Engineering Center (HEC).
Baseline HEC-RAS models (geometry and flow files) were developed and documented by Andrew Walker of Weston & Samson Engineers, Portsmouth NH.
HEC-RAS input flow data was revised in September/October 2014 with updated runoff data obtained from the HEC-HMS models using frequency-storm rainfall distributions.
HEC-RAS input geometry XS data was revised in December 2014 through January 2015. New XS data points (station and elevation) were obtained in ArcGIS (v10.1) using the 3D Analyst tools, and extracted from the project LiDAR, as obtained directly from A. Walker of Weston & Samson Engineers of Portsmouth NH. The LiDAR data is a 32-bit, floating-point, grid raster having a horizontal datum of NAD 1983 UTM Zone 19N (meter), and a vertical datum of NAD 1983. Flight date or publish date were not available.
Vertical datum shift for XS revisions was computed by planar coordinates at Great Dam using *NOAA VERTCON* utility (*http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl*) showing a shift of 0.233 meters (0.76115 feet) between NAD 88 and NGVD 29 vertical datum.
Tidal elevations used for HEC-RAS downstream boundary conditions were provided by P. Kirchen of University of NH (UNH) in Durham NH. This data can be found in the Excel file (P.Kirshen):
C:\Users\lfc24.WILDCAT\Desktop\CAPE\CAPE Flood Models\ FloodScenariosMatrix092014 PK.xlsx.
The HEC-RAS model file can be found in: *C:\Users\lfc24.WILDCAT\Desktop\CAPE\CAPE Flood Models\HEC-RAS Model\AdditionalRuns.prj.*

HEC-RAS Export Data and HEC-GeoRAS in ArcGIS

The four HEC-RAS modeled plans (1A, 1B, 2A, and 2B) were imported into GIS using the HEC-GeoRAS (v10.1) tools add-on utility within the ESRI ArcGIS software platform. The plans are described as:

Plan 1A: Dam In geometry file, MHHW flow file

Profiles for 10-, 25-, and 100-year HEC-HMS frequency-storm events for 2010, 2040, and 2070 Low. (9 profiles exported from HEC-RAS).

Plan 1B Dam In geometry file, Surge flow file
Profiles for 10-, 25-, and 100-year HEC-HMS frequency-storm events for 2010, 2040, and 2070 High. (9 profiles exported from HEC-RAS).

Plan 2A Dam Out geometry file, MHHW flow file
Profiles for 10-, 25-, and 100-year HEC-HMS frequency-storm events for 2010, 2040, and 2070 Low. (9 profiles exported from HEC-RAS).

Plan 2B Dam Out geometry file, Surge flow file
Profiles for 10-, 25-, and 100-year HEC-HMS frequency-storm events for 2010, 2040, and 2070 High. (9 profiles exported from HEC-RAS).

Only 24 of the total 36 profiles/scenarios were analyzed in GIS: All Dam Out (18 scenarios), and Dam In for 2010 only (6 scenarios). Table 1 shows the scenarios that were analyzed in GIS.

Water surface elevation (WSEL) data for each scenario (24) was exported from HEC-RAS in a GIS importable format using HEC-GeoRAS tools within HEC-RAS. This exported data is a structured table that identifies the WSEL at each georeferenced XS for each scenario. The WSEL is always the same on both the left and right stations for each XS, and XS stations advance from left to right as one is standing at the XS facing downstream. The starting station is arbitrary.

Table 1. HEC-RAS Scenarios Analyzed

Analysis Number	Time Period	Geometry File	Storm Event	Flow File	HEC-RAS Plan Number
1	2010	1 – Dam In	10-Year	A - MHHW	1A
2			25-Year		
3			100-Year		
4			10-Year	B - Surge	1B
5			25-Year		
6			100-Year		
7	2010	2 – Dam Out	10-Year	A - MHHW	2A
8			25-Year		
9			100-Year		
10			10-Year	B - Surge	2B
11			25-Year		
12			100-Year		
13	2040		10-Year	A - MHHW	2A
14			25-Year		
15			100-Year		
16			10-Year	B - Surge	2B
17			25-Year		
18			100-Year		
19	2070-Low		10-Year	A - MHHW	2A
20			25-Year		
21			100-Year		
22	2070-High		10-Year	B - Surge	2B
23			25-Year		
24			100-Year		

HEC-GeoRAS v10.1 (US ACOE) is a add-in application that works within ArcGIS. HEC-GeoRAS is a tool package that facilitates the translation of the exported HEC-RAS results into georeferenced data usable within the GIS framework. These tools were used to extract and delineate both a mapped flood extent and a depth raster for each scenario by intersecting the HEC-RAS exported WSELs and the GIS-based LiDAR data set (raster). One flood extent polygon and one depth raster are generated for each of the 24 CC scenarios.

The flood extent defines the planar limits of the scenario flooding, and is created as a 2-dimensional (2D, flat) polygon coverage across the (georeferenced) base mapping with no elevation (z) data. A 2D polygon is closed shape or 'object' connected by bounding vectors having unique x,y vertices. HEC-GeoRAS creates this polygon by first generating a 3-dimensional (3D) surface from the WSELs, the georeferenced cutlines (XSs), and the project LiDAR. The resulting flood extent polygon is simply the 2D boundary of the 3D surface.

Flood Extent polygons were exported to: *C:\RAS_GIS\GIS\Flood Extents*.

From the same 3D WSEL surface generated to create the flood extent polygon, another HEC-GeoRAS tool creates a 'depth raster' for each scenario. A raster is a type of data format that uses pixel-based data in a gridded format. The 'depth raster' represents the difference between the 3D WSEL surface and the LiDAR data. That is, for every pixel, the 'depth raster' is the mathematical difference between each pixel of the two surfaces. (depth raster pixel1 = WSEL surface pixel1 – LiDAR surface pixel1). Of note, for all areas where surface water was physically encountered during the LiDAR flight, flood depths generated represent the depth above the WSEL at the time of LiDAR data collection. Flooding depths are in feet.

Depth raster files were exported to: *C:\RAS_GIS\GIS\Depth Rasters*.

GIS Overlay Analyses

An overlay analysis spatially crosses two (or more) different data sets and creates a new data set merging the data that intersects. Six project data sets were analyzed using an overlay analysis intersecting each data set of interest with the depth raster or depth polygon for each CC scenario (24). The six data sets of interest were:

- buildings,
- roads,
- structures,
- town reference locations,
- recreation areas, and
- wetlands.

All data used was based on available existing data sets. Data sources included, but were not limited to: the Town of Exeter, GRANIT, NHDES, RPC, and NHDOT. Existing data was also used to compile and build additional data sets only as essential. Existing data was used as-is unless edits or adjustments were deemed extremely necessary, and then, only in the most limited capacity.

Each analysis resulted in the export of select intersected data such as minimum, mean, and maximum flood depths for each record in the data set (specific building or road, etc…), or the area of flooding for a record. With 24 CC scenarios analyzed for each of the 6 data of interest, 144 overlay analyses were completed within the GIS framework.

All overlay analyses were developed using similar methods. In general, an overlay analysis cannot be performed between raster (pixel-based) and object- or vector-based data. Given that restriction, it was necessary to convert the raster data to polygon data. This was done using an integer-raster conversion tool that truncates (not rounds) each pixel value to an integer (1.9 becomes 1), and groups the data in integer bands (0-1 foot, 1-2 feet, 2-3 feet...). This truncation of pixel values results in a slightly lower flood depth at most locations. However this is consistent throughout all scenarios, and therefore comparisons are consistent. Raster conversion was necessary for all data sets of interest except 'structures', which is point data that can be evaluated on a point-to-pixel basis.

Following performing each overlay analysis, the analyses-generated GIS data; a combination of merged attributes and intersected data; was exported into Excel where additional values were calculated from the raw GIS data and summarized both by scenario and then comparatively.

Commonalities for all analyses:

- All data and analyses completed are static. GIS data was obtained and compiled from various sources, models were developed with then-current assumptions and data, exports and analyses are the results of static models. Updates to any one of the components (GIS, model, results) will not update the system directly.

- All flooding depths represent the difference in the 3D flood extent surface, generated in HEC-GeoRAS, over the project LiDAR. LiDAR does not evaluate/include man-made structures such as bridge decks or building locations.
- all overlay analyses use integer-banded depth polygons with the exception of the point-driven 'structure' analysis.

Buildings Analysis (polygon / integer-banded depth polygon)

Within ArcGIS, town-supplied building location and parcel data was merged with town-supplied tax data, matched both spatially and with parcel numbers. This provided a singular comprehensive building data set. However, given that the structure of that tax data (only one total building assessment for each parcel), all buildings on in a single parcel was assigned the same tax assessment resulting in a cumulative parcel assessment that was too high. To correct, the data set was manually adjusted by visually inspecting each additional building on a single parcel using GRANIT 2010 aerial mapping. To be consistent, only the 'main' or largest structure on the site was assigned the full assessment of the parcel, and all other buildings were listed having a zero-value. Only parcels of interest, within the most extensive flooded extent (2070-High, 100 year), were adjusted.
The overlay analysis of the building-parcel-tax-data resulted in raw GIS export data of:

- a unique building-parcel number (BLDG_PARC),
- the (main) building style from tax records (Bldg_Style),
- minimum, mean, and maximum flooding depths within each building (Min. Flood Depth (ft)),
- the parcel assessment (linked to the 'main' building on the parcel), (TOWN_Bldg_Assess),
- neighborhood (from Rockingham Planning Commission data), (Neighborhood), and
- other potentially useful parcel attributes (location, (then) current grantee, land area, etc.).

From the exported GIS data, the percent of damage for each building record was determined using a depth versus building style matrix developed by the US ACOE and provided by P. Kirshen. Two matrices were applied, one for building/structure damage and one for contents damage.
To obtain the percent of damage for each flooded building from the US ACOE matrices, first the 'Bldg_Style' attribute for each flooded building was converted to a matching 'damage category' listed in the US ACOE matrix. This conversion table can be found on the '*BldgTypes*' tab in the '*Buildings2.xlsx*' analysis file. Next, the flooded depth of each building is required. As the LiDAR and subsequently depth rasters, do not account for buildings along the topography, depths within each flooded building vary. Three depth statistics were exported from the GIS analysis; minimum, mean, and maximum. Since flooding in buildings generally fills a space and seeks to be level, and also given that the depth raster to depth polygon conversions truncate flood depths (see discussion above), it was discussed and decided to use the maximum flood depth for the US ACOE depth-damage matrices to obtain '%Damage'.
To compute the estimated damage cost per flooded building, the fractional '%Damage' was multiplied by the GIS-exported 'TOWN_Bldg_Assess' value. Values for structure and contents were added together for a total per-building damage cost based on the localized depth of flooding. All building costs were combined for a total damage cost and then summarized by neighborhood, ownership (public/town or private) and per scenario.
Finally, chosen data from each of 24 CC scenarios was tabulated and graphed in the SUMMARY tab of the analysis spreadsheet. For buildings, the total damage cost of each neighborhood is presented for each CC scenario.
The data analysis for buildings can be found in the path and file: *C:\RAS_GIS\GIS\ANALYSES\Buildings\Buildings2.xlsx*.

Data Sources:

Building locations from Town of Exeter GIS export obtained via CD dated 03.06.2014.
Parcel layer from Town of Exeter GIS export obtained via CD dated 03.06.2014.
Tax data obtained via email from the Town of Exeter dated 04.01.2014.
US ACOE building depth-damage matrix provided by P. Kirchen via 04.19.2014 email.
Neighborhood delineation from Rockingham Planning Commission via email with files dates 04.22.2014.

2010 aerial mapping downloaded from NH GRANIT.

Road Analysis (polyline / integer-banded depth polygon)

In GIS, GRANIT and town-supplied road data was merged and overlaid with the 24 depth polygons to obtain the sections of road and depth of flooding for each CC scenario. Since roads are continuous and flooding depth varies spatially along a roadway, and given the banded nature (0-1 foot, 1-2 feet, 2-3 feet, etc..) of the converted depth polygons, the analysis results were generated such that each road was segmented into depth of flooding bands. That is to say, if a roadway flooding depth varies from 0-4, the analysis reported 4 separate segments of road flooding in the raw GIS results.
GIS exported data included:

- street name (STREET),
- the lower limit of the depth band (0 = 0-1 foot band), (DEPTH)
- length of the flooded band segment (LENGTH_FT),
- legislative class and ownership of the road (LEGIS_CLAS, OWNERSHIP), and
- surface type of the road (SURF_TYPE).

An attempt was made to develop a damage cost estimate similar to the building analysis using a matrix with the road's 'function code' including ownership, legislative class, and surface type (OWN_CLS_SRF) versus the depth of flooding. 16 different combinations of road 'type' were identified. The developed matrix and road 'type' coding can be found on the '*RoadFunc*' tab of the '*Roads.xlsx*' analysis spreadsheet file.
The Town of Exeter (Town) was consulted for roadway repair cost estimates due to flooding damage but was not able to supply any specific costs. An email received from M.Dugas of NH DOT through a personal contact provided a cost of "roughly $1.5 million per mile for a two-lane road with narrow shoulders". From this cost, the matrix was populated with VERY ROUGHLY ESTIMATED repair costs. First, 1.5 million per mile was converted to roughly $300 per linear foot (LF). Next, an assumption was made that any road segment with flooding over 4-feet in depth (truncated depth) would require full reconstruction and therefore the maximum cost was applied for all flood depths above the 4-foot band. Finally, various fractions of the full $300 per LF were applied to depths less than 4-feet and differing road 'types', and were based solely on profession estimation.
For each road segment depth-band, the damage cost per LF ($Damage/LF) is obtained from the cost matrix and multiplied by the segment length (LENGTH_FT) to compute the estimated cost of each flooded road segment. A pivot table that summarizes the combined flooded length of each road, the maximum flooded depth of each road, and the total VERY ROUGHLY estimated damage cost is also shown for each CC scenario.
Although the road depth-damage cost matrix was VERY ROUGHLY ESTIMATED at this point in time, it was set up within the spreadsheet to easily be updated should better, more accurate or trusted cost data become available or developed. Simply entering in the new cost data directly into the matrix tab will propagate through the all 24 CC scenario tabs (pivot tables must be refreshed manually).
Two summary tabs are included in the roads analysis file. The first tab, '*SUMMAY COST*', tabulates and graphs the total VERY ROUGHLY ESTIMATED road damage costs for each CC scenario. The second tab, '*SUMMARY +2FT*', shows data for roads with maximum flooding over 2-feet in depth; the total length of all flooded road segments, and total number of roads for each scenario.
The spreadsheet data analysis for roads can be found in the path and file: *C:\RAS_GIS\GIS\ANALYSES\Roads\Roads.xlsx*.
Road flooding was also summarized by maps per the request of the Town. These maps show the flooding depths graphically in bands of 0-1 foot, 1-2 feet, 2-5 feet, and over 5-feet. One limitation that was discovered with the depth polygons (integer-banded polygons) is that since most, if not all, man-made structures are removed from LiDAR data, bridge deck data is not evaluated. Therefore the flood depth at bridges is represented at the depth of flooding above the river WSEL at the time of the LiDAR flight. For this reason, bridges shown on the mapping were masked to show no depth data. Actual depth data (WESLs) at each bridge in the model limits can be found directly in the HEC-RAS model output (that I assume will be included the report Appendices).

Data Sources:

Road data from Town of Exeter GIS export obtained via CD dated 03.06.2014, merged with road data from NH GRANIT downloaded via internet 09.07.2012.
Cost matrix data derived from email from NH DOT, M.Dugas, 11.03.2014.
Road data code descriptions obtained from *library.modot.mo.gov/cadd/.../Roads_DOT_Code_Descriptions.doc*

Structure Analysis (point / depth raster)

'Structure' data sets were compiled from several sources. The initial structure data set merged all surface structures (manholes, pump stations, well heads, etc...) from GIS data layers supplied to CAPE from the Exeter DPW. These layers included, sewer, water, and stormwater data sets. Additional GIS data was obtained from the NH DES and included DES-registered aboveground and underground tanks. Following an initial review of the data set by the Town, it was decided to focus the analysis on only public well heads, pump stations, and above ground storage tanks. No stormwater structures were included, as a separate model and analysis are being completed on the stormwater system by GeoSyntec. A final structures working layer was then parsed out to include only the feature points of interest per the Town.
Within the supplied data sets, most, if not all of these points did not include elevation/rim data. Therefore, the LiDAR surface elevation at each structure point was used in the depth analysis.
The structure points were overlaid with the depth raster (actual pixel data, not integer-banded). Therefore, the depths obtained in the analysis are the true model-to-LiDAR depths, not truncated values. Data derived in the overlay and exported to Excel included:

- the assigned CAPE label (used in mapping), (CAPE_LBL),
- type of structure (TYPE), and
- depth of flooding above the LiDAR (DEPTH (FT)).

No intermediate calculations were performed on this data. Data selected from each of 24 CC scenarios was tabulated and graphed in the SUMMARY tab of the analysis spreadsheet. For structures, the total number of flooded structures by DPW department (water or sewer), and the maximum depth of any structure in that scenario is presented.
The spreadsheet data analysis for structures can be found in the path and file:
C:\RAS_GIS\GIS\ANALYSES\Structures\Structures.xlsx.

Data Sources:
Structure point data from the Town of Exeter DPW GIS export obtained via email dated 04.08.2014, merged with data from NH DES obtained by email 05.28.2014.
Additional town structure locations provided by Town of Exeter DPW via email date 05.28.2014.

Town Reference Location Analysis (polygon / integer-banded depth polygon)

The town reference data layer was created specifically for the CAPE project at the direction of the Town for important locations that were of interest both for flooding analysis and also reference labeling on project mapping. This data was synthesized from both existing data (town-supplied GIS data) and/or visual inspection of aerial mapping. Attributes assigned to this data set included: the map label (name) as identified by the Town; whether the location was public (town owned) or private; and a legend code for the mapping. This data set was created as a polygon feature. A secondary data set was also created that converted the polygon data set into a point data with the point located at the centroid of each polygon.
For each flooded polygon and CC scenario, the overlay analysis of the town reference data resulted in raw GIS export data of:

- the map legend code (LEGND_CODE),
- the map label/identification (MAP LABEL),
- minimum, mean, and maximum flooded depths within each polygon/location (MIN,MEAN,MAX_DEPTH (FT)),

- whether the location was publically or privately owned (PUBLIC OR PRIVATE), and
- flood depth (actual computed) at the centroid of each polygon (DEPTH AT CENTROID (FT)).

The polygon overlay was performed using the polygon data set intersected with the integer-banded depth polygons to obtain the locations affected by flooding as well as the minimum, mean, maximum flood depths overall for each record. The centroid depths were obtained by overlay analysis of the converted point data and the 24 CC depth rasters (pixel data).

In review of the overlay results, two issues were identified. First, in the integer-banded depth overlay, the extracted depth values (min, mean, max) are truncated and each value reported could have a variance of as much as minus 0.99-feet (1.01=1 and 1.99=1). Second, given the areal nature of the entire reference location polygon to the actual flooded areas, the centroid of any reference location may fall outside the flooding extents. In this case, no centroid depth is evaluated. This is because with point analysis, even if a portion the reference location polygon was flooded, if the centroid was not within that flooded area, it is not seen in the overlay analysis (point to pixel only). Additionally, the position of the reference location's centroid with respect to the area of flooding, which may only occur within a small portion of the subject polygon, is fairly arbitrary and doesn't generally represent the mean or maximum flooding at that location of interest.

Since the actual computed depth of flooding at each of the reference locations was desired, the analysis was used to first generate a table of all potentially flooded locations for all CC scenarios. Next, all 24 of the CC scenario depth rasters (pixel values) were manually inspected at each reference location identified in the list to obtain the maximum flooded depth value (pixel). The resulting table in the analysis spreadsheet (SUMMARY tab) provides the maximum depth of flooding for each CC scenario at each reference location identified as important by the Town.

The spreadsheet data analysis for the town reference locations can be found in the path and file:
C:\RAS_GIS\GIS\ANALYSES\Reference\TownReferencePlaces.xlsx.

Data Sources:
Building locations and evaluated attribute data from Town of Exeter GIS export obtained via CD dated 03.06.2014 and tax data obtained via email from the Town of Exeter dated 04.01.2014.
Visual data of Town identified locations made on 2010 aerial mapping obtained from GRANIT downloaded on 03.23.2013.

Recreational Area Analysis (polygon / integer-banded depth polygon)

Recreational areas were merged from both existing town and RPC (Rockingham Planning Commission) data sets that consisted of polygon, polyline, and point data. To merge the different types of data into one polygon data set, the polylines (trails) were offset by a consistent conservative total width of 4-meters. Areas identified by point data were visually traced using the 2010 GRANIT aerial maps.

For each recreational area, overlay analysis of the 24 CC scenarios yielded the following exported GIS data:

- depth of flooding*, incremental areas by depth bands, the same as described for the road analysis (DEPTH)**,
- name of the recreational area (Name),
- location of the recreational area (Location),
- total area within the model limits (TOTAL AREA (FT^2)), and
- flooded area per depth band (FLOODED AREA (FT^2)).

*Note: in order to eliminate non-zero division, depth values of 0-feet (0 to 1-foot band) were edited to 0.25-feet.
**Note: road depth analysis results were broken into banded segments (0 to 1 foot, 1 to 2 feet, etc…). See Road Analysis for details on segmented results.

Because the depth of flooding can vary non-uniformly across a spatial area, an area-weighted average depth was calculated. From the raw GIS data, an incremental area-weighted depth was computed for each flooded segment/area.

A summary pivot table was used to sum all the weighted depths for each identified recreational area to obtain a total area-weighted depth for each recreational area. Also summarized by recreation area is the total area flooded, total area within the model limits, the arithmetic average flooded depth, and the maximum flooded depth. Using this summary data, the percent of flooding was calculated for each recreation area, and also as a total of all flooded area to total area within the model limits.

Finally, chosen data from each of 24 CC scenarios was tabulated and graphed in the SUMMARY tab of the analysis spreadsheet. For recreation, the total percent of flooded wetland (total of all flooded area to total area within the model limits) is presented.

The spreadsheet data analysis for recreational areas can be found in the path and file:
C:\RAS_GIS\GIS\ANALYSES\Recreation\Recreation.xlsx.

Data Sources:

Merged and compiled data from recreational facilities and trails (2009) data taken from Town of Exeter GIS export obtained via CD dated 03.06.2014; and community facilities from RPC via email dated 05.20.2015. Visual data of Town identified locations made on 2010 aerial mapping obtained from GRANIT downloaded on 03.23.2013.

Wetlands Analysis (polygon / integer-banded depth polygon)

Existing data used for this analysis was the US F&W National Wetlands Inventory (NWI) as downloaded from GRANIT and by direction of D.Burdick of the UNH CAPE team. Attribute information included a NWI ID numbers, and NWI wetland codes. An attribute was added to calculate the total area of each wetland record in square feet.

The overlay analysis of the NWI resulted in raw GIS export data of:

- depth of flooding*, incremental areas by depth bands, the same as described for the road analysis (GRIDCODE)**,
- NWI ID numbers (NWINH_ID),
- NWI code and type (NWITYPE),
- flooded area per depth band (FLOODED AREA (FT^2)), and
- total area within the model limits (TOTAL WETLAND AREA (FT^2)).

*Note: in order to eliminate non-zero division, depth values of 0-feet (0 to 1-foot band) were edited to 0.25-feet.

**Note: road depth analysis results were broken into banded segments (0 to 1 foot, 1 to 2 feet, etc…). See Road Analysis for details on segmented results.

Because the depth of flooding can vary non-uniformly across a spatial area, an area-weighted average depth was calculated. From the raw GIS data, an incremental area-weighted depth was calculated for each flooded segment/area. A summary pivot table was used to sum all the weighted depths for each wetland area to obtain a total area-weighted depth. Also summarized by wetland area is the total area flooded, maximum flooded depth, arithmetic average flooded depth, the total area within the model limits, and NWI wetland type.

Summary data by CC scenario and for each NWI type (3 types: E, Estuarine; P, Palustrine; and R, Riverine) included: the total areas; the percent flooded within the model limits; and the average of the weighted depths.

Two extra tabs in the Excel file were created. One SUMMARY tab showing the total percent of flooded wetland (total of all flooded area to total area within the model limits). And two, '*ANALYSIS 1*' tab, (at end of all tabs), analyzing the wetland flooding by NWI type for both percent flooded and average weighted depth per direction of D.Burdick.

The spreadsheet data analysis for wetlands can be found in the path and file:
C:\RAS_GIS\GIS\ANALYSES\Wetlands\Wetlands.xlsx.

Data Sources:

Wetland data taken from 2005 US F&W National Wetlands Inventory (NWI) as downloaded from GRANIT.

Directories and files

Major working files and directories are identified below.

<u>Models</u>

C:\Users\lfc24.WILDCAT\Desktop\CAPE\CAPE Flood Models\
C:\Users\lfc24.WILDCAT\Desktop\CAPE\CAPE Flood Models\HEC-HMS Models\
… 2010_Conditions\2010_Conditions.hms
… 2040_Conditions\2040_Conditions.hms
… 2070_Conditions\2070_Conditions.hms
… 2070Rain_2040Land\2070Rain_2040Land.hms

Within models:	Basin Model:	ExeterRiverWatershed
	Meteorologic Models Used:	2010-10-4.72Freq
		2010-25-6.00Freq
		2010-100-8.62Freq
		2040-10-5.29Freq
		2040-25-6.72Freq
		2040-100-10.43Freq
		2070LOW-10-5.33Freq
		2070LOW-25-6.78Freq
		2070LOW-100-9.83Freq
		2070HIGH-10-5.66Freq
		2070HIGH-25-7.20Freq
		2070HIGH-100-11.38Freq
	Control Specifications:	Freq-24hr

C:\Users\lfc24.WILDCAT\Desktop\CAPE\CAPE Flood Models\HEC-RAS Model\
… AdditionalRuns.prj

Within model:	2 Geometry Files:	UNH-Existing3 (1- DamIn)
		UNH-DamOut3 (2- DamOut)
	2 Flow files:	UNH-AddRuns-MHHW for Freq (A)
		UNH-AddRuns-MHHW+SURGE for Freq (B)
	9 Flow profiles per flow file	
		2010, 2040, 2070 (high/low)
		x 10-, 25-, 100-year storm events
	Plans:	1A, 1B, 2A, 2B
	Scenarios modeled:	9 Flow Profiles x 4 Plans = 36 total scenarios

C:\Users\lfc24.WILDCAT\Desktop\CAPE\CAPE Flood Models\
C:\Users\lfc24.WILDCAT\Desktop\CAPE\CAPE Flood Models\HEC-RAS Model\
… XS-Revisions 2015-01.xlsx (Dec2014/Jan2015 XS revision worksheet)
… XS-Revisions Prep 2014-12.xlsx (Dec2014 cutline revisions)

C:\Users\lfc24.WILDCAT\Desktop\CAPE\CAPE Flood Models\
… FloodScenariosMatrix092014 PK.xlsx (CC scenario parameters)
… HMS-RAS Transfer.xlsx (HEC-HMS output reformatting for HEC-RAS flow input)

<u>GIS Analyses</u>

C:\RAS_GIS\
… GeoRAS_2015.mxd (working ArcGIS file used for HEC-GeoRAS import and conversions from

HEC-RAS)

C:\RAS_GIS\GIS\ANALYSES\

… Buildings\Buildings2.xlsx

… Recreation\Recreation.xlsx

… Reference\ TownReferencePlaces.xlsx

… Roads\Roads.xlsx

… Structures\Structures.xlsx

… Wetlands\Wetlands.xlsx

C:\RAS_GIS\GIS\ANALYSES\ANALYSIS-2015.mxd (working ArcGIS file for flood analyses)

C:\RAS_GIS\GIS\Depth Rasters\

C:\RAS_GIS\GIS\Flood Extents\

Mapping

C:\Users\lfc24.WILDCAT\Desktop\CAPE\GIS\ (All GIS data)

C:\Users\lfc24.WILDCAT\Desktop\CAPE\GIS\MAPS\FINAL MAPS\

… 2015-0330 Depth\ (Project map exports: color depth rasters over aerial maps, pdfs, 24x36 format)

… 2015-0421 Roads\ (Project map exports: color-coded road flooding, pdfs, 24x36 format)

C:\Users\lfc24.WILDCAT\Desktop\CAPE\GIS\MAPS\Figures\ (report figures, pdf)

C:\Users\lfc24.WILDCAT\Desktop\CAPE\GIS\MAPS\Index\ (map figures, jpg)

C:\Users\lfc24.WILDCAT\Desktop\CAPE\GIS\MAPS\Index\

… FEMA Compare 2015.mxd (ArcGIS file comparing CAPE 2010 model and 2005 FEMA 100-year flood extents)

… FINAL DEPTH Mapping_2015.mxd (ArcGIS file for project mapping, depth rasters over aerials)

… INDEX.mxd (working ArcGIS file for indexing figures)

… Mapping-Working_2015 ROADS.mxd (ArcGIS file for project mapping, roads analysis)

GLOSSARY

analysis spreadsheet	the file containing all of the GIS export data for each of the CC scenarios, the resulting analyses, and summaries.
depth band	see depth polygon, except a band is specifi to adjacent depths (0 to 1, 1 to 2, etc…)
data layer	any unique data set that is stored in a single unit having the same collection of attributes.
depth polygon	derived from the depth raster, each pixel is truncated to an integer (1.9=1) and depths are segregated into bands. Bands are grouped converted into area-based ‘objects’.
depth raster	a pixel-based date set generated from the difference between the 3D water surface profile surface and the 3D LiDAR surface for each given CC scenario (24).
flood extent	maximum 2D/planar flooding limits for each given CC scenario (24).
integer-banded depth polygon	see depth polygon
overlay analysis	the intersection of 2 (or more) data sets
polygon data	a feature that bounds an area at a given scale (ESRI GIS Dictionary)
polyline data	data that has length but not area at a given scale (ESRI GIS Dictionary)
point data	a feature that has neither length nor area at a given scale (ESRI GIS Dictionary)
rainfall-runoff model	hydrologic model of the effects of precipitation as it interacts with a natural environment and results in computed base flow and overland surface runoff.
raster data	spatial data model that defines space as an array of equally sized cells arranged in rows and columns. Each cell contains an attribute value and location coordinates. Unlike a vector structure, which stores coordinates explicitly, raster coordinates are contained in the ordering of the matrix. (ESRI GIS Dictionary)
raw GIS data	select data exported directly from GIS
record	a singular collection to data in a row
scenario	a collection of varying modeled conditions including: dam in or out (HEC-RAS only); a time period (2010,2040, 2070); a hypothetical storm event (10-, 25-, 100-year); and a tidal condition (HEC-RAS model only, MHHW or Storm Surge).
spreadsheet tab	a single worksheet within the same MS Excel file.
static	characterized by fixed conditions. Having no linkage to outside data; not subject to dynamic updating. (ie revising and rerunning HEC-RAS model does not update previously imported GIS data.)

CC	climate change
GRANIT	NH GIS free data repository
H&H	hydrologic and hydraulic/open channel
HEC	Hydrologic Engineering Center
NHDES	NH Department of Environmental Services
NHDOT	NH Department of Transportation
RPC	Rockingham (County) Planning Commission
Town	Town of Exeter
US ACOE	US Army Corps of Engineers
WSEL	water surface elevation
XS	cross-section

Mapping

input data

- source
- prep
- limitations

GIS analysis

- data exported

Spreadsheet calcs

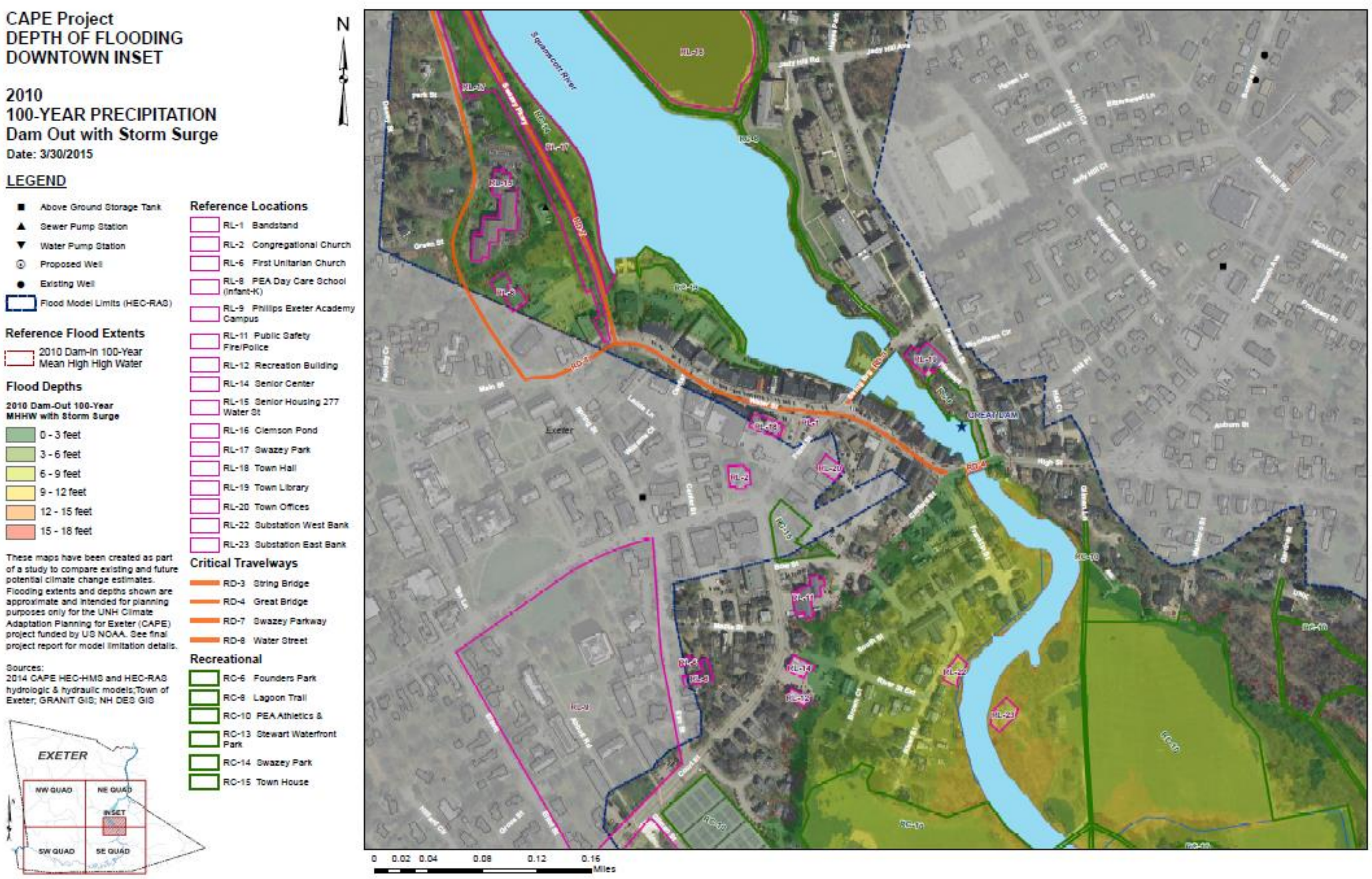
Spreadsheet summaries/results

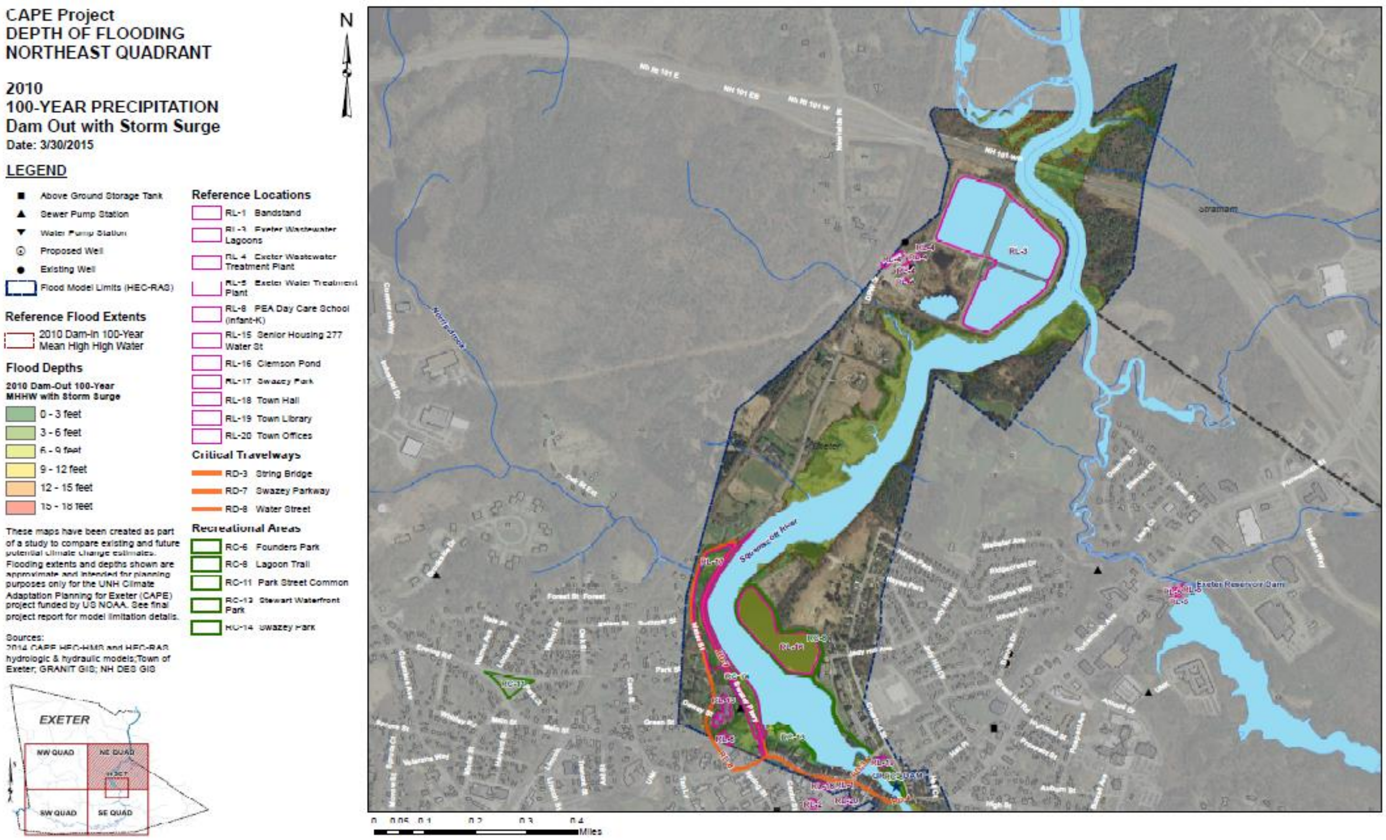
data sources

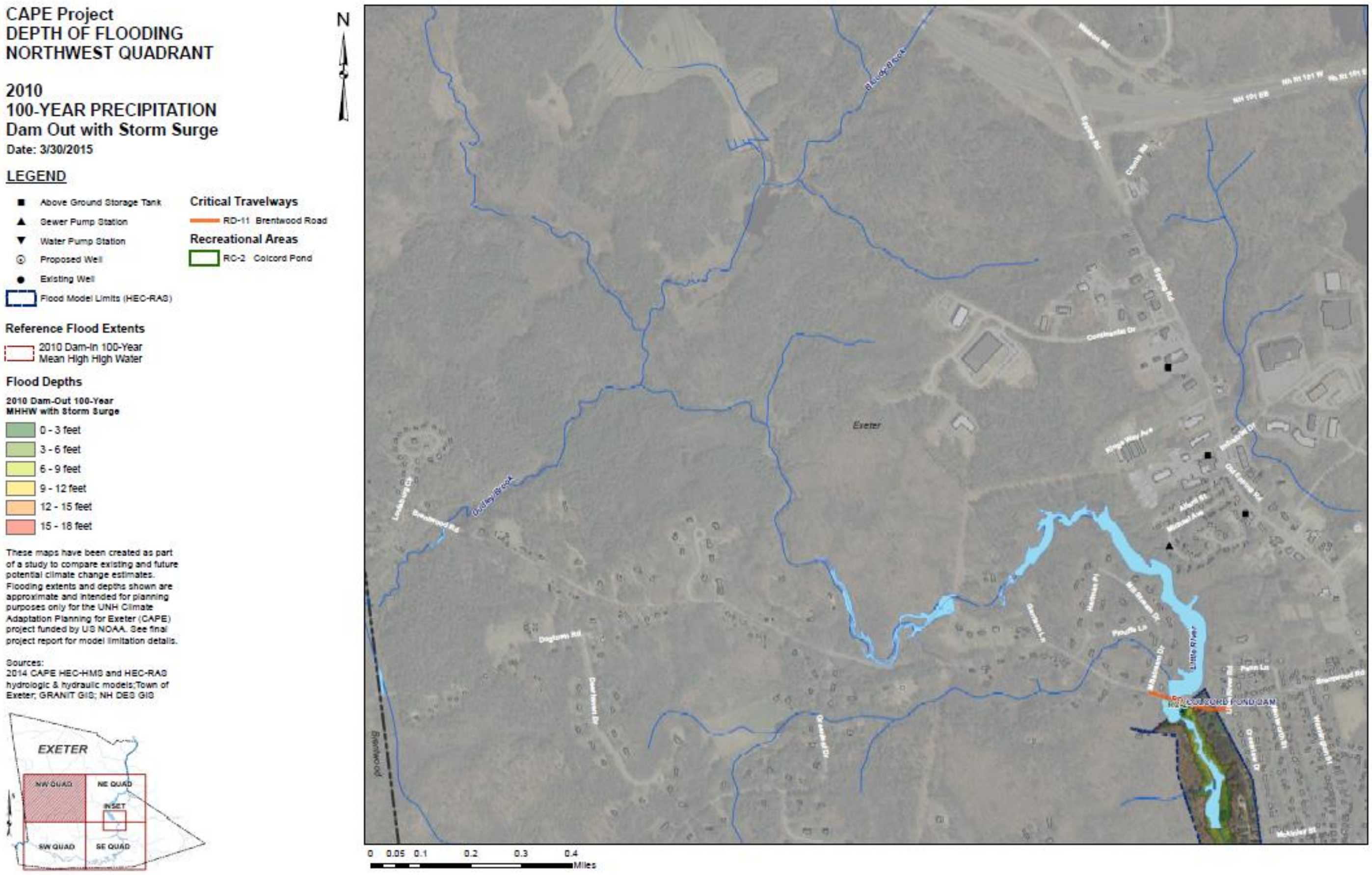
notes/limitations

Appendix AS7

Flood Maps for Present and Future Climates for Present and 2070 with Great Dam Removed and Various Surge Conditions in Squamscott River and Results. Maps of Flooded Roads




CAPE Project
DEPTH OF FLOODING
NORTHEAST QUADRANT
2010
100-YEAR PRECIPITATION
Dam Out with Storm Surge
Date: 3/30/2015
LEGEND
Above Ground Storage Tank
Sewer Pump Station
Water Pump Station
Proposed Well
Existing Well
Flood Model Limits (HEC-RAS)
Reference Flood Extents
2010 Dam-In 100-Year Mean High High Water
Flood Depths
2010 Dam-Out 100-Year MHHW with Storm Surge
0 - 3 feet
3 - 6 feet
6 - 9 feet
9 - 12 feet
12 - 15 feet
15 - 18 feet
These maps have been created as part of a study to compare existing and future potential climate change estimates. Flooding extents and depths shown are approximate and intended for planning purposes only for the UNH Climate Adaptation Planning for Exeter (CAPE) project funded by US NOAA. See final project report for model limitation details.
Sources:
2014 CAPE HEC-HMS and HEC-RAS hydrologic & hydraulic models; Town of Exeter; GRANIT GIS; NH DES GIS
Reference Locations
RL-1 Bandstand
RL-3 Exeter Wastewater Lagoons
RL-4 Exeter Wastewater Treatment Plant
RL-5 Exeter Water Treatment Plant
RL-8 PEA Day Care School (Infant-K)
RL-15 Senior Housing 277 Water St
RL-16 Clemson Pond
RL-17 Swazey Park
RL-18 Town Hall
RL-19 Town Library
RL-20 Town Offices
Critical Travelways
RD-3 String Bridge
RD-7 Swazey Parkway
RD-8 Water Street
Recreational Areas
RC-6 Founders Park
RC-8 Lagoon Trail
RC-11 Park Street Common
RC-13 Stewart Waterfront Park
RC-14 Swazey Park
EXETER
NW QUAD
NE QUAD
SW QUAD
SE QUAD
N
Exeter Reservoir Dam
Stratham
0 0.05 0.1 0.2 0.3 0.4
Miles


CAPE Project
DEPTH OF FLOODING
NORTHWEST QUADRANT
2010
100-YEAR PRECIPITATION
Dam Out with Storm Surge
Date: 3/30/2015
LEGEND
Above Ground Storage Tank
Sewer Pump Station
Water Pump Station
Proposed Well
Existing Well
Flood Model Limits (HEC-RAS)
Critical Travelways
RD-11 Brentwood Road
Recreational Areas
RC-2 Colcord Pond
Reference Flood Extents
2010 Dam-In 100-Year Mean High High Water
Flood Depths
2010 Dam-Out 100-Year MHHW with Storm Surge
0 - 3 feet
3 - 6 feet
6 - 9 feet
9 - 12 feet
12 - 15 feet
15 - 18 feet
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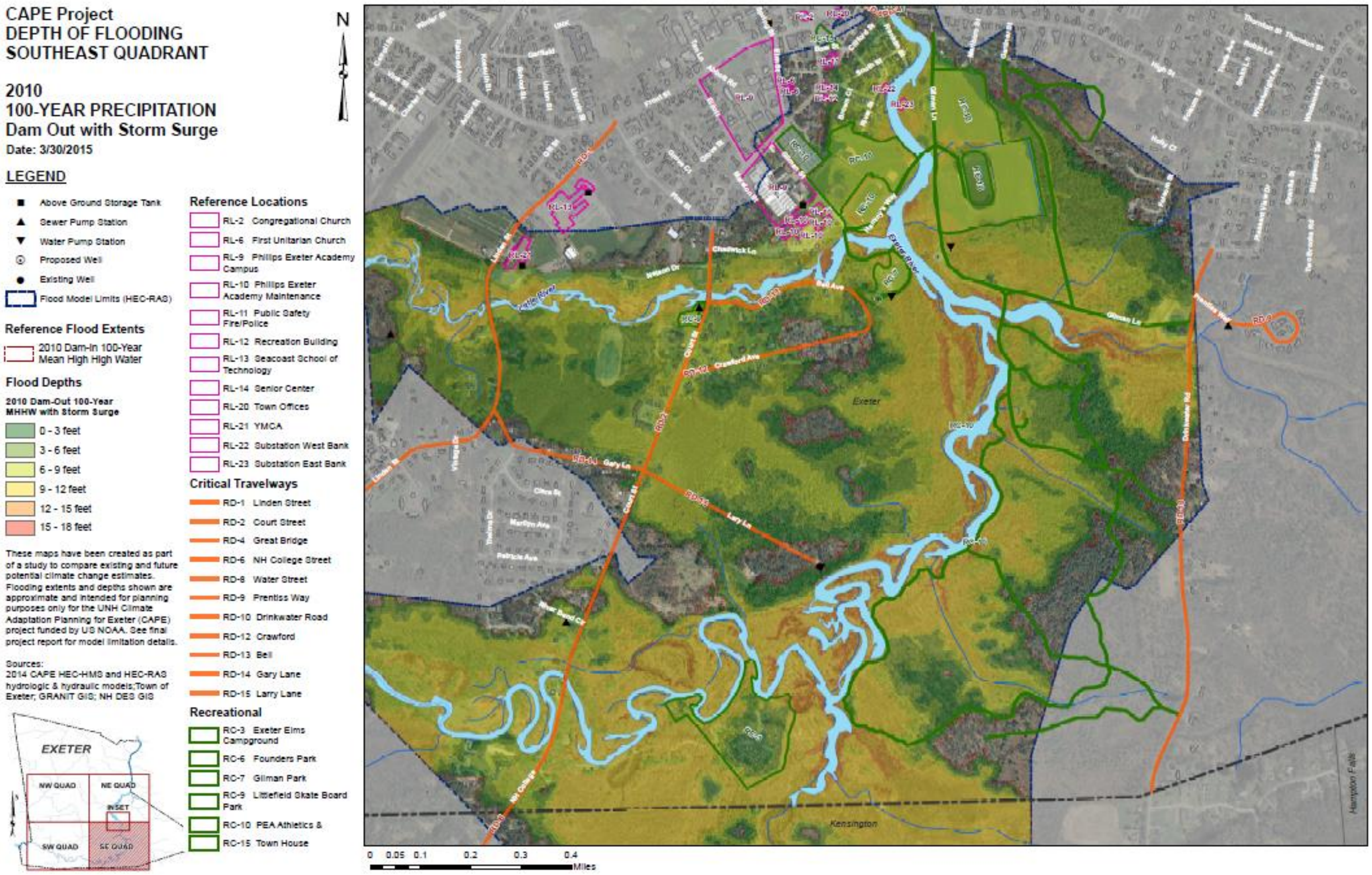
Sources:
2014 CAPE HEC-HMS and HEC-RAS hydrologic & hydraulic models;Town of Exeter; GRANIT GIS; NH DES GIS
EXETER
NW QUAD
NE QUAD
INSET
SW QUAD
SE QUAD
N
Exeter
Little River
Brentwood
0 0.05 0.1 0.2 0.3 0.4
Miles



CAPE Project
DEPTH OF FLOODING
SOUTHEAST QUADRANT
2010
100-YEAR PRECIPITATION
Dam Out with Storm Surge
Date: 3/30/2015
N
LEGEND
Above Ground Storage Tank
Sewer Pump Station
Water Pump Station
Proposed Well
Existing Well
Flood Model Limits (HEC-RAS)
Reference Flood Extents
2010 Dam-In 100-Year Mean High High Water
Flood Depths
2010 Dam-Out 100-Year MHHW with Storm Surge
0 - 3 feet
3 - 6 feet
6 - 9 feet
9 - 12 feet
12 - 15 feet
15 - 18 feet
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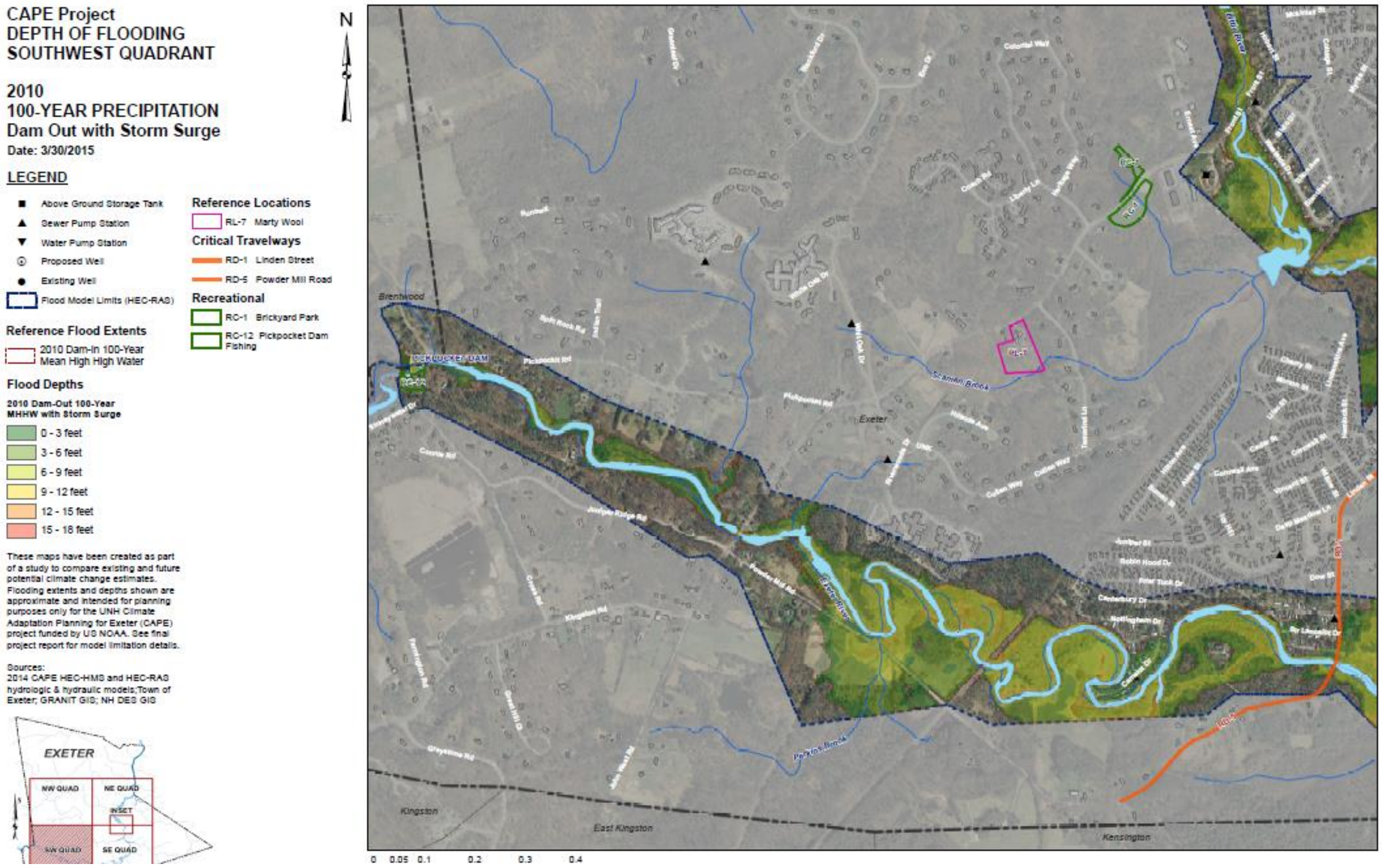
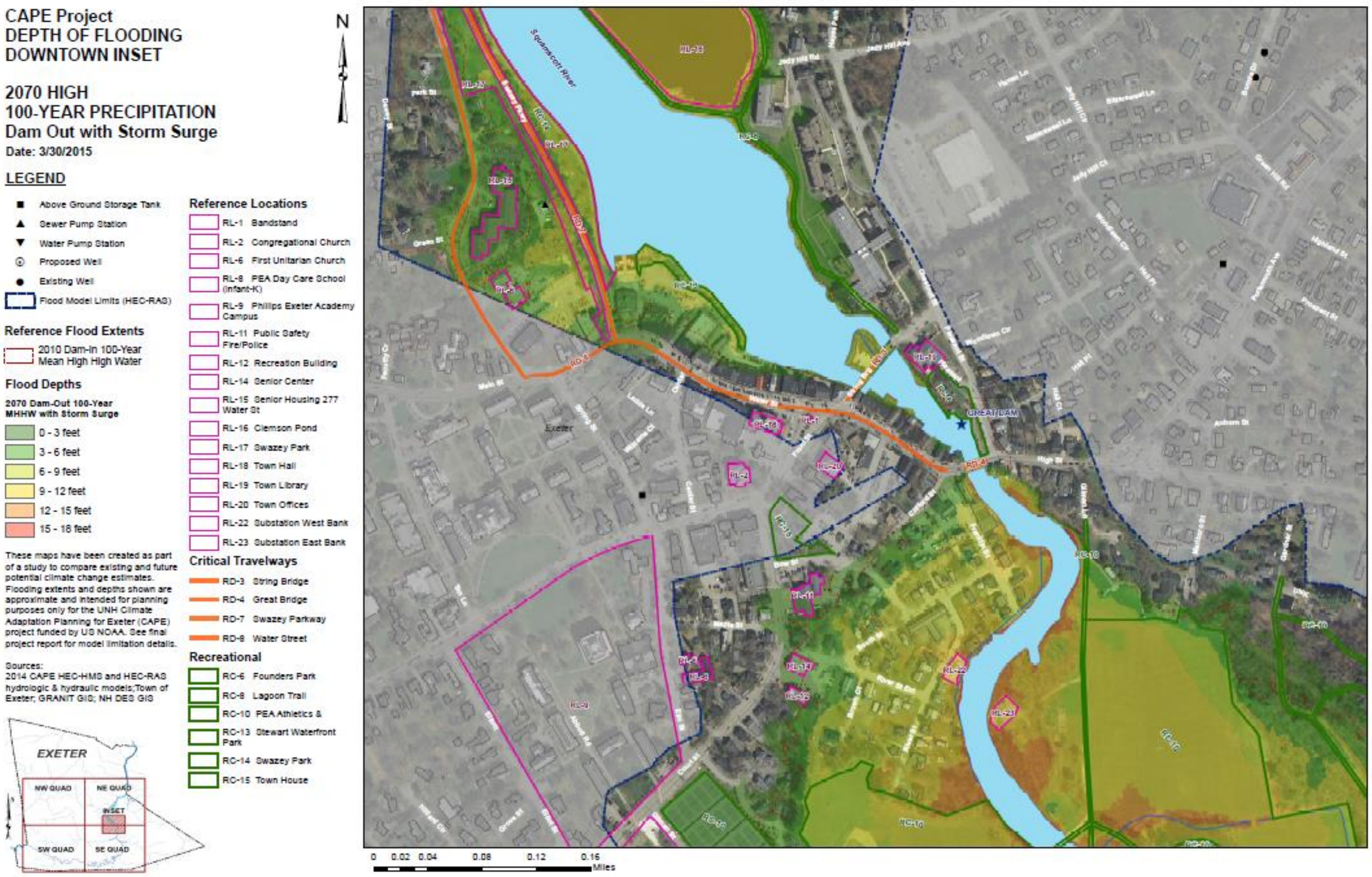
EXETER
NW QUAD
NE QUAD
INSET
SW QUAD
SE QUAD
Reference Locations
RL-2 Congregational Church
RL-6 First Unitarian Church
RL-9 Phillips Exeter Academy Campus
RL-10 Phillips Exeter Academy Maintenance
RL-11 Public Safety Fire/Police
RL-12 Recreation Building
RL-13 Seacoast School of Technology
RL-14 Senior Center
RL-20 Town Offices
RL-21 YMCA
RL-22 Substation West Bank
RL-23 Substation East Bank
Critical Travelways
RD-1 Linden Street
RD-2 Court Street
RD-4 Great Bridge
RD-6 NH College Street
RD-8 Water Street
RD-9 Prentiss Way
RD-10 Drinkwater Road
RD-12 Crawford
RD-13 Bell
RD-14 Gary Lane
RD-15 Larry Lane
Recreational
RC-3 Exeter Elms Campground
RC-6 Founders Park
RC-7 Gilman Park
RC-9 Littlefield Skate Board Park
RC-10 PEA Athletics &
RC-15 Town House
Exeter
Kensington
0 0.05 0.1 0.2 0.3 0.4
Miles


CAPE Project
DEPTH OF FLOODING
SOUTHWEST QUADRANT
2010
100-YEAR PRECIPITATION
Dam Out with Storm Surge
Date: 3/30/2015
LEGEND
Above Ground Storage Tank
Sewer Pump Station
Water Pump Station
Proposed Well
Existing Well
Flood Model Limits (HEC-RAS)
Reference Flood Extents
2010 Dam-In 100-Year Mean High High Water
Flood Depths
2010 Dam-Out 100-Year MHHW with Storm Surge
0 - 3 feet
3 - 6 feet
6 - 9 feet
9 - 12 feet
12 - 15 feet
15 - 18 feet
Reference Locations
RL-7 Marty Wool
Critical Travelways
RD-1 Linden Street
RD-5 Powder Mill Road
Recreational
RC-1 Brickyard Park
RC-12 Pickpocket Dam Fishing
These maps have been created as part of a study to compare existing and future potential climate change estimates. Flooding extents and depths shown are approximate and intended for planning purposes only for the UNH Climate Adaptation Planning for Exeter (CAPE) project funded by US NOAA. See final project report for model limitation details.
Sources:
2014 CAPE HEC-HMS and HEC-RAS hydrologic & hydraulic models; Town of Exeter; GRANIT GIS; NH DES GIS
EXETER
NW QUAD
NE QUAD
INSET
SW QUAD
SE QUAD
N
Brentwood
Exeter
Kingston
East Kingston
Kensington
0 0.05 0.1 0.2 0.3 0.4

2070


CAPE Project
DEPTH OF FLOODING
DOWNTOWN INSET
2070 HIGH
100-YEAR PRECIPITATION
Dam Out with Storm Surge
Date: 3/30/2015
LEGEND
Above Ground Storage Tank
Sewer Pump Station
Water Pump Station
Proposed Well
Existing Well
Flood Model Limits (HEC-RAS)
Reference Flood Extents
2010 Dam-In 100-Year Mean High High Water
Flood Depths
2070 Dam-Out 100-Year MHHW with Storm Surge
0 - 3 feet
3 - 6 feet
6 - 9 feet
9 - 12 feet
12 - 15 feet
15 - 18 feet
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RL-6 First Unitarian Church
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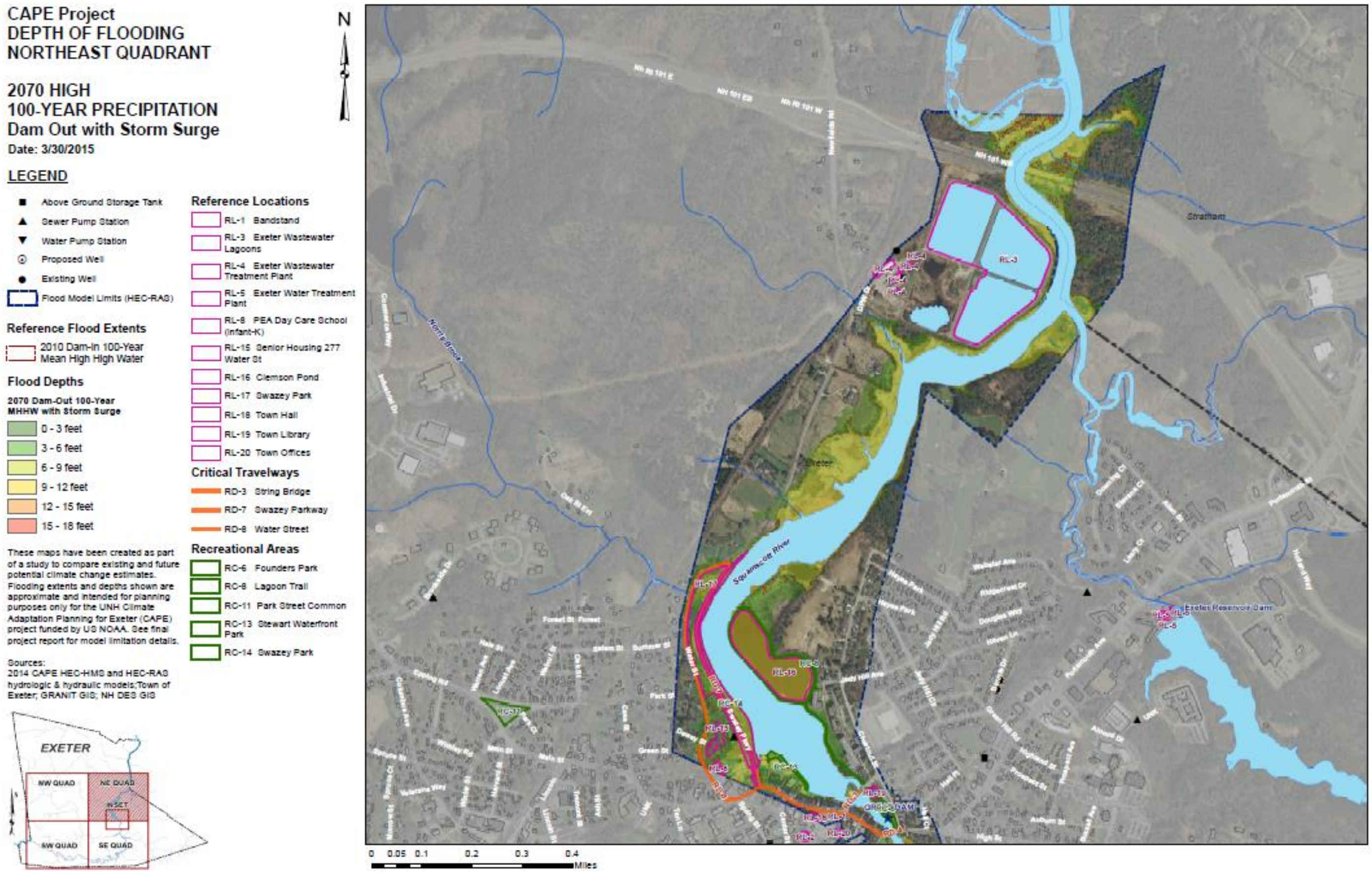
RL-9 Phillips Exeter Academy Campus
RL-11 Public Safety Fire/Police
RL-12 Recreation Building
RL-14 Senior Center
RL-15 Senior Housing 277 Water St
RL-16 Clemson Pond
RL-17 Swazey Park
RL-18 Town Hall
RL-19 Town Library
RL-20 Town Offices
RL-22 Substation West Bank
RL-23 Substation East Bank
Critical Travelways
RD-3 String Bridge
RD-4 Great Bridge
RD-7 Swazey Parkway
RD-8 Water Street
Recreational
RC-6 Founders Park
RC-8 Lagoon Trail
RC-10 PEA Athletics &
RC-13 Stewart Waterfront Park
RC-14 Swazey Park
RC-15 Town House
EXETER
NW QUAD
NE QUAD
INSET
SW QUAD
SE QUAD
N
Squamscott River
GREAT DAM
Exeter
0 0.02 0.04 0.08 0.12 0.16
Miles



CAPE Project
DEPTH OF FLOODING
NORTHEAST QUADRANT
2070 HIGH
100-YEAR PRECIPITATION
Dam Out with Storm Surge
Date: 3/30/2015
LEGEND
Above Ground Storage Tank
Sewer Pump Station
Water Pump Station
Proposed Well
Existing Well
Flood Model Limits (HEC-RAS)
Reference Flood Extents
2010 Dam-In 100-Year Mean High High Water
Flood Depths
2070 Dam-Out 100-Year MHHW with Storm Surge
0 - 3 feet
3 - 6 feet
6 - 9 feet
9 - 12 feet
12 - 15 feet
15 - 18 feet
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RL-15 Senior Housing 277 Water St
RL-16 Clemson Pond
RL-17 Swazey Park
RL-18 Town Hall
RL-19 Town Library
RL-20 Town Offices
Critical Travelways
RD-3 String Bridge
RD-7 Swazey Parkway
RD-8 Water Street
Recreational Areas
RC-6 Founders Park
RC-8 Lagoon Trail
RC-11 Park Street Common
RC-13 Stewart Waterfront Park
RC-14 Swazey Park
EXETER
NW QUAD
NE QUAD
INSET
SW QUAD
SE QUAD
N
Squamscott River
Exeter Reservoir Dam
Stratham
0 0.05 0.1 0.2 0.3 0.4 Miles

CAPE Project
DEPTH OF FLOODING
NORTHWEST QUADRANT

2070 HIGH
100-YEAR PRECIPITATION
Dam Out with Storm Surge
Date: 3/30/2015

LEGEND

- ■ Above Ground Storage Tank
- ▲ Sewer Pump Station
- ▼ Water Pump Station
- ⦿ Proposed Well
- ● Existing Well
- Flood Model Limits (HEC-RAS)

Critical Travelways

- RD-11 Brentwood Road

Recreational

- RC-2 Colcord Pond

Reference Flood Extents

- 2010 Dam-In 100-Year Mean High High Water

Flood Depths

2070 Dam-Out 100-Year MHHW with Storm Surge

- 0 - 3 feet
- 3 - 6 feet
- 6 - 9 feet
- 9 - 12 feet
- 12 - 15 feet
- 15 - 18 feet

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Sources:
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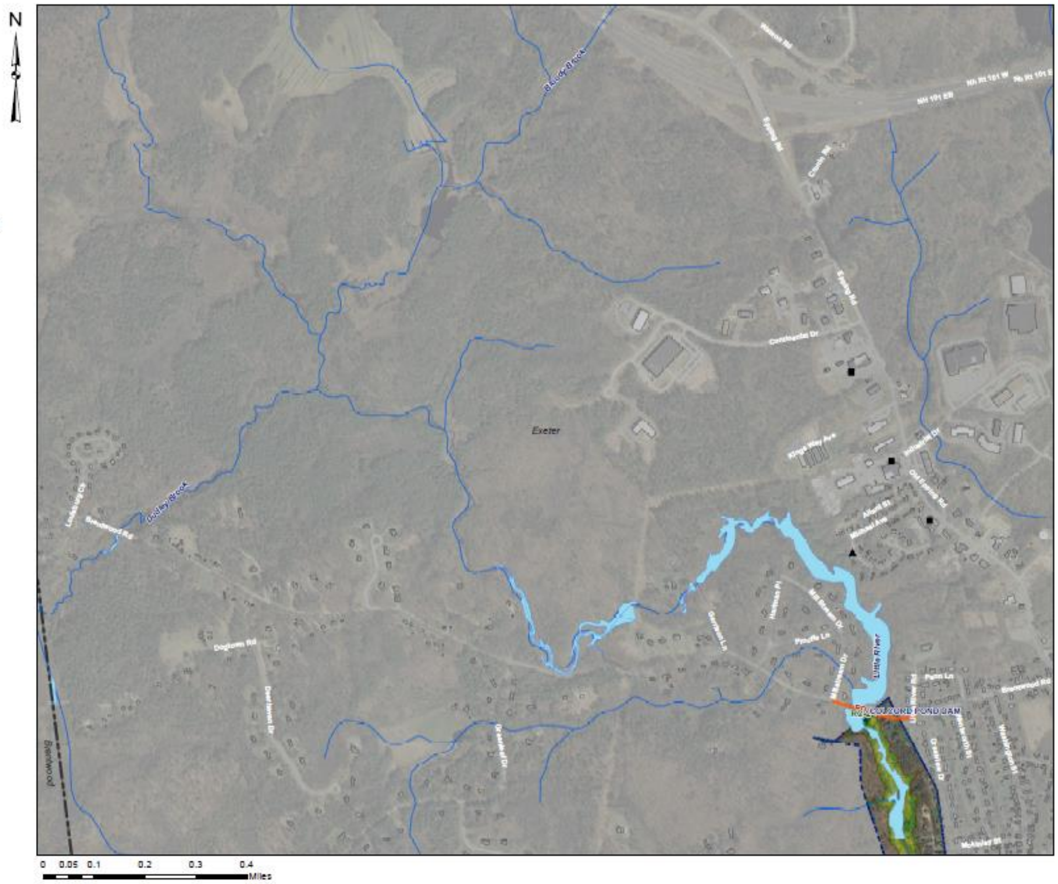
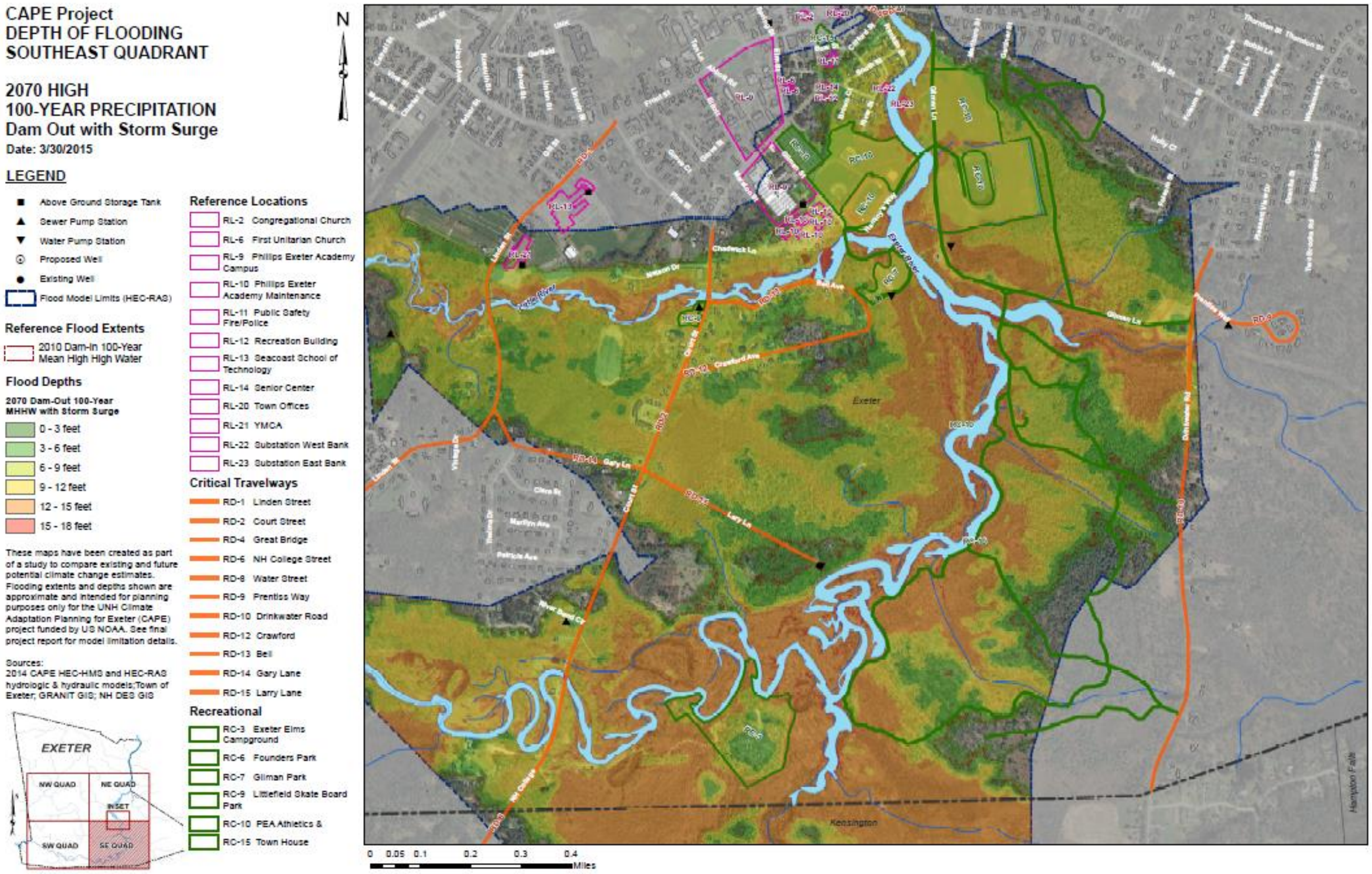
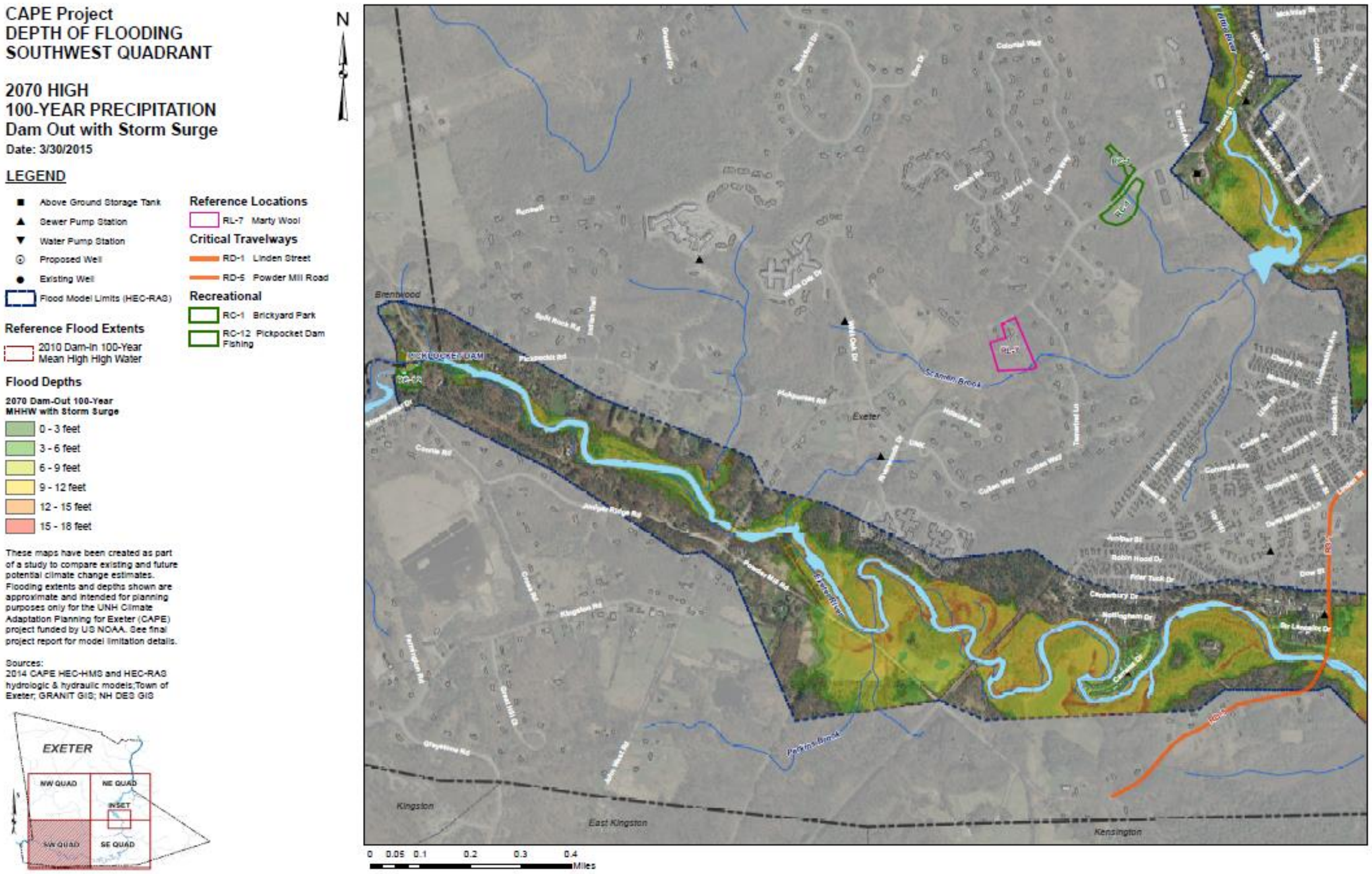
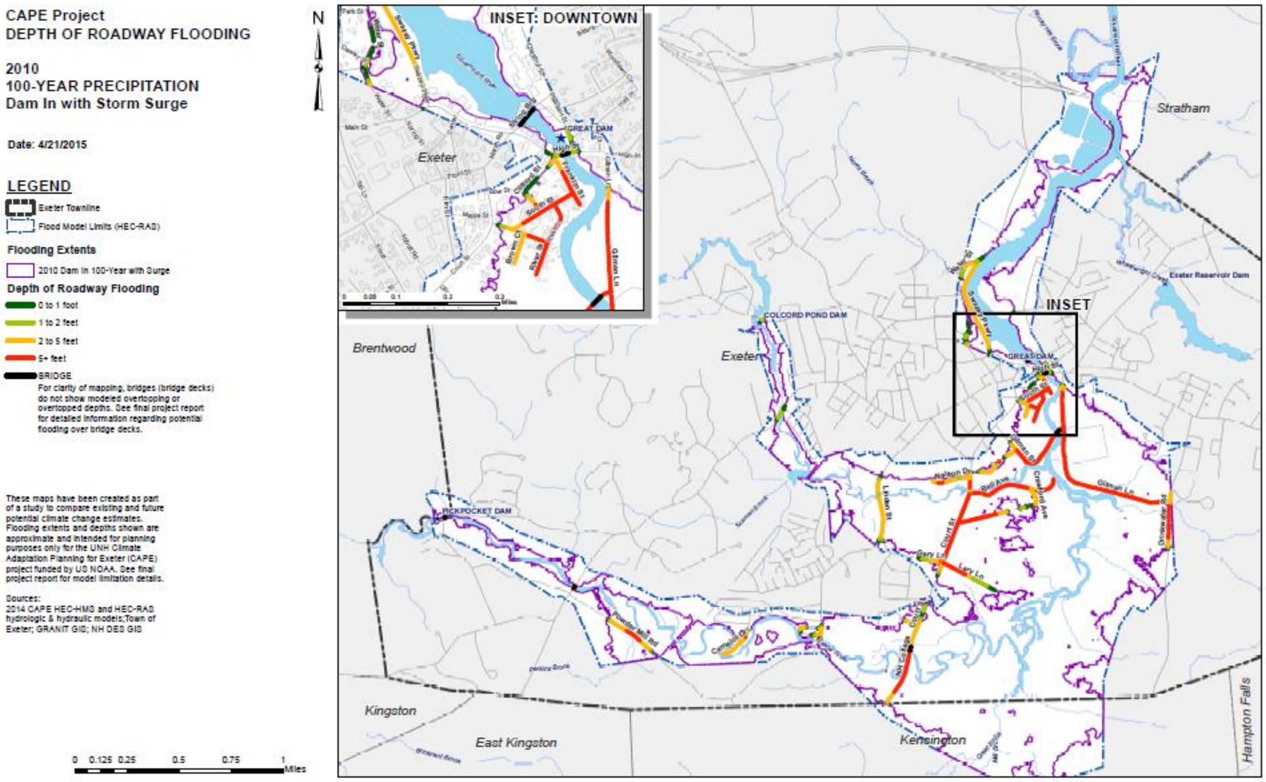



CAPE Project
DEPTH OF FLOODING
SOUTHEAST QUADRANT
2070 HIGH
100-YEAR PRECIPITATION
Dam Out with Storm Surge
Date: 3/30/2015
N
LEGEND
Above Ground Storage Tank
Sewer Pump Station
Water Pump Station
Proposed Well
Existing Well
Flood Model Limits (HEC-RAS)
Reference Flood Extents
2010 Dam-In 100-Year Mean High High Water
Flood Depths
2070 Dam-Out 100-Year MHHW with Storm Surge
0 - 3 feet
3 - 6 feet
6 - 9 feet
9 - 12 feet
12 - 15 feet
15 - 18 feet
These maps have been created as part of a study to compare existing and future potential climate change estimates. Flooding extents and depths shown are approximate and intended for planning purposes only for the UNH Climate Adaptation Planning for Exeter (CAPE) project funded by US NOAA. See final project report for model limitation details.
Sources:
2014 CAPE HEC-HMS and HEC-RAS hydrologic & hydraulic models;Town of Exeter; GRANIT GIS; NH DES GIS
EXETER
NW QUAD
NE QUAD
INSET
SW QUAD
SE QUAD
Reference Locations
RL-2 Congregational Church
RL-6 First Unitarian Church
RL-9 Phillips Exeter Academy Campus
RL-10 Phillips Exeter Academy Maintenance
RL-11 Public Safety Fire/Police
RL-12 Recreation Building
RL-13 Seacoast School of Technology
RL-14 Senior Center
RL-20 Town Offices
RL-21 YMCA
RL-22 Substation West Bank
RL-23 Substation East Bank
Critical Travelways
RD-1 Linden Street
RD-2 Court Street
RD-4 Great Bridge
RD-6 NH College Street
RD-8 Water Street
RD-9 Prentiss Way
RD-10 Drinkwater Road
RD-12 Crawford
RD-13 Bell
RD-14 Gary Lane
RD-15 Larry Lane
Recreational
RC-3 Exeter Elms Campground
RC-6 Founders Park
RC-7 Gilman Park
RC-9 Littlefield Skate Board Park
RC-10 PEA Athletics &
RC-15 Town House
Exeter
Kensington
0 0.05 0.1 0.2 0.3 0.4
Miles


CAPE Project
DEPTH OF FLOODING
SOUTHWEST QUADRANT
2070 HIGH
100-YEAR PRECIPITATION
Dam Out with Storm Surge
Date: 3/30/2015
LEGEND
Above Ground Storage Tank
Sewer Pump Station
Water Pump Station
Proposed Well
Existing Well
Flood Model Limits (HEC-RAS)
Reference Flood Extents
2010 Dam-In 100-Year Mean High High Water
Flood Depths
2070 Dam-Out 100-Year MHHW with Storm Surge
0 - 3 feet
3 - 6 feet
6 - 9 feet
9 - 12 feet
12 - 15 feet
15 - 18 feet
Reference Locations
RL-7 Marty Wool
Critical Travelways
RD-1 Linden Street
RD-5 Powder Mill Road
Recreational
RC-1 Brickyard Park
RC-12 Pickpocket Dam Fishing
These maps have been created as part of a study to compare existing and future potential climate change estimates. Flooding extents and depths shown are approximate and intended for planning purposes only for the UNH Climate Adaptation Planning for Exeter (CAPE) project funded by US NOAA. See final project report for model limitation details.
Sources:
2014 CAPE HEC-HMS and HEC-RAS hydrologic & hydraulic models;Town of Exeter; GRANIT GIS; NH DES GIS
EXETER
NW QUAD
NE QUAD
INSET
SW QUAD
SE QUAD
N
Brentwood
Exeter
Kingston
East Kingston
Kensington
0 0.05 0.1 0.2 0.3 0.4
Miles

Road Flooding



CAPE Project
DEPTH OF ROADWAY FLOODING

2010
100-YEAR PRECIPITATION
Dam Out with Storm Surge

Date: 4/21/2015

LEGEND

Exeter Townline
Flood Model Limits (HEC-RAS)

Flooding Extents

2010 Dam Out 100-Year with Surge

Depth of Roadway Flooding

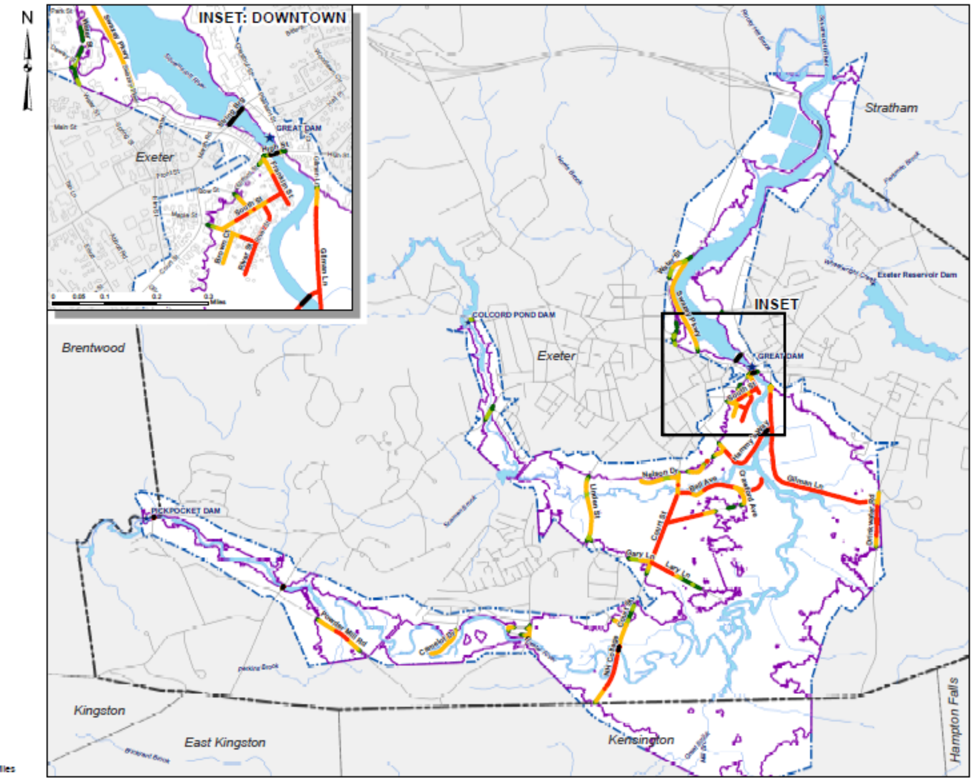
- 0 to 1 foot
- 1 to 2 feet
- 2 to 5 feet
- 5+ feet
- BRIDGE

For clarity of mapping, bridges (bridge decks) do not show modeled overtopping or overtopped depths. See final project report for detailed information regarding potential flooding over bridge decks.

These maps have been created as part of a study to compare existing and future potential climate change estimates. Flooding extents and depths shown are approximate and intended for planning purposes only for the UNH Climate Adaptation Planning for Exeter (CAPE) project funded by US NOAA. See final project report for model limitation details.

Sources:
2014 CAPE HEC-HMS and HEC-RAS hydrologic & hydraulic models;Town of Exeter; GRANIT GIS; NH DES GIS

0 0.125 0.25 0.5 0.75 1 Miles



CAPE Project
DEPTH OF ROADWAY FLOODING

2040
100-YEAR PRECIPITATION
Dam Out with Storm Surge

Date: 4/21/2015

LEGEND

Exeter Townline
Flood Model Limits (HEC-RAS)

Flooding Extents

2040 Dam Out 100-Year with Surge

Depth of Roadway Flooding

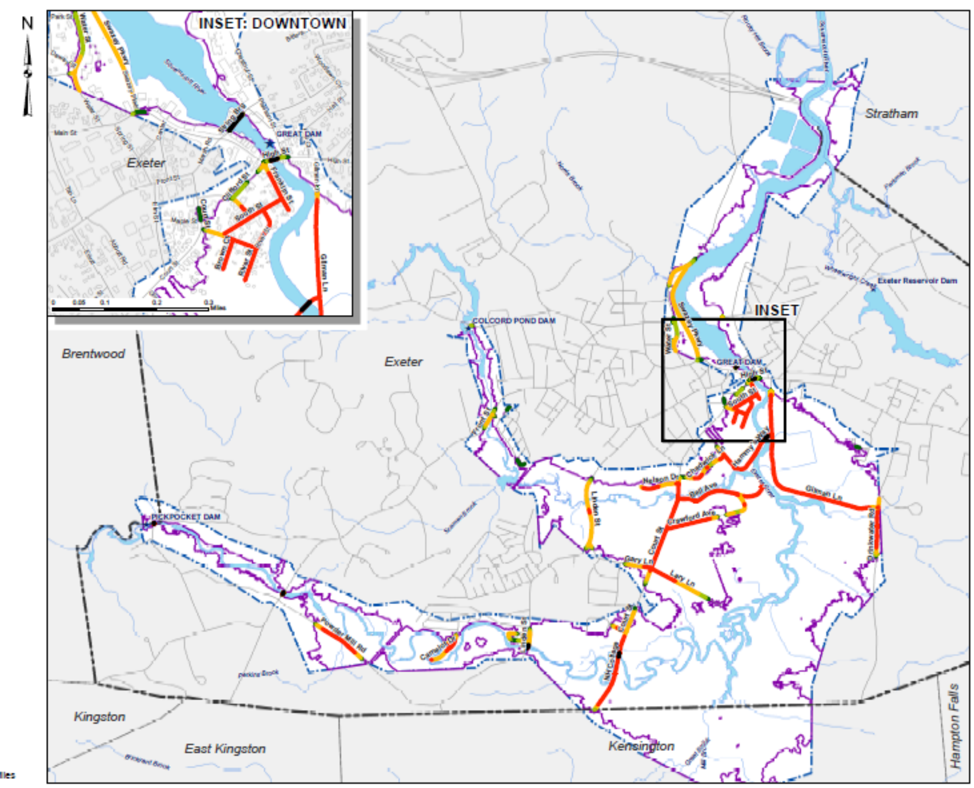
- 0 to 1 foot
- 1 to 2 feet
- 2 to 5 feet
- 5+ feet
- BRIDGE

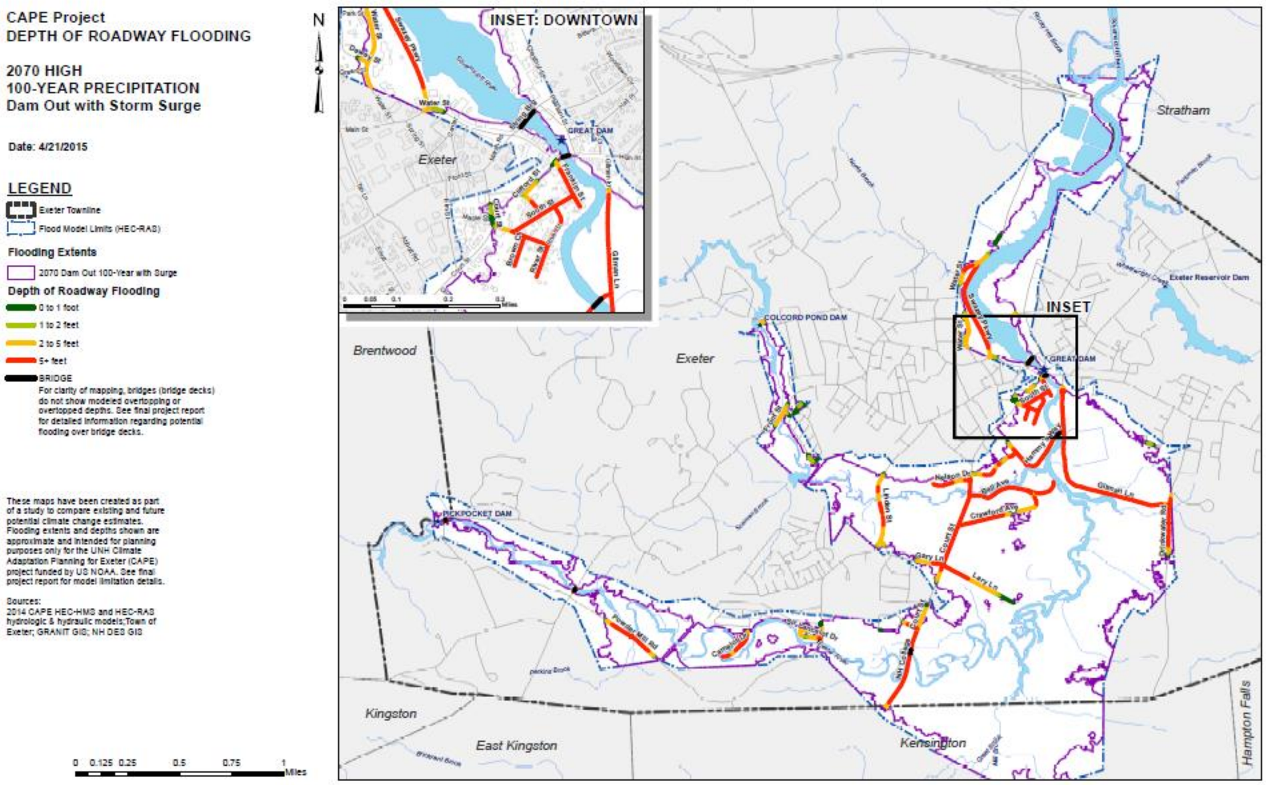
For clarity of mapping, bridges (bridge decks) do not show modeled overtopping or overtopped depths. See final project report for detailed information regarding potential flooding over bridge decks.

These maps have been created as part of a study to compare existing and future potential climate change estimates. Flooding extents and depths shown are approximate and intended for planning purposes only for the UNH Climate Adaptation Planning for Exeter (CAPE) project funded by US NOAA. See final project report for model limitation details.

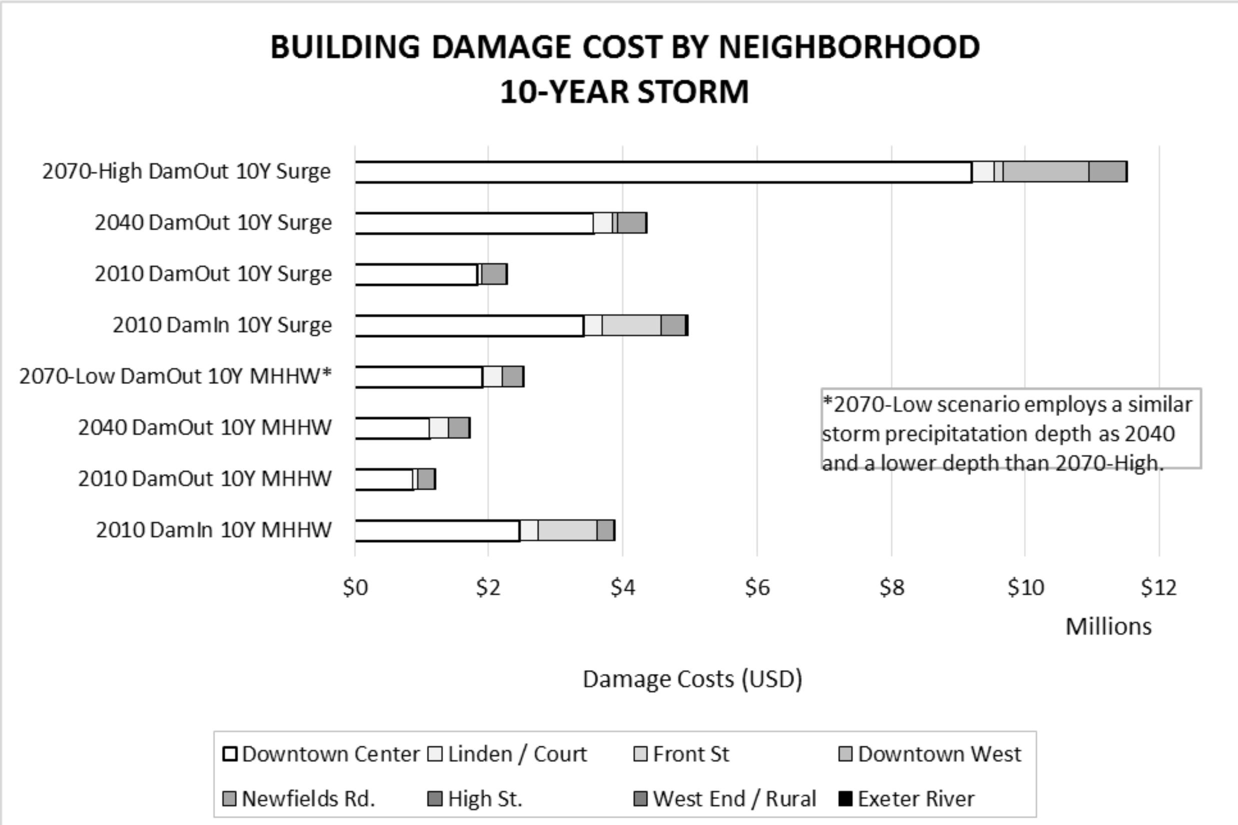
Sources:
2014 CAPE HEC-HMS and HEC-RAS hydrologic & hydraulic models;Town of Exeter; GRANIT GIS; NH DES GIS

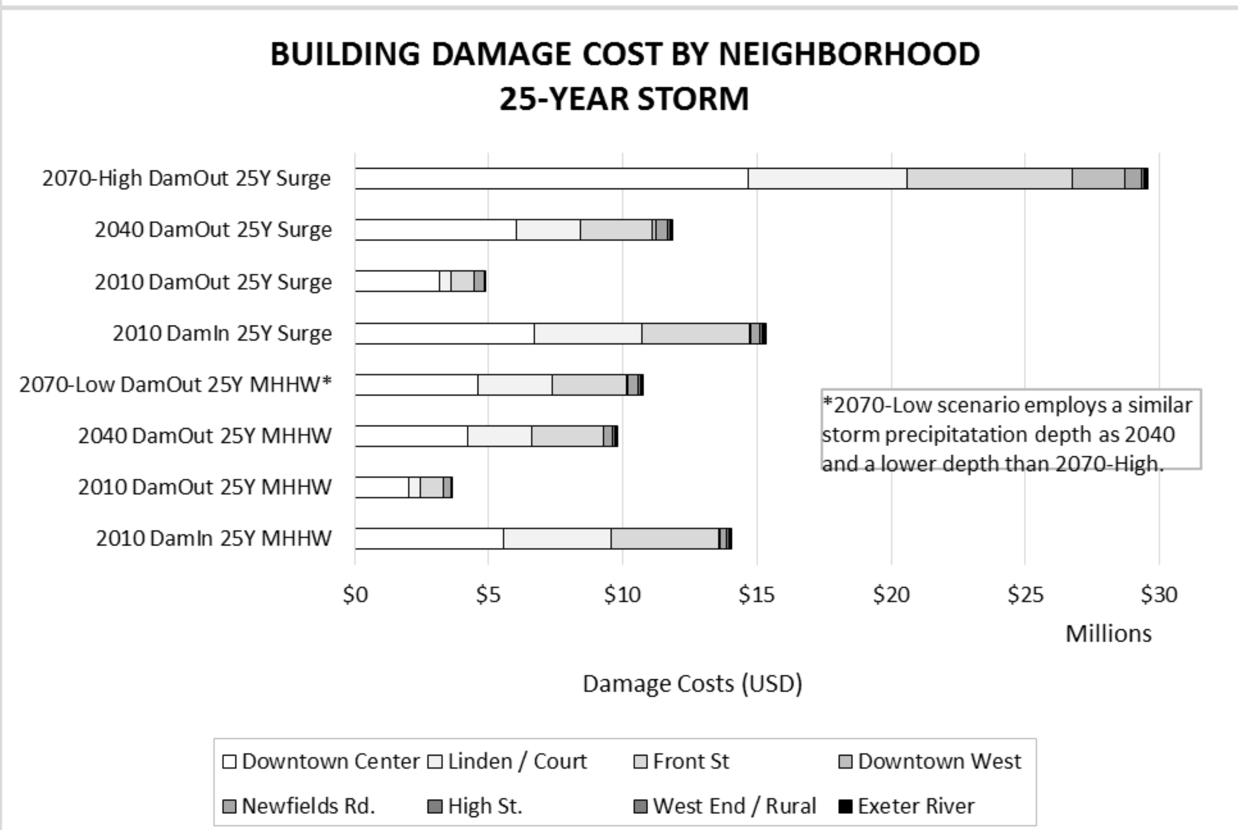
0 0.125 0.25 0.5 0.75 1 Miles

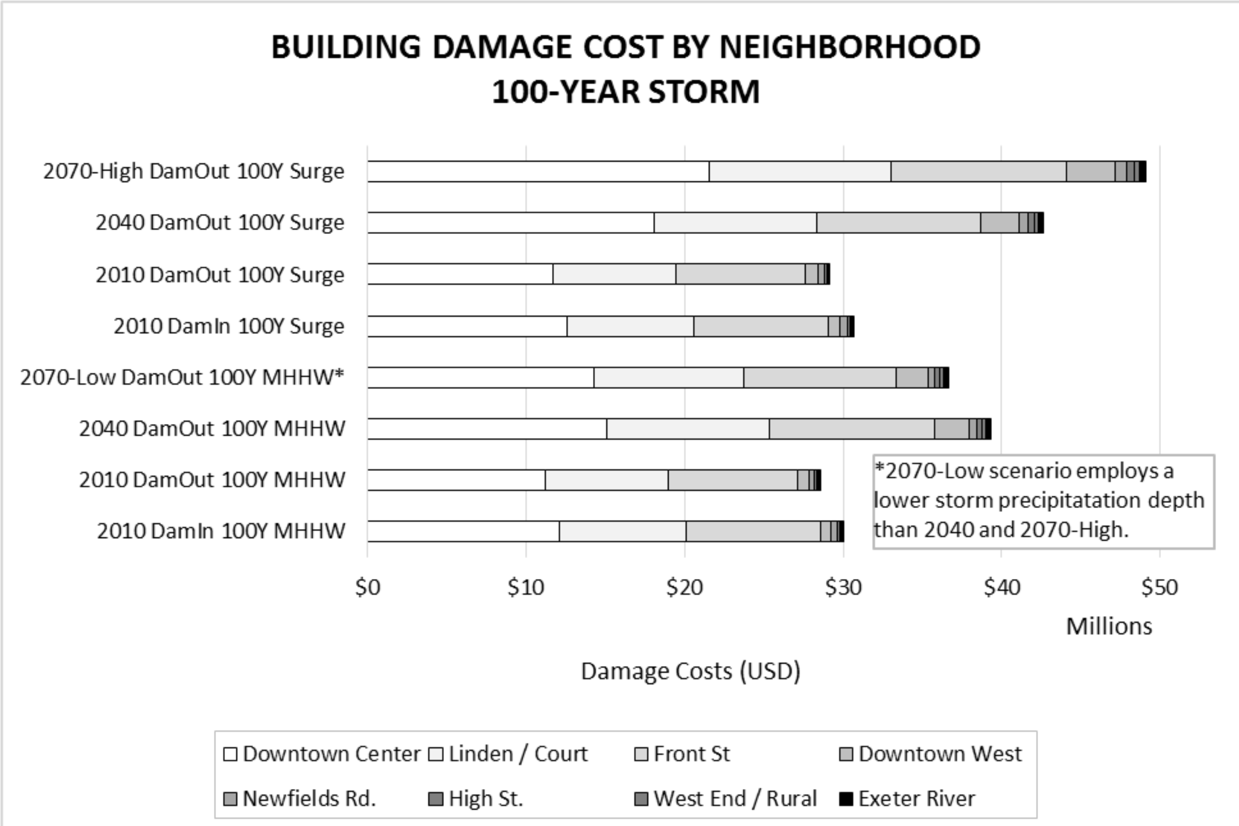


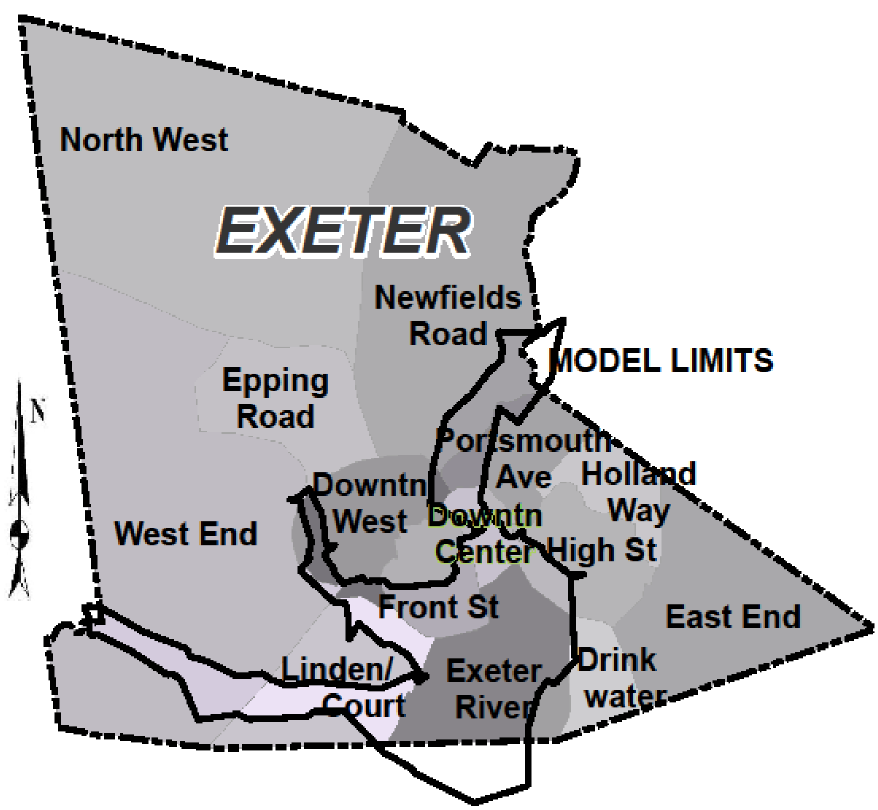


Impacts of Flooding


BUILDING DAMAGE COST BY NEIGHBORHOOD
10-YEAR STORM
2070-High DamOut 10Y Surge
2040 DamOut 10Y Surge
2010 DamOut 10Y Surge
2010 DamIn 10Y Surge
2070-Low DamOut 10Y MHHW*
2040 DamOut 10Y MHHW
2010 DamOut 10Y MHHW
2010 DamIn 10Y MHHW
*2070-Low scenario employs a similar storm precipitatation depth as 2040 and a lower depth than 2070-High.
$0
$2
$4
$6
$8
$10
$12
Millions
Damage Costs (USD)
Downtown Center
Linden / Court
Front St
Downtown West
Newfields Rd.
High St.
West End / Rural
Exeter River

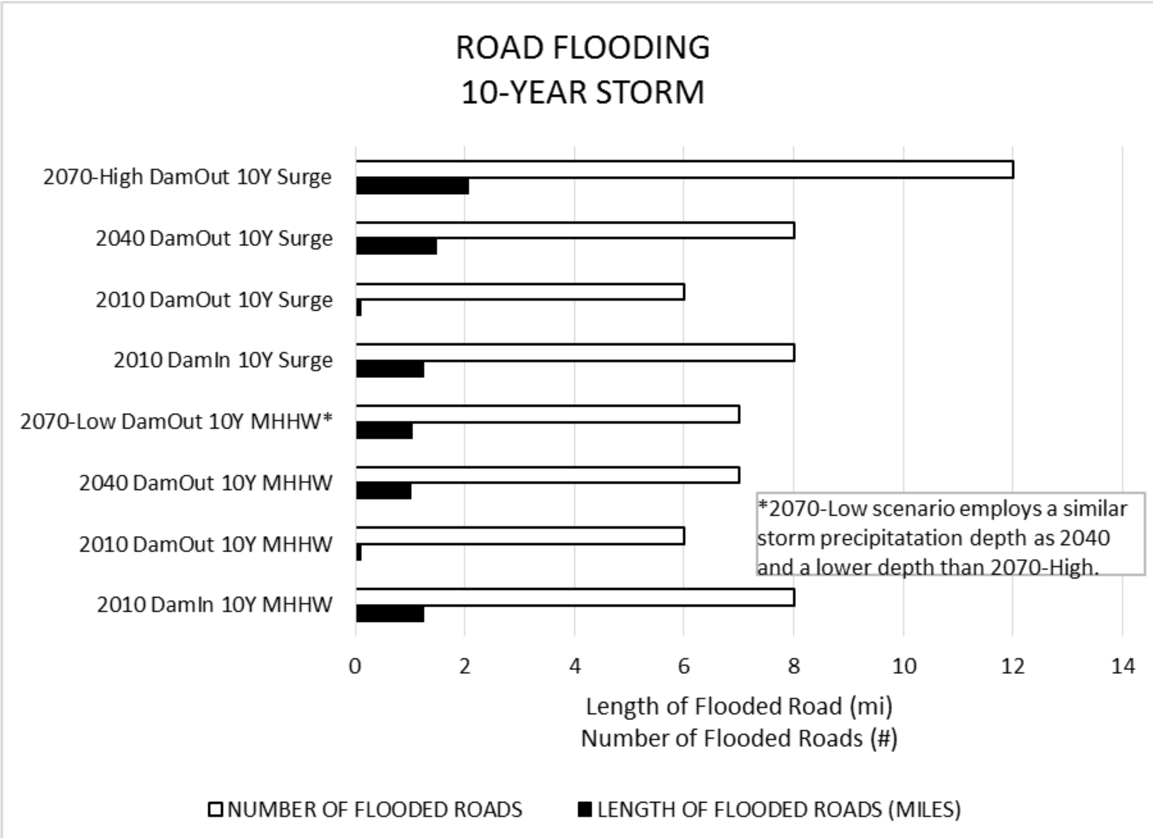

BUILDING DAMAGE COST BY NEIGHBORHOOD
25-YEAR STORM
2070-High DamOut 25Y Surge
2040 DamOut 25Y Surge
2010 DamOut 25Y Surge
2010 DamIn 25Y Surge
2070-Low DamOut 25Y MHHW*
2040 DamOut 25Y MHHW
2010 DamOut 25Y MHHW
2010 DamIn 25Y MHHW
*2070-Low scenario employs a similar storm precipitatation depth as 2040 and a lower depth than 2070-High.
$0
$5
$10
$15
$20
$25
$30
Millions
Damage Costs (USD)
Downtown Center
Linden / Court
Front St
Downtown West
Newfields Rd.
High St.
West End / Rural
Exeter River

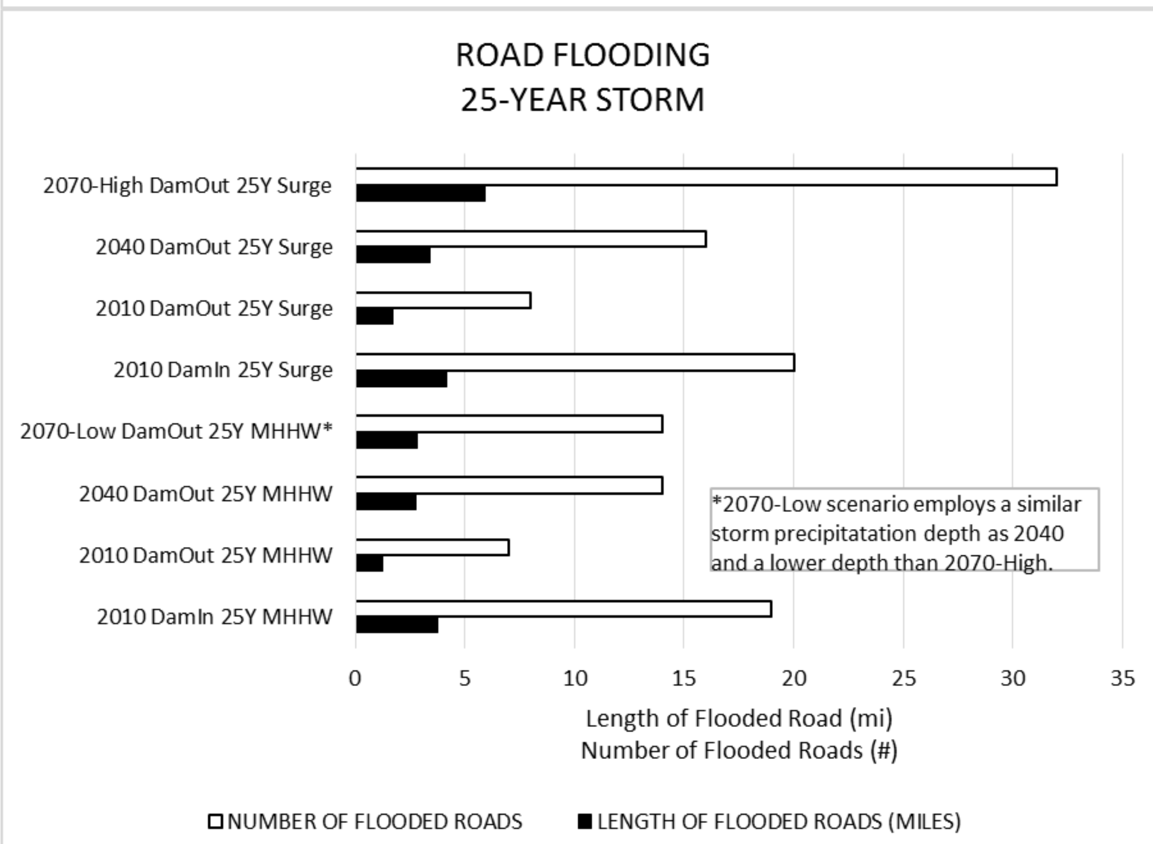

BUILDING DAMAGE COST BY NEIGHBORHOOD
100-YEAR STORM
2070-High DamOut 100Y Surge
2040 DamOut 100Y Surge
2010 DamOut 100Y Surge
2010 DamIn 100Y Surge
2070-Low DamOut 100Y MHHW*
2040 DamOut 100Y MHHW
2010 DamOut 100Y MHHW
2010 DamIn 100Y MHHW
*2070-Low scenario employs a lower storm precipitation depth than 2040 and 2070-High.
$0
$10
$20
$30
$40
$50
Millions
Damage Costs (USD)
Downtown Center
Linden / Court
Front St
Downtown West
Newfields Rd.
High St.
West End / Rural
Exeter River

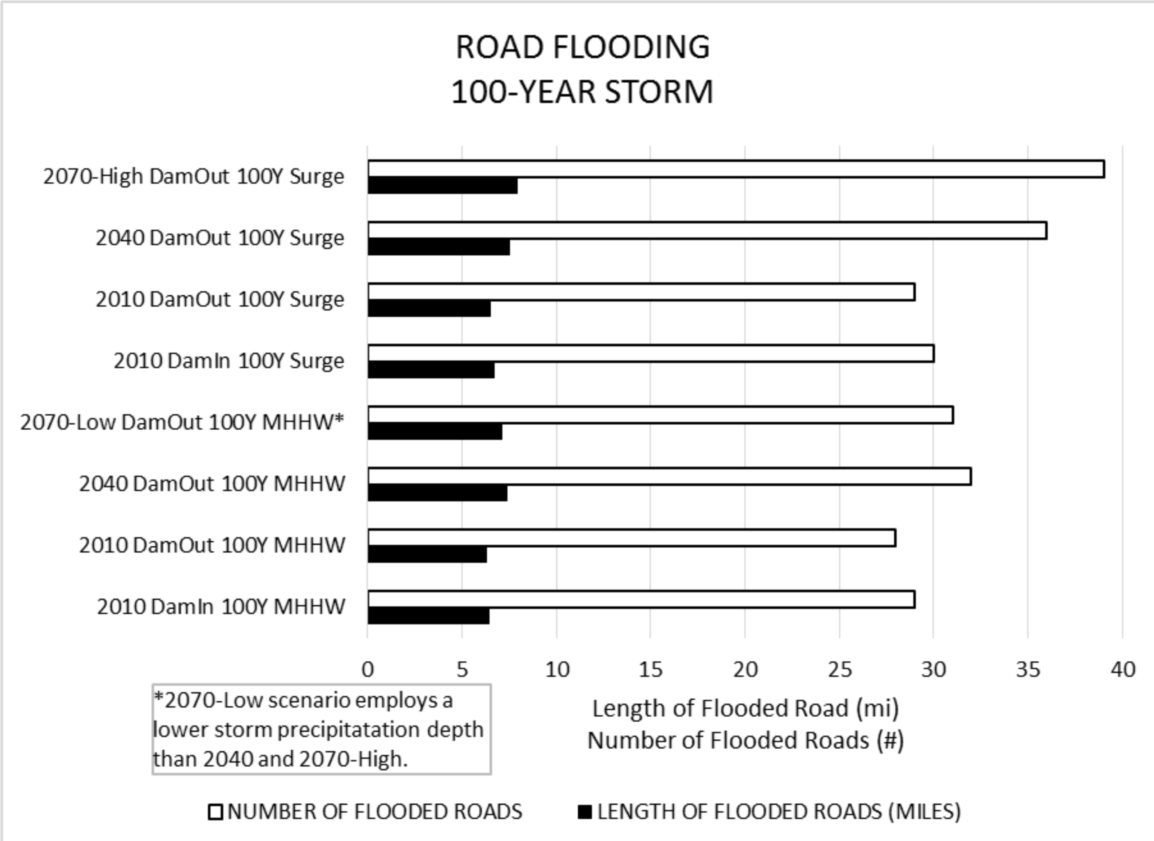

North West
EXETER
Newfields Road
MODEL LIMITS
Epping Road
Portsmouth Ave
Holland Way
Downtn West
Downtn Center
High St
West End
Front St
East End
Linden/ Court
Exeter River
Drink water
N

SUMMARY OF TOTAL BUILDING DAMAGE COSTS (Millions of USD)								
SCENARIO / NEIGHBORHOOD	**Down town Center**	**Down town West**	**Exeter River**	**Front St**	**High St.**	**Linden/ Court**	**Newfields Rd.**	**West End/ Rural**
2010 DamIn 10Y MHHW	$2.5	$0.0	$0.0	$0.9	$0.0	$0.3	$0.3	$0.0
2010 DamOut 10Y MHHW	$0.9	$0.0	$0.0	$0.0	$0.0	$0.1	$0.3	$0.0
2040 DamOut 10Y MHHW	$1.1	$0.0	$0.0	$0.0	$0.0	$0.3	$0.3	$0.0
2070-Low DamOut 10Y MHHW*	$1.9	$0.0	$0.0	$0.0	$0.0	$0.3	$0.3	$0.0
2010 DamIn 10Y Surge	$3.4	$0.0	$0.0	$0.9	$0.0	$0.3	$0.4	$0.0
2010 DamOut 10Y Surge	$1.8	$0.0	$0.0	$0.0	$0.0	$0.1	$0.4	$0.0
2040 DamOut 10Y Surge	$3.6	$0.1	$0.0	$0.0	$0.0	$0.3	$0.4	$0.0
2070-High DamOut 10Y Surge	$9.2	$1.3	$0.0	$0.1	$0.0	$0.3	$0.5	$0.0
2010 DamIn 25Y MHHW	$5.5	$0.0	$0.1	$4.0	$0.0	$4.0	$0.3	$0.1
2010 DamOut 25Y MHHW	$2.0	$0.0	$0.0	$0.9	$0.0	$0.4	$0.3	$0.0
2040 DamOut 25Y MHHW	$4.2	$0.0	$0.1	$2.7	$0.0	$2.4	$0.3	$0.1
2070-Low DamOut 25Y MHHW*	$4.6	$0.0	$0.1	$2.7	$0.0	$2.8	$0.4	$0.1
2010 DamIn 25Y Surge	$6.7	$0.0	$0.1	$4.0	$0.0	$4.0	$0.4	$0.1
2010 DamOut 25Y Surge	$3.2	$0.0	$0.0	$0.9	$0.0	$0.4	$0.4	$0.0
2040 DamOut 25Y Surge	$6.0	$0.1	$0.1	$2.7	$0.0	$2.4	$0.4	$0.1
2070-High DamOut 25Y Surge	$14.6	$2.0	$0.1	$6.1	$0.0	$5.9	$0.6	$0.1
2010 DamIn 100Y MHHW	$12.1	$0.6	$0.2	$8.5	$0.0	$8.0	$0.4	$0.2
2010 DamOut 100Y MHHW	$11.2	$0.7	$0.2	$8.2	$0.0	$7.7	$0.4	$0.2
2040 DamOut 100Y MHHW	$15.1	$2.2	$0.3	$10.4	$0.4	$10.3	$0.5	$0.3
2070-Low DamOut 100Y MHHW*	$14.3	$2.0	$0.3	$9.6	$0.3	$9.4	$0.4	$0.2
2010 DamIn 100Y Surge	$12.6	$0.8	$0.2	$8.5	$0.0	$8.0	$0.4	$0.2
2010 DamOut 100Y Surge	$11.7	$0.8	$0.2	$8.2	$0.0	$7.7	$0.4	$0.2
2040 DamOut 100Y Surge	$18.0	$2.4	$0.3	$10.4	$0.4	$10.3	$0.5	$0.3
2070-High DamOut 100Y Surge	$21.6	$3.1	$0.3	$11.1	$0.5	$11.5	$0.7	$0.4

TOTAL ROADWAY FLOODING		
SCENARIO	**LENGTH OF FLOODED ROADS (MILES)**	**NUMBER OF FLOODED ROADS**
2010 DamIn 10Y MHHW	1.2	8
2010 DamOut 10Y MHHW	0.1	6
2040 DamOut 10Y MHHW	1.0	7
2070-Low DamOut 10Y MHHW*	1.0	7
2010 DamIn 10Y Surge	1.2	8
2010 DamOut 10Y Surge	0.1	6
2040 DamOut 10Y Surge	1.5	8
2070-High DamOut 10Y Surge	2.1	12
2010 DamIn 25Y MHHW	3.7	19
2010 DamOut 25Y MHHW	1.2	7
2040 DamOut 25Y MHHW	2.7	14
2070-Low DamOut 25Y MHHW*	2.8	14
2010 DamIn 25Y Surge	4.2	20
2010 DamOut 25Y Surge	1.7	8
2040 DamOut 25Y Surge	3.4	16
2070-High DamOut 25Y Surge	5.9	32
2010 DamIn 100Y MHHW	6.5	29
2010 DamOut 100Y MHHW	6.3	28
2040 DamOut 100Y MHHW	7.4	32
2070-Low DamOut 100Y MHHW*	7.1	31
2010 DamIn 100Y Surge	6.7	30
2010 DamOut 100Y Surge	6.5	29
2040 DamOut 100Y Surge	7.5	36
2070-High DamOut 100Y Surge	7.9	39

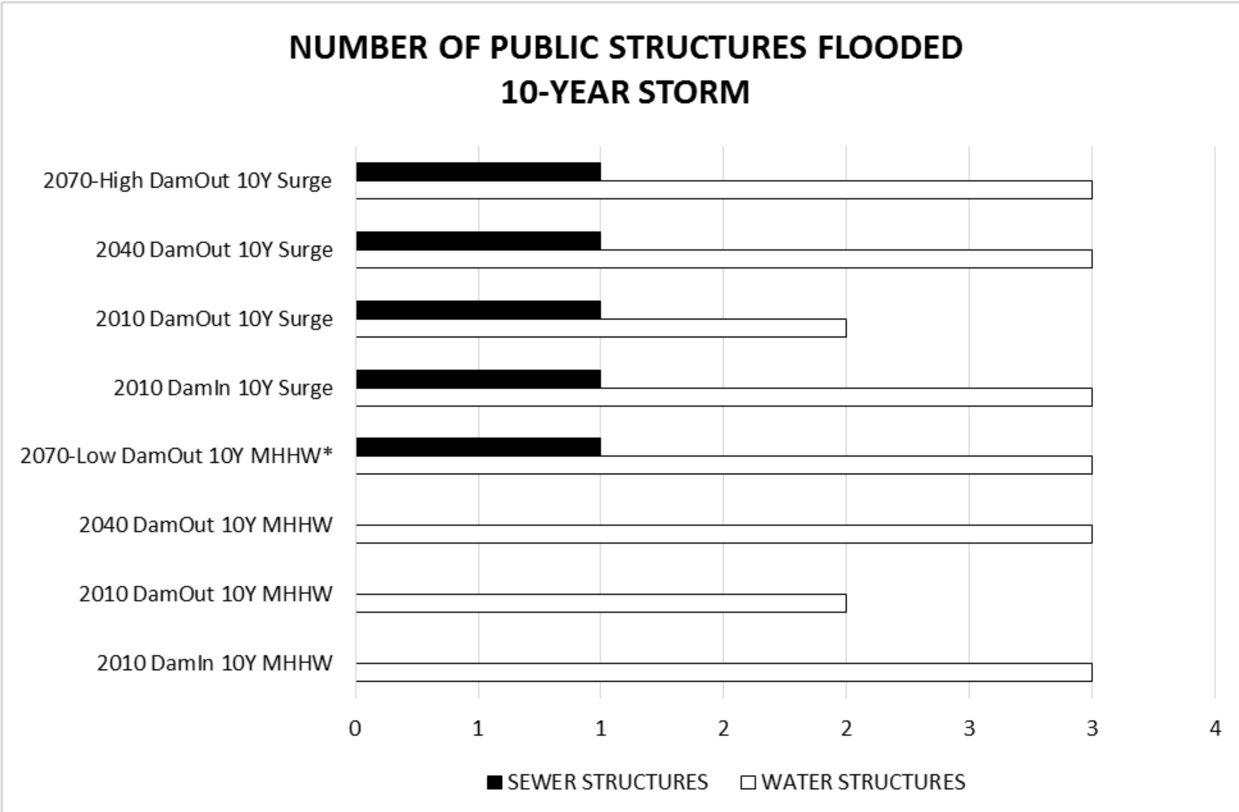

ROAD FLOODING
10-YEAR STORM
2070-High DamOut 10Y Surge
2040 DamOut 10Y Surge
2010 DamOut 10Y Surge
2010 DamIn 10Y Surge
2070-Low DamOut 10Y MHHW*
2040 DamOut 10Y MHHW
2010 DamOut 10Y MHHW
2010 DamIn 10Y MHHW
*2070-Low scenario employs a similar storm precipitatation depth as 2040 and a lower depth than 2070-High.
0 2 4 6 8 10 12 14
Length of Flooded Road (mi)
Number of Flooded Roads (#)
NUMBER OF FLOODED ROADS
LENGTH OF FLOODED ROADS (MILES)

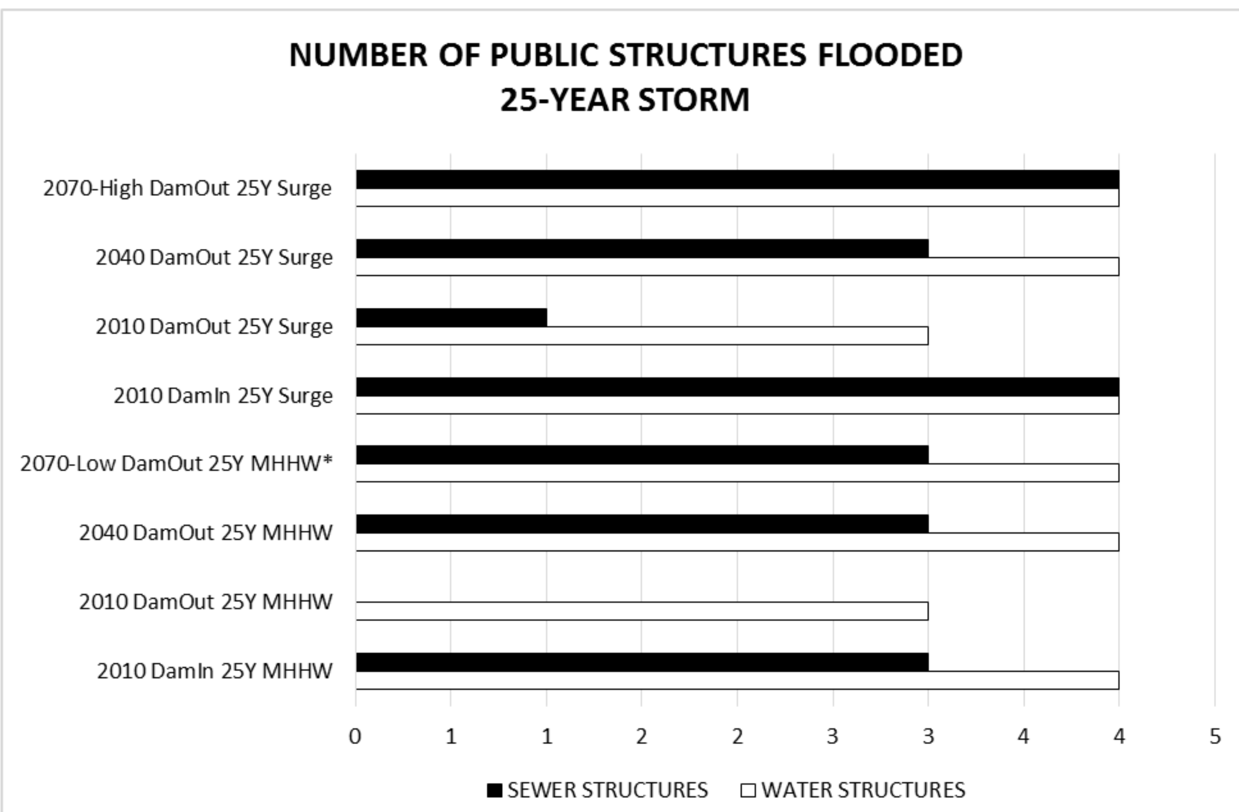

ROAD FLOODING
25-YEAR STORM
2070-High DamOut 25Y Surge
2040 DamOut 25Y Surge
2010 DamOut 25Y Surge
2010 DamIn 25Y Surge
2070-Low DamOut 25Y MHHW*
2040 DamOut 25Y MHHW
2010 DamOut 25Y MHHW
2010 DamIn 25Y MHHW
*2070-Low scenario employs a similar storm precipitatation depth as 2040 and a lower depth than 2070-High.
0 5 10 15 20 25 30 35
Length of Flooded Road (mi)
Number of Flooded Roads (#)
NUMBER OF FLOODED ROADS
LENGTH OF FLOODED ROADS (MILES)

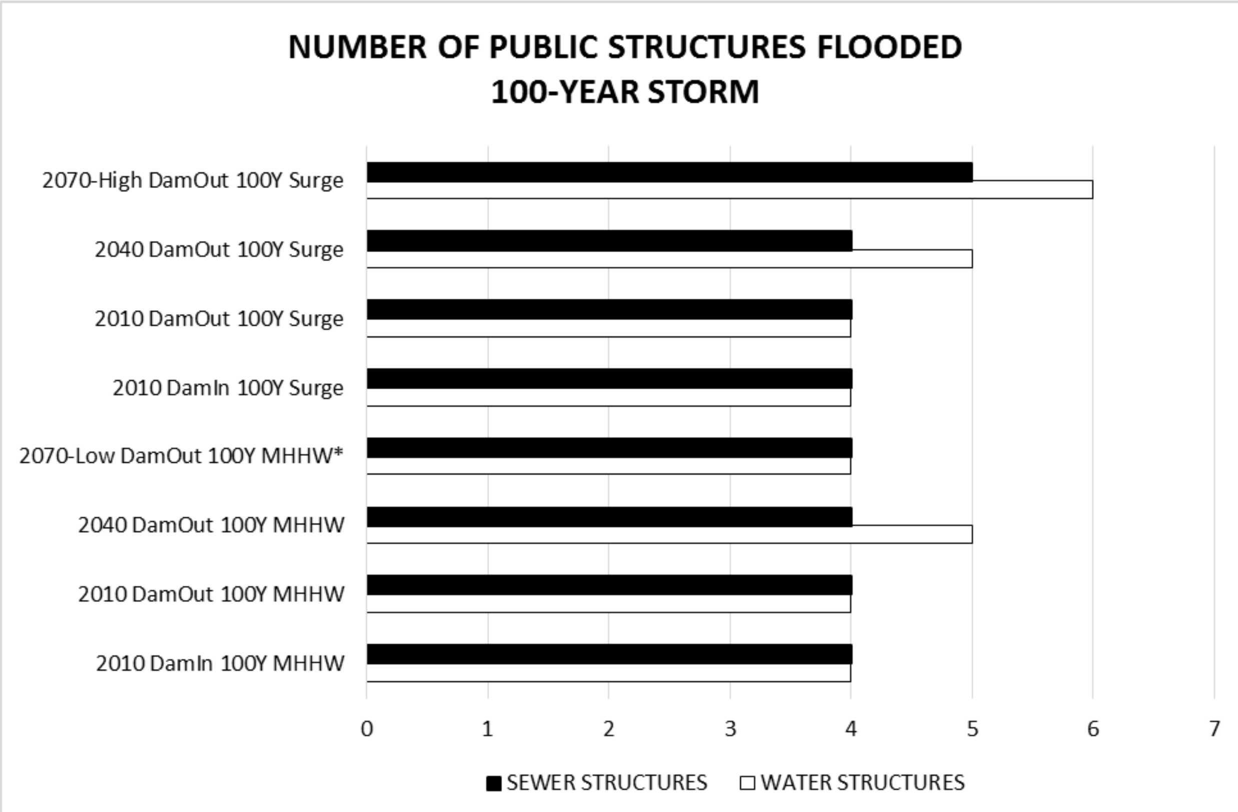


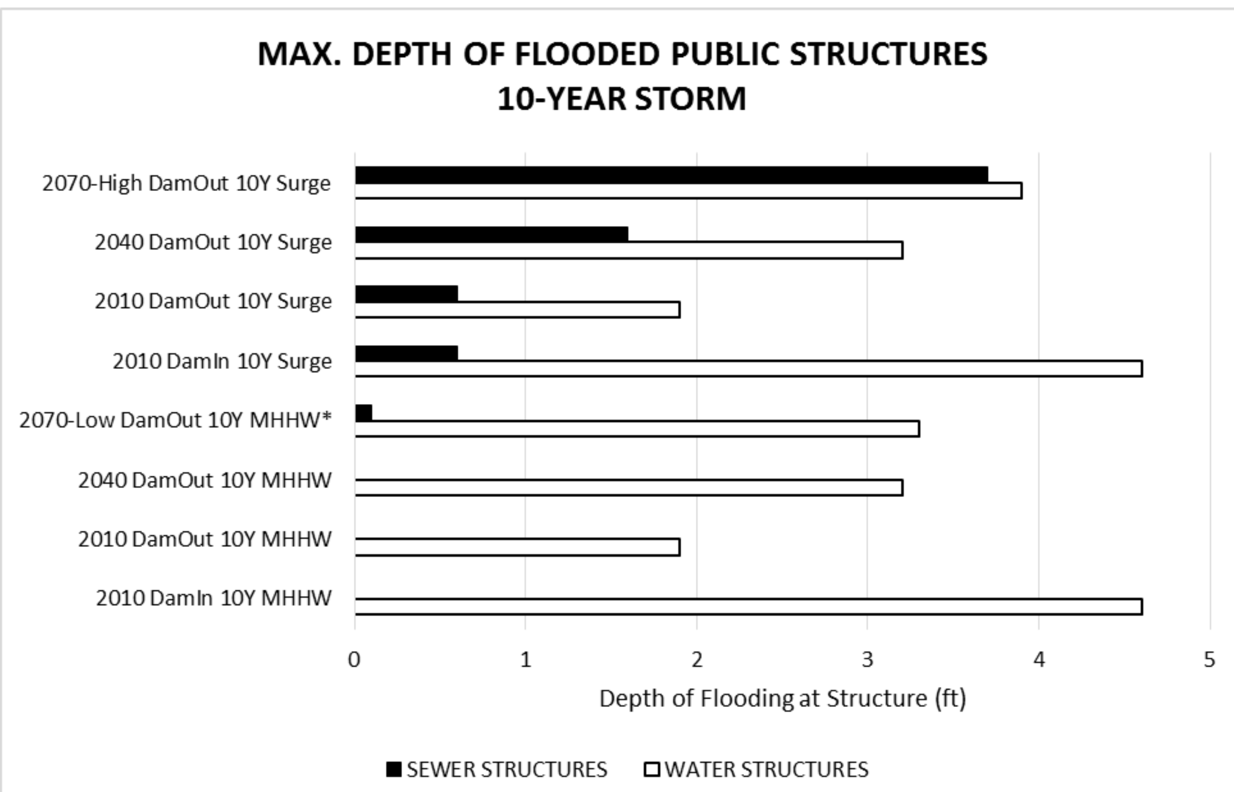
FLOODED ROADS LIST BY MIN. / MAX. SCENARIO					
2010 DamOut 10Y MHHW (6)	**2070-High DamOut 100Y Surge (39)**				
Cross Rd	Bell Ave	Crawford Ave	Gilman St	Maid Marion Dr	River St
Gilman Ln	Bow St	Cross Rd	Green St	Nelson Dr	River St Ext
Gilman St	Brentwood Rd	Dewey St	Hammy's Way	Newfields Rd	Sir Lancelot
Hammy's Way	Brown Ct	Drinkwater Rd	High St	NH College	South St
High St	Camelot Dr	Franklin St	Jady Hill Rd	North Haverhill Rd	Swazey Pkwy
Kingston Rd	Chadwick Ln	Front St	Kingston Rd	Park St	Water St
NH College	Clifford St	Gary Ln	Lary Ln	Powder Mill Rd	Westside Dr
Powder Mill Rd	Court St	Gilman Ln	Linden St	River Bend Cir	

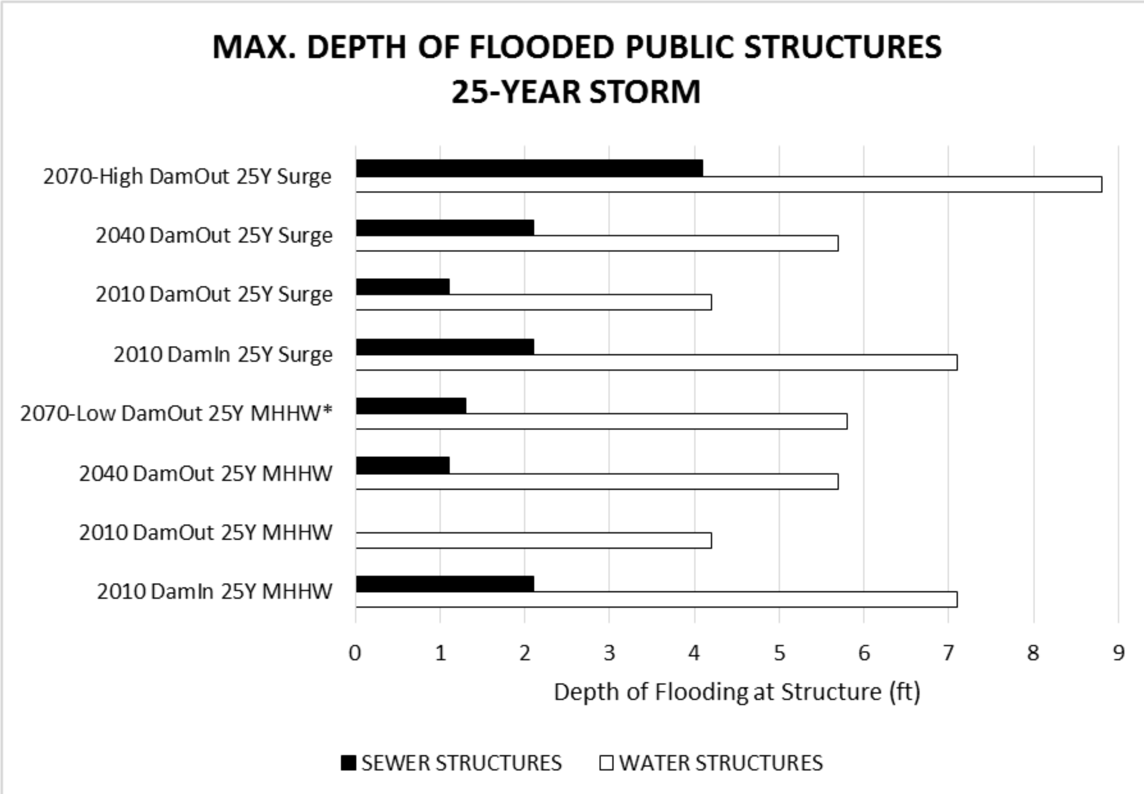
PUBLIC STRUCTURE FLOODING				
SCENARIO	WATER		SEWER	
	NUMBER FLOODED STRUCTURES	MAX. DEPTH (FT)	NUMBER FLOODED STRUCTURES	MAX. DEPTH (FT)
2010 DamIn 10Y MHHW	3	4.6	0	0.0
2010 DamOut 10Y MHHW	2	1.9	0	0.0
2040 DamOut 10Y MHHW	3	3.2	0	0.0
2070-Low DamOut 10Y MHHW*	3	3.3	1	0.1
2010 DamIn 10Y Surge	3	4.6	1	0.6
2010 DamOut 10Y Surge	2	1.9	1	0.6
2040 DamOut 10Y Surge	3	3.2	1	1.6
2070-High DamOut 10Y Surge	3	3.9	1	3.7
2010 DamIn 25Y MHHW	4	7.1	3	2.1
2010 DamOut 25Y MHHW	3	4.2	0	0.0
2040 DamOut 25Y MHHW	4	5.7	3	1.1
2070-Low DamOut 25Y MHHW*	4	5.8	3	1.3
2010 DamIn 25Y Surge	4	7.1	4	2.1
2010 DamOut 25Y Surge	3	4.2	1	1.1
2040 DamOut 25Y Surge	4	5.7	3	2.1
2070-High DamOut 25Y Surge	4	8.8	4	4.1
2010 DamIn 100Y MHHW	4	11.0	4	5.8
2010 DamOut 100Y MHHW	4	10.6	4	5.4
2040 DamOut 100Y MHHW	5	12.4	4	7.1
2070-Low DamOut 100Y MHHW*	4	11.9	4	6.7
2010 DamIn 100Y Surge	4	11.0	4	5.8
2010 DamOut 100Y Surge	4	10.6	4	5.4
2040 DamOut 100Y Surge	5	12.4	4	7.1
2070-High DamOut 100Y Surge	6	13.2	5	7.9

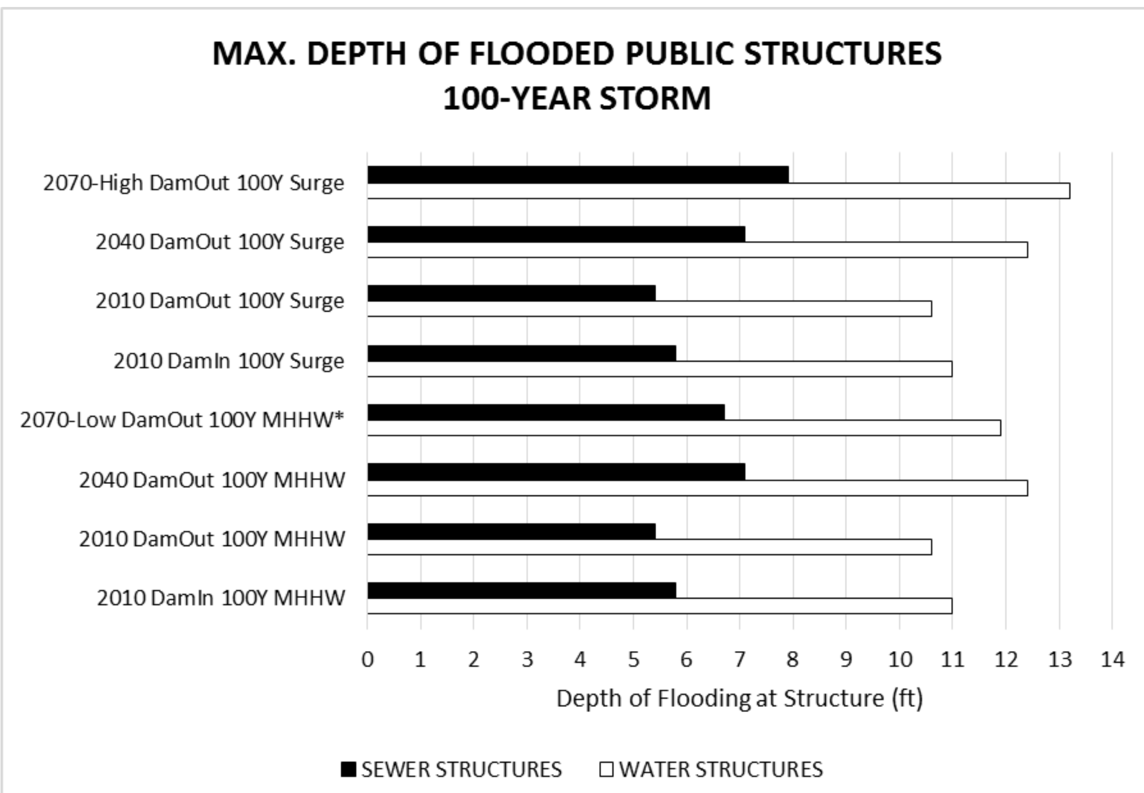

NUMBER OF PUBLIC STRUCTURES FLOODED
10-YEAR STORM
2070-High DamOut 10Y Surge
2040 DamOut 10Y Surge
2010 DamOut 10Y Surge
2010 DamIn 10Y Surge
2070-Low DamOut 10Y MHHW*
2040 DamOut 10Y MHHW
2010 DamOut 10Y MHHW
2010 DamIn 10Y MHHW
0 1 1 2 2 3 3 4
SEWER STRUCTURES
WATER STRUCTURES


NUMBER OF PUBLIC STRUCTURES FLOODED
25-YEAR STORM
2070-High DamOut 25Y Surge
2040 DamOut 25Y Surge
2010 DamOut 25Y Surge
2010 DamIn 25Y Surge
2070-Low DamOut 25Y MHHW*
2040 DamOut 25Y MHHW
2010 DamOut 25Y MHHW
2010 DamIn 25Y MHHW
0 1 1 2 2 3 3 4 4 5
SEWER STRUCTURES
WATER STRUCTURES


NUMBER OF PUBLIC STRUCTURES FLOODED
100-YEAR STORM
2070-High DamOut 100Y Surge
2040 DamOut 100Y Surge
2010 DamOut 100Y Surge
2010 DamIn 100Y Surge
2070-Low DamOut 100Y MHHW*
2040 DamOut 100Y MHHW
2010 DamOut 100Y MHHW
2010 DamIn 100Y MHHW
0
1
2
3
4
5
6
7
SEWER STRUCTURES
WATER STRUCTURES

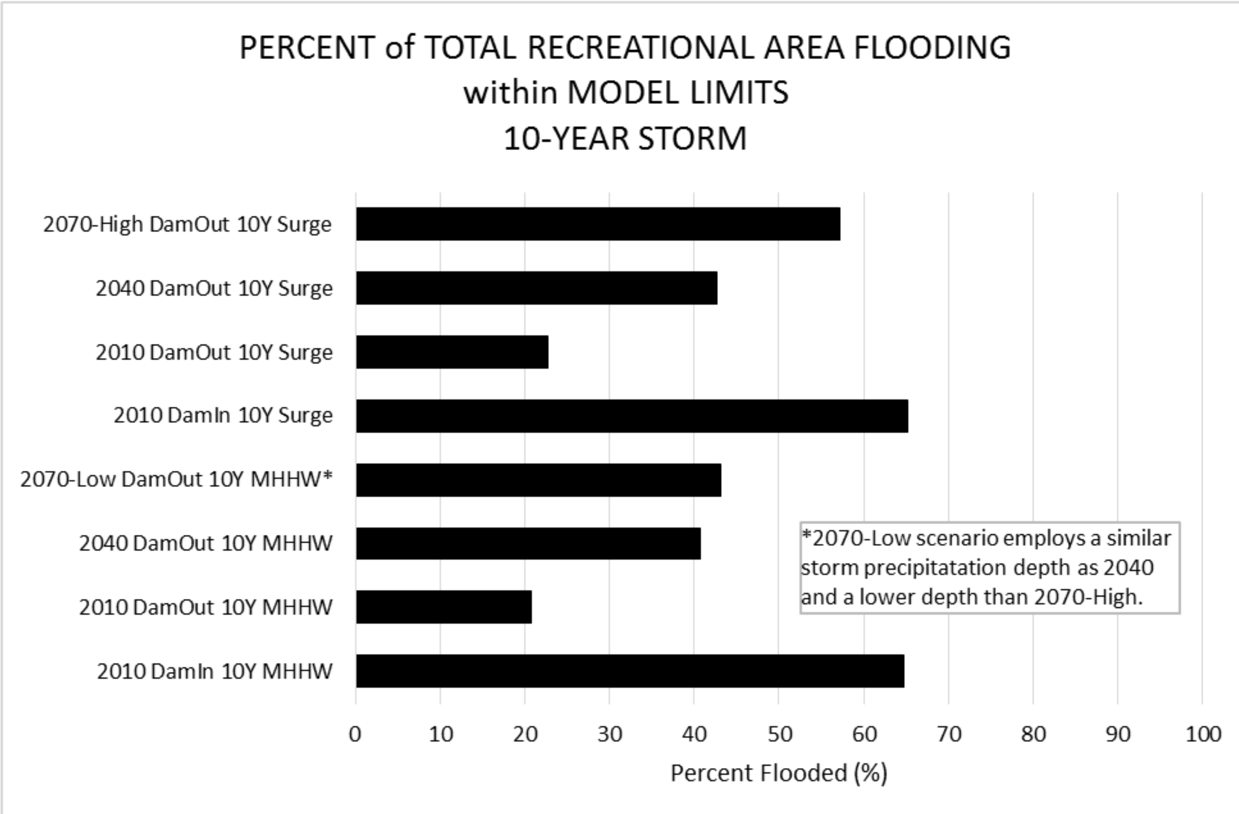

MAX. DEPTH OF FLOODED PUBLIC STRUCTURES
10-YEAR STORM
2070-High DamOut 10Y Surge
2040 DamOut 10Y Surge
2010 DamOut 10Y Surge
2010 DamIn 10Y Surge
2070-Low DamOut 10Y MHHW*
2040 DamOut 10Y MHHW
2010 DamOut 10Y MHHW
2010 DamIn 10Y MHHW
0
1
2
3
4
5
Depth of Flooding at Structure (ft)
SEWER STRUCTURES
WATER STRUCTURES

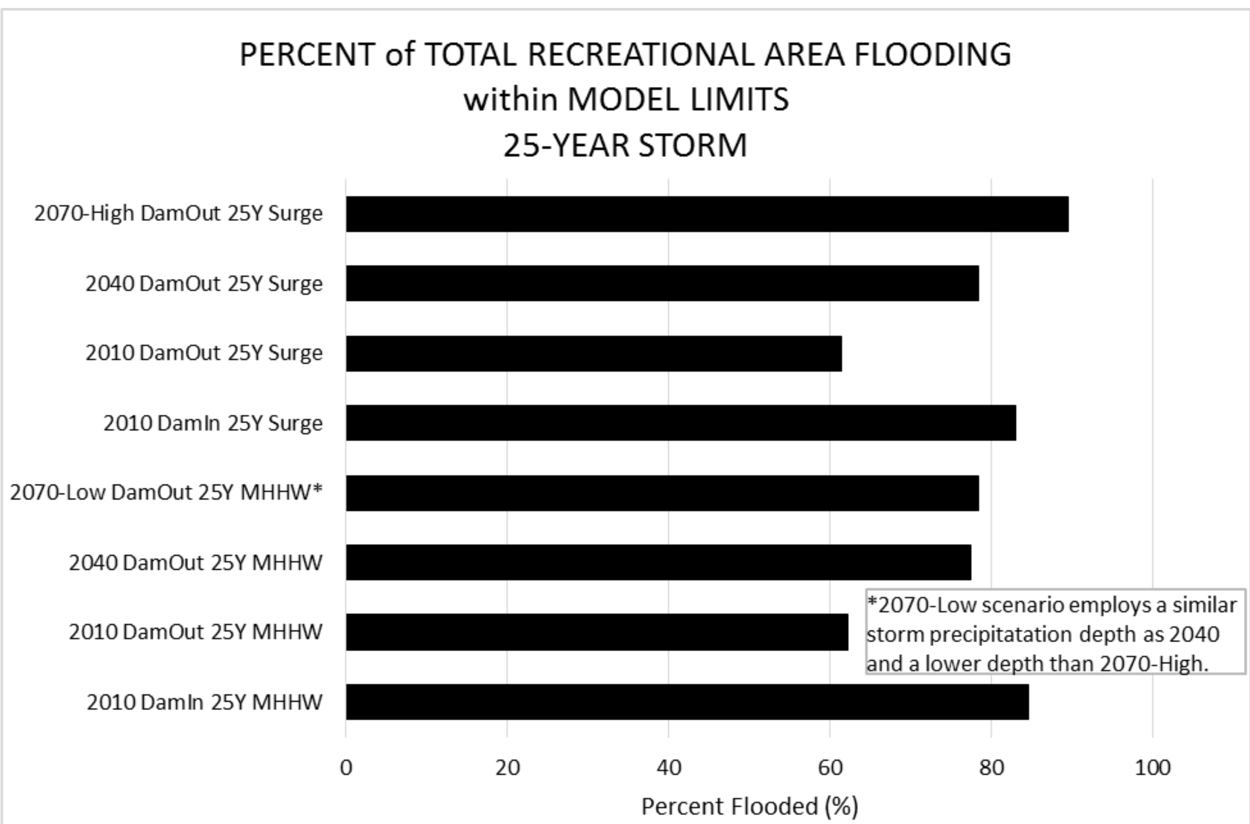


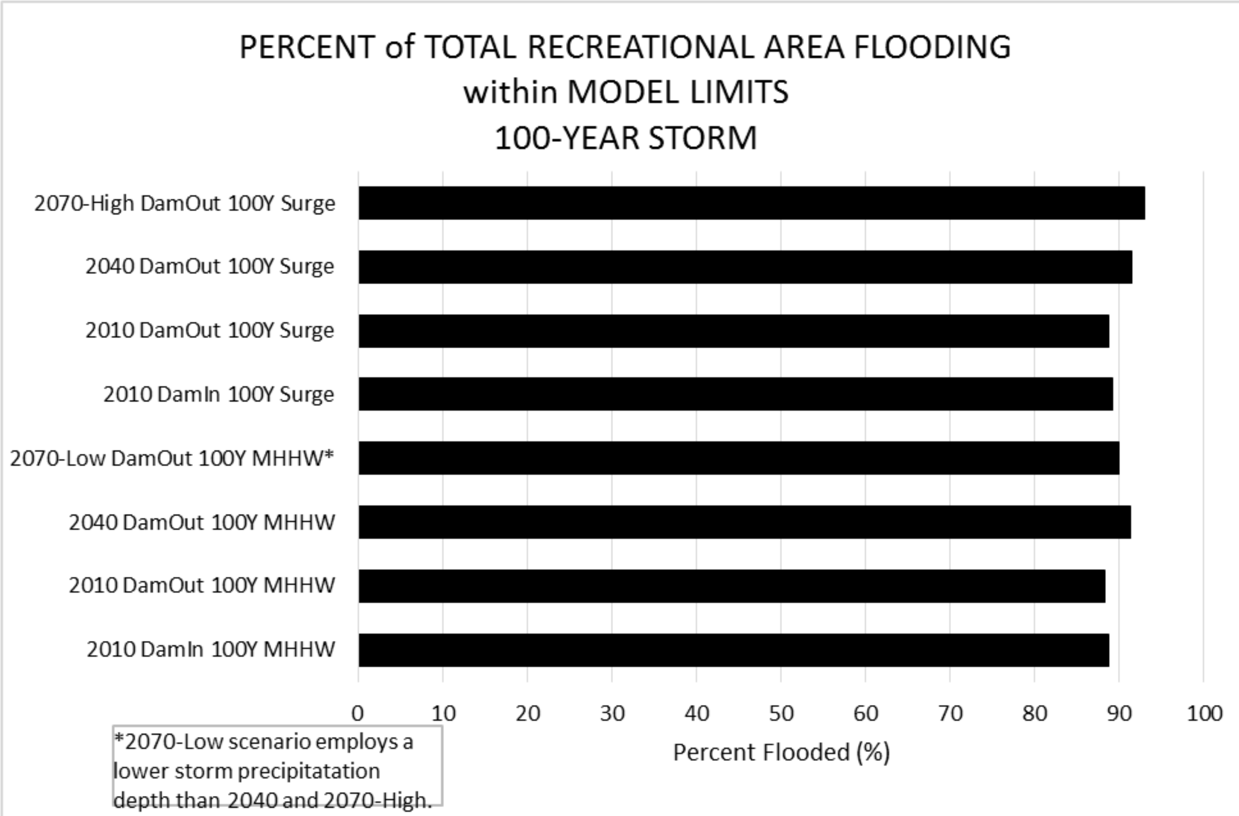


SUMMARY OF RECREATIONAL FLOODING

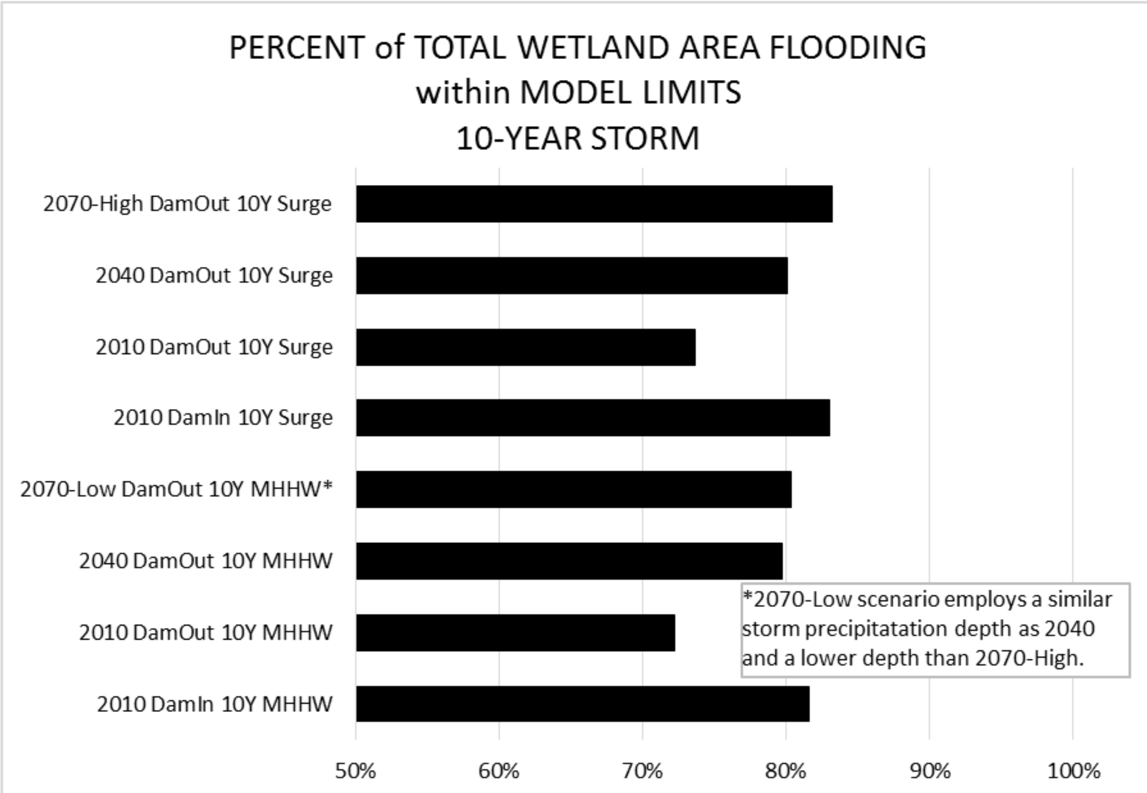
SCENARIO	% AREA FLOODED w/i MODEL LIMITS
2010 DamIn 10Y MHHW	64.8
2010 DamOut 10Y MHHW	20.7
2040 DamOut 10Y MHHW	40.7
2070-Low DamOut 10Y MHHW*	43.1
2010 DamIn 10Y Surge	65.2
2010 DamOut 10Y Surge	22.7
2040 DamOut 10Y Surge	42.7
2070-High DamOut 10Y Surge	57.2
2010 DamIn 25Y MHHW	84.7
2010 DamOut 25Y MHHW	62.2
2040 DamOut 25Y MHHW	77.5
2070-Low DamOut 25Y MHHW*	78.5
2010 DamIn 25Y Surge	83.1
2010 DamOut 25Y Surge	61.5
2040 DamOut 25Y Surge	78.4
2070-High DamOut 25Y Surge	89.5
2010 DamIn 100Y MHHW	88.7
2010 DamOut 100Y MHHW	88.3
2040 DamOut 100Y MHHW	91.4
2070-Low DamOut 100Y MHHW*	90.0
2010 DamIn 100Y Surge	89.2
2010 DamOut 100Y Surge	88.8
2040 DamOut 100Y Surge	91.5
2070-High DamOut 100Y Surge	93.0

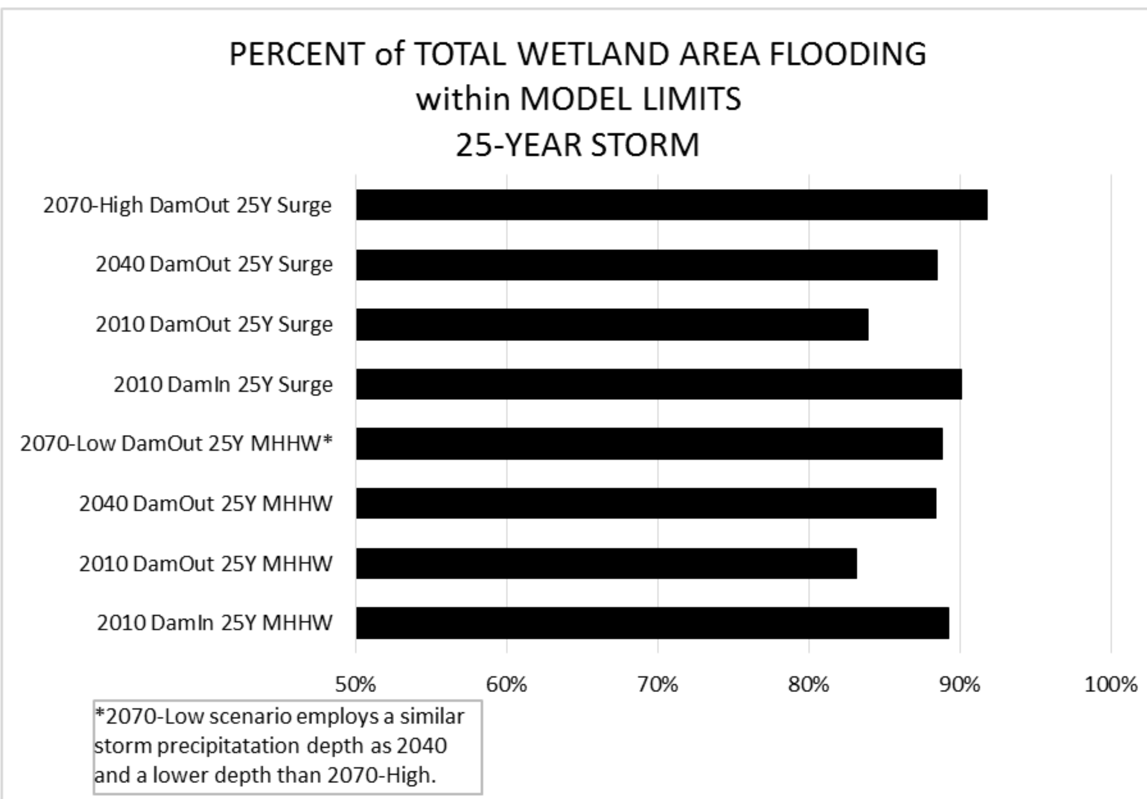

PERCENT of TOTAL RECREATIONAL AREA FLOODING
within MODEL LIMITS
10-YEAR STORM
2070-High DamOut 10Y Surge
2040 DamOut 10Y Surge
2010 DamOut 10Y Surge
2010 DamIn 10Y Surge
2070-Low DamOut 10Y MHHW*
2040 DamOut 10Y MHHW
2010 DamOut 10Y MHHW
2010 DamIn 10Y MHHW
*2070-Low scenario employs a similar storm precipitatation depth as 2040 and a lower depth than 2070-High.
0
10
20
30
40
50
60
70
80
90
100
Percent Flooded (%)

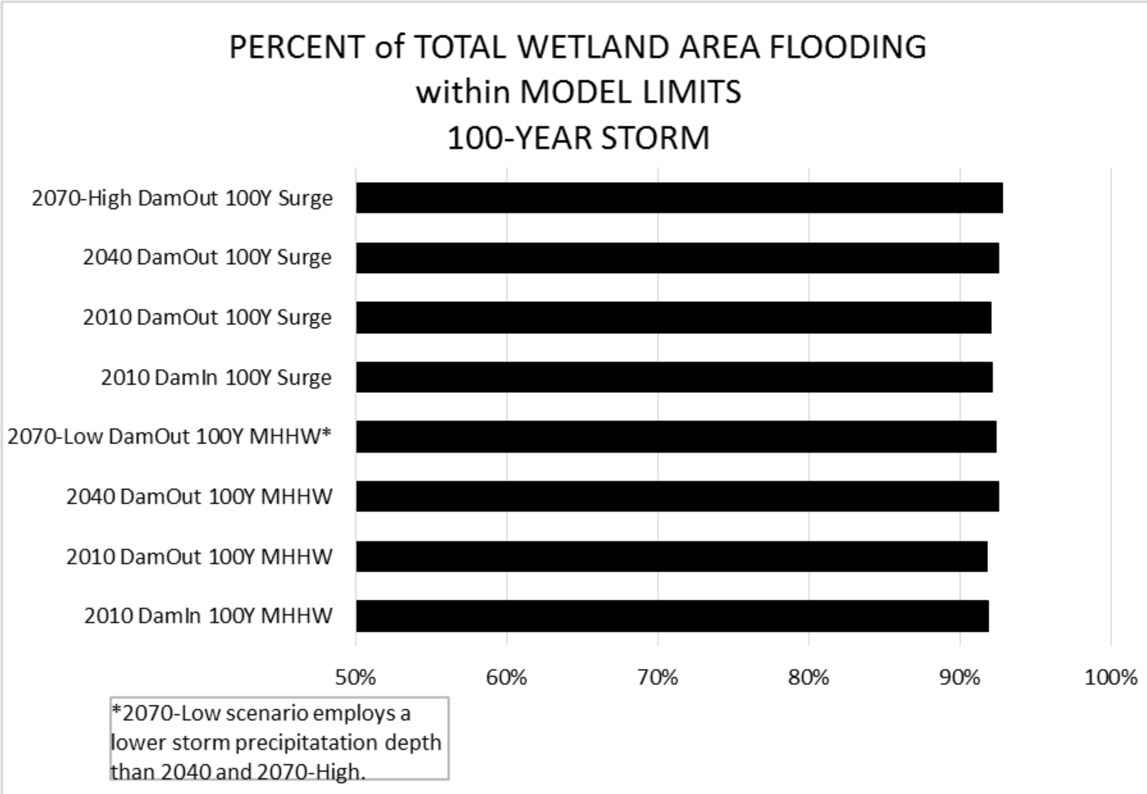

PERCENT of TOTAL RECREATIONAL AREA FLOODING
within MODEL LIMITS
25-YEAR STORM
2070-High DamOut 25Y Surge
2040 DamOut 25Y Surge
2010 DamOut 25Y Surge
2010 DamIn 25Y Surge
2070-Low DamOut 25Y MHHW*
2040 DamOut 25Y MHHW
2010 DamOut 25Y MHHW
2010 DamIn 25Y MHHW
*2070-Low scenario employs a similar storm precipitatation depth as 2040 and a lower depth than 2070-High.
0
20
40
60
80
100
Percent Flooded (%)


PERCENT of TOTAL RECREATIONAL AREA FLOODING
within MODEL LIMITS
100-YEAR STORM
2070-High DamOut 100Y Surge
2040 DamOut 100Y Surge
2010 DamOut 100Y Surge
2010 DamIn 100Y Surge
2070-Low DamOut 100Y MHHW*
2040 DamOut 100Y MHHW
2010 DamOut 100Y MHHW
2010 DamIn 100Y MHHW
0 10 20 30 40 50 60 70 80 90 100
Percent Flooded (%)
*2070-Low scenario employs a lower storm precipitatation depth than 2040 and 2070-High.

SUMMARY OF WETLAND FLOODING	
SCENARIO	% AREA FLOODED w/i MODEL LIMITS
2010 DamIn 10Y MHHW	81.6%
2010 DamOut 10Y MHHW	72.2%
2040 DamOut 10Y MHHW	79.7%
2070-Low DamOut 10Y MHHW*	80.3%
2010 DamIn 10Y Surge	83.0%
2010 DamOut 10Y Surge	73.6%
2040 DamOut 10Y Surge	80.1%
2070-High DamOut 10Y Surge	83.2%
2010 DamIn 25Y MHHW	89.3%
2010 DamOut 25Y MHHW	83.1%
2040 DamOut 25Y MHHW	88.4%
2070-Low DamOut 25Y MHHW*	88.9%
2010 DamIn 25Y Surge	90.1%
2010 DamOut 25Y Surge	84.0%
2040 DamOut 25Y Surge	88.5%
2070-High DamOut 25Y Surge	91.8%
2010 DamIn 100Y MHHW	91.9%
2010 DamOut 100Y MHHW	91.8%
2040 DamOut 100Y MHHW	92.6%
2070-Low DamOut 100Y MHHW*	92.4%
2010 DamIn 100Y Surge	92.2%
2010 DamOut 100Y Surge	92.1%
2040 DamOut 100Y Surge	92.6%
2070-High DamOut 100Y Surge	92.8%


PERCENT of TOTAL WETLAND AREA FLOODING
within MODEL LIMITS
10-YEAR STORM
2070-High DamOut 10Y Surge
2040 DamOut 10Y Surge
2010 DamOut 10Y Surge
2010 DamIn 10Y Surge
2070-Low DamOut 10Y MHHW*
2040 DamOut 10Y MHHW
2010 DamOut 10Y MHHW
2010 DamIn 10Y MHHW
*2070-Low scenario employs a similar storm precipitatation depth as 2040 and a lower depth than 2070-High.
50%
60%
70%
80%
90%
100%


PERCENT of TOTAL WETLAND AREA FLOODING
within MODEL LIMITS
25-YEAR STORM
2070-High DamOut 25Y Surge
2040 DamOut 25Y Surge
2010 DamOut 25Y Surge
2010 DamIn 25Y Surge
2070-Low DamOut 25Y MHHW*
2040 DamOut 25Y MHHW
2010 DamOut 25Y MHHW
2010 DamIn 25Y MHHW
50%
60%
70%
80%
90%
100%
*2070-Low scenario employs a similar storm precipitatation depth as 2040 and a lower depth than 2070-High.


PERCENT of TOTAL WETLAND AREA FLOODING
within MODEL LIMITS
100-YEAR STORM
2070-High DamOut 100Y Surge
2040 DamOut 100Y Surge
2010 DamOut 100Y Surge
2010 DamIn 100Y Surge
2070-Low DamOut 100Y MHHW*
2040 DamOut 100Y MHHW
2010 DamOut 100Y MHHW
2010 DamIn 100Y MHHW
50%
60%
70%
80%
90%
100%
*2070-Low scenario employs a lower storm precipitatation depth than 2040 and 2070-High.

TOWN REFERENCE LOCATIONS	Clemson Pond	PEA Day Care School (infant-K)	Phillips Exeter Academy Campus	Phillips Exeter Academy Maintenance	Public Safety Fire/Police	Recreation Building	Senior Center	Senior Housing 277 Water St	Substation East Bank	Substation West Bank	Swazey Park	Town Library	YMCA
	RL-16	**RL-8**	**RL-9**	**RL-10**	**RL-11**	**RL-12**	**RL-14**	**RL-15**	**RL-23**	**RL-22**	**RL-17**	**RL-19**	**RL-21**
	PUBLIC	PRIVATE	PRIVATE	PRIVATE	PUBLIC	PUBLIC	PUBLIC	PUBLIC	PRIVATE	PRIVATE	PUBLIC	PUBLIC	PRIVATE
SCENARIO	**MAX. FLOODING DEPTH (FT)**												
2010 DamIn 10Y MHHW	4.7			0.7					3.8	5.0	2.3		
2010 DamOut 10Y MHHW	4.7								1.0	2.1	2.3		
2040 DamOut 10Y MHHW	5.8								2.2	3.3	3.3		
2070-Low DamOut 10Y MHHW*	6.4								2.3	3.4	4.0		
2010 DamIn 10Y Surge	6.9	0.1		0.7					3.8	5.0	4.5		
2010 DamOut 10Y Surge	6.9								1.0	2.1	4.5		
2040 DamOut 10Y Surge	7.9	0.9							2.2	3.3	5.5		
2070-High DamOut 10Y Surge	10.0	3.0		0.1				0.9	2.9	4.1	7.7		
2010 DamIn 25Y MHHW	5.8		0.1	3.3					6.4	7.6	3.2		0.9
2010 DamOut 25Y MHHW	5.8			0.3					3.2	4.4	3.2		
2040 DamOut 25Y MHHW	6.8			1.8					4.7	5.8	4.2		

2070-Low DamOut 25Y MHHW*	7.3	0.4		1.9					4.8	5.9	4.7		0.1
2010 DamIn 25Y Surge	7.4	0.6	0.1	3.3					6.4	7.6	4.9		0.9
2010 DamOut 25Y Surge	7.4	0.5		0.3					3.2	4.4	4.9		
2040 DamOut 25Y Surge	8.4	1.4		1.8					4.7	5.8	5.9		
2070-High DamOut 25Y Surge	10.4	3.4	1.7	5.0				1.3	8.1	9.3	8.0	0.1	2.5
2010 DamIn 100Y MHHW	8.0	1.3	3.9	7.2			1.3		10.3	11.5	5.3	0.7	4.5
2010 DamOut 100Y MHHW	8.0	1.1	3.5	6.7			0.9		9.9	11.1	5.3	0.7	4.2
2040 DamOut 100Y MHHW	9.6	2.6	5.3	8.6		1.0	2.7	0.5	11.7	12.9	6.8	1.8	6.0
2070-Low DamOut 100Y MHHW*	9.4	2.4	4.8	8.1		0.5	2.2	0.3	11.3	12.4	6.6	1.5	5.5
2010 DamIn 100Y Surge	8.8	2.1	3.9	7.2			1.3		10.3	11.5	6.2	0.7	4.5
2010 DamOut 100Y Surge	8.8	1.9	3.5	6.7			0.9		9.9	11.1	6.2	0.7	4.2
2040 DamOut 100Y Surge	10.3	3.3	5.3	8.6		1.0	2.7	1.2	11.7	12.9	7.6	1.8	6.0
2070-High DamOut 100Y Surge	12.0	4.9	6.1	9.4	0.4	1.8	3.4	2.9	12.5	13.7	9.3	2.3	6.8

Appendix AS8. Drainage Methods

Memorandum

Date: 27 July 2015

To: Paul Kirshen, University of New Hampshire

From: Renee Bourdeau and Chad Yaindl, Geosyntec Consultants

Subject: Exeter Storm Sewer Infrastructure Model Evaluation
Climate Adaptation Plan for Exeter (CAPE)

The purpose of this memorandum is to provide the methodology and results of the hydrologic and hydraulic stormwater runoff model ("Model") for the Town of Exeter downstream of Pickpocket Dam, developed as part of the Climate Adaptation Plan for Exeter (CAPE). The Model was created using the USEPA Storm Water Management Model (SWMM) modeling platform to evaluate the flooding potential of the stormwater infrastructure network under varying storm depths, tidal storm surge and future buildout conditions.

METHODOLOGY

The Model framework consists of several components including: watershed drainage areas (i.e., storm sewered areas and non-sewered areas), storm sewer infrastructure network (i.e., catch basins, manholes, pipes and outfalls), and river segments (i.e., Little River and Exeter/Squamscott River).

Drainage Areas and Infrastructure Network

Two types of drainage areas were delineated for the Model, which include: areas where storm sewer infrastructure is present and areas where storm sewer infrastructure is not present. In the storm sewered areas, the drainage area or "sewershed" represents the areas draining to catch basins, manholes, culverts, pipes and outfalls (Figure 1). Areas where storm sewer infrastructure is not present, represent areas where stormwater follows natural drainage patterns and/or is intercepted by roadside swales and conveyed to receiving waters. These drainage areas were delineated using standard HUC-12 watersheds. In areas where a HUC-12 watershed intersected a delineated sewershed, the HUC-12 watershed was clipped so as to not overlap.

To delineate the drainage areas within the storm sewered area, Geosyntec obtained copies of Exeter Department of Public Works (DPW) storm sewer infrastructure logbooks as well as the current DPW GIS files of stormwater infrastructure. The logbooks contain depth to inverts at catch basins and manholes. The GIS shapefiles contain location information for catch basins, manholes, culverts, and stormwater pipes, as well as pipe diameters. The data were assembled in ArcGIS and critical information (such as depth, invert, material, etc.) was transcribed from the logbooks into the shapefile attribute information.

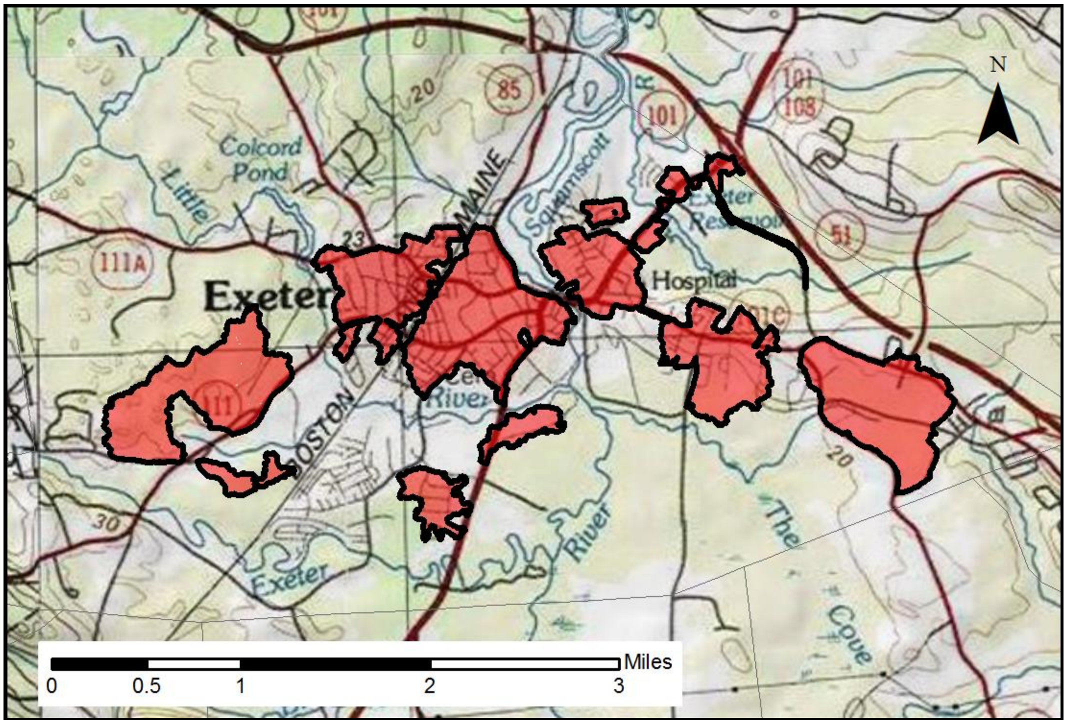


Figure 1. Exeter Sewershed Areas (highlighted in red).

Due to the number of catch basins, manholes, pipes and outfalls, Geosyntec developed a methodology to accurately model the storm sewer infrastructure by reducing the number of nodes within the model to only represent the main trunk lines of the system. Based on this approach, within the model, catch basins and manhole were only represented at areas where there was a change in pipe diameter. Drainage areas were delineated for the areas which drained to this pipe. This approach provides an accurate representation of the capacity of the system; however, does not include analysis of single catch basins and associate pipes which convey flows to the main trunk line. The modeling approach and analysis provides a conservative estimate of the system and represents the flow in the pipe at its maximum value along the length of the run, rather than gradually increasing flow as each catch basin downstream successively contributes to the system.

Geosyntec obtained ARRA (American Recovery and Reinvestment Act) LiDAR Data for the Northeast from the University of New Hampshire GRANIT spatial data distribution site. The primary use of the LiDAR topographic data was to delineate drainage areas and to determine approximate rim elevations of catch basins and manholes, as these were not readily available.

River Segments

To understand the effects of backwater within the storm sewer network, caused by elevated water surface elevations in the receiving waters (i.e., Little River and Exeter-Squamscott Rivers) from the tidal cycle as well as storm surge, cross sections of the river networks were modeled. To include this effect in the simulations, the two rivers were represented in SWMM using custom conduits. The conduits' cross-sectional geometry and physical parameters (i.e. Manning's n) were imported from the existing Hydrologic Engineering Centers River Analysis System (HEC-RAS) model of the two rivers.

Precipitation and Boundary Conditions

To simulate runoff, SWMM model was run using the 25-yr, 24-hr design storm as the primary model driver. The design storm distribution was obtained from a distribution provided through HSPF, as shown in Figure 2 below. This unitless distribution was scaled up according to the total estimated storm event depth. The storm event depths were 6.0", 6.72", and 7.2" for 2015, 2040, and 2070, respectively. The increased storm event depth for 2040 and 2070 is intended to reflect the projected levels of precipitation increase due to climate change.

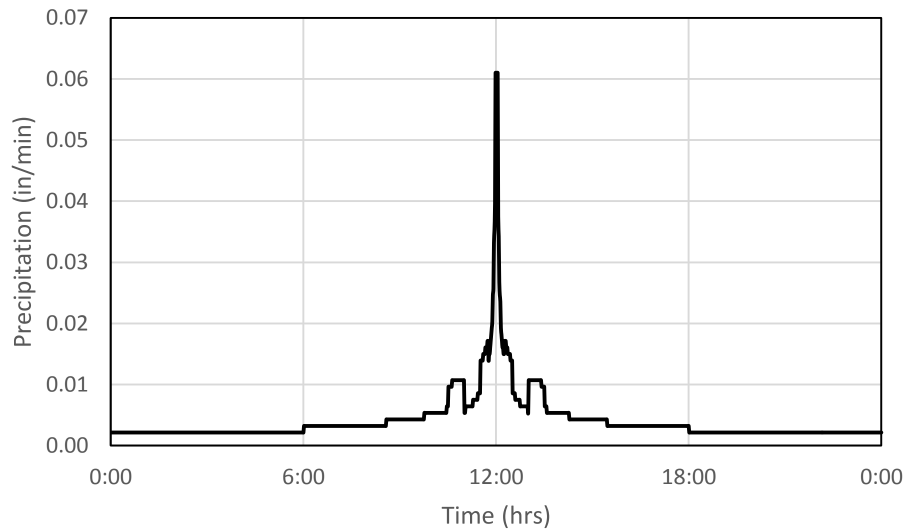


Figure 2. 25-yr, 24-hr design storm (current 2010 precipitation depth, 6.0”).

As part of the CAPE Project, additional models were developed to evaluate the area upstream of Pickpocket Dam in the Exeter-Squamscott watershed. These models included HEC-HMS model of the entire watershed to quantify flood conditions. . One upstream boundary condition of the SWMM Model represents Pickpocket Dam. Therefore, the 25-yr, 24-hr storm peak flowrate, as predicted by the HEC-HMS model, was entered into SWMM as a constant flowrate in the Exeter River. This upstream boundary conditions represents the behavior of the portions of the Exeter-Squamscott River watershed that are beyond the scope of the SWMM model. Another boundary was the Little River.

The downstream boundary is the water surface elevation of the tidal portion of the Squamscott River at its intersection with Wheelwright Creek. Depending on the model scenario, this water surface elevation either represents a typical tidal elevation (Mean Higher-High Water), or the 100-year coastal storm surge elevation. In either case, the boundary condition is maintained at a static elevation for the duration of the model runs. Table 1 summarizes the precipitation data and boundary conditions for the five model runs performed in this analysis.

Table 1. Modeling Scenarios and Boundary Conditions

Scenario	Year	Build-out, Land Use	Upstream Boundary Discharge Exeter River (cfs)	Downstream Boundary (Water Surface Elevation, ft)	Precipitation Event Depth (in)	Description
1	2010	Present, 2005	NA	NA	6.00	Model included sewersheds and river segments. Non-sewershed drainage areas were removed.
2	2010	Present, 2005	2023	4.1	6.00	Downstream Boundary represents Mean Higher-High Water (MHHW)
3	2010	Present, 2005	2023	7	6.00	Downstream Boundary represents 100-yr coastal storm surge elevation for 2010
4	2040	Future, 2040	2447	7.9	6.72	Downstream Boundary represents 100-yr coastal storm surge elevation for 2040
5	2070	Future, 2070	2787	10.2	7.20	Downstream Boundary represents 100-yr coastal storm surge elevation for 2070

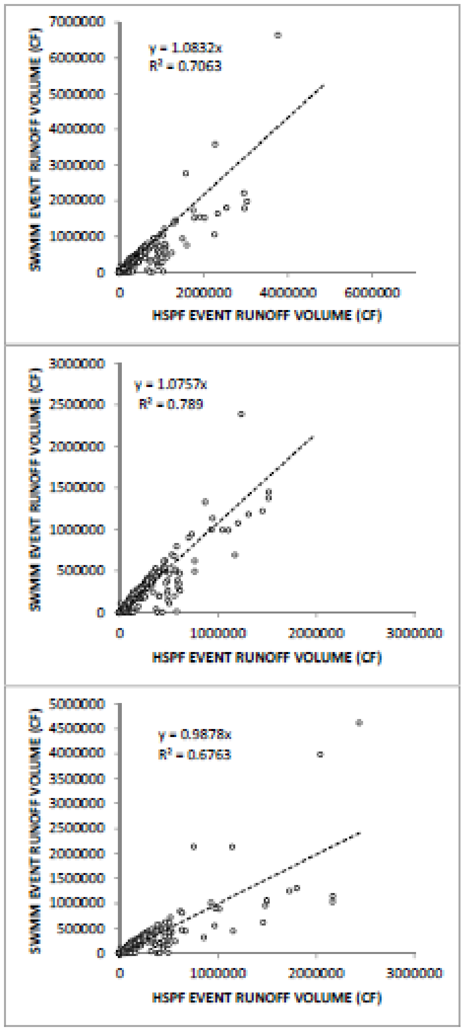
Model Calibration

To ensure that the modeled flows accurately represent observed flows within Exeter, the SWMM Model was calibrated using flow records for the storm sewered areas and the HSPF model for the non-sewered areas. For the sewered areas of Exeter, flow records were obtained from a pressure transducer at a catch basin located at the intersection of Park Street and Water Street in Exeter, during June and July of 2013[1]. Observed flows at this catch basin were compared to modeled flows to calibrate the model to ensure that it represents observed conditions. Sewershed drainage area parameters were adjusted in an iterative process to maximize Nash-Sutcliffe efficiency (E) and minimize the difference in runoff volume during four precipitation events. The final set of calibration parameters caused the model to perform with an efficiency E = 0.352 and a runoff volume difference of -5.3%. The calibration is shown in Figure 3. Due to the paucity of rainfall events, no independent verification was performed but we still consider the model a good representation of reality. The results of this calibration were used in the other sewersheds in the urbanized portion of Exeter.

HSPF and SWMM, while used for different purposes, modeled the same runoff areas in the non-sewered areas modeled by SWMM. For the non-sewered areas, the HSPF model results for the overlapping drainage areas were used to calibrate the SWMM Model. Based on the calibration[2], the two models appear to be in modest agreement. Results were compared for the non-snow months for subareas BB2, LR1, and ET1. The parameters for subarea BB2 were first adjusted to obtain the strongest fit, and the these adjustments were applied to the parameters for the other subareas. The results are in Figure 4.

[1] Methodology and results are summarized in the memorandum prepared by Geosyntec Consultants, dated 31 October 2013, entitled "*CAPE: Storm sewershed runoff model calibration*."

[2] Methodology and results are summarized in the memorandum prepared by Geosyntec Consultants, dated 10 April 2014, entitled "*CAPE" Calibration of SWMM using HSPF model results."*



Figures 1-3. Comparison of runoff event volumes for catchments BB2 (top), LR1 (middle), ET1 (bottom) (HSPF areas 5, 15,18).

Figure 3.

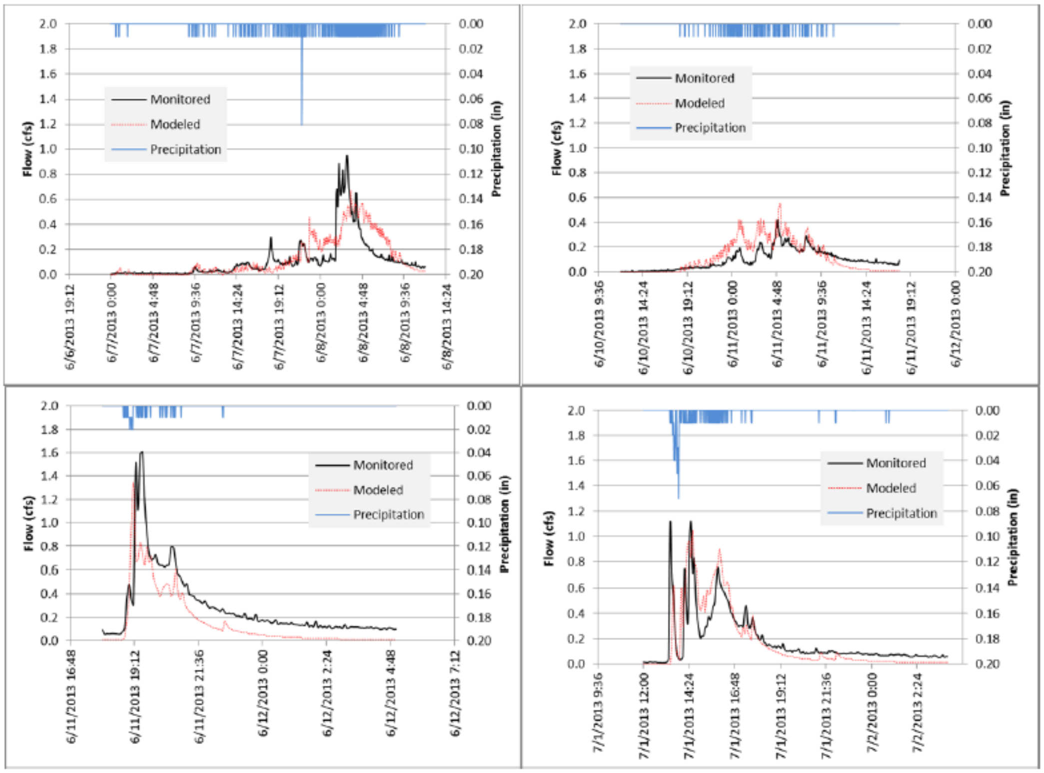


Figure 1. Four calibration events, monitored and modeled flowrates, location CB 534.

Figure 4.

Build-out Analysis

A build-out analysis[3] was performed for the entire Exeter-Squamscott watershed to determine the location of potential future development and predict its impact on stormwater runoff volume and rates. The build-out analysis was performed by analyzing trends in past development (1968-present) and projecting these trends into the future (years 2040 and 2070). Based on the trends of development, the amount of future development was determined and its location estimated by creating a GIS grid coverage of "developable land." At each point in the grid, development potential was estimated using a combination of factors, including distance to existing development, distance to wetlands and receiving waters, distance to existing major roads, etc. It was assumed that development would first occur in areas with high development potential, gradually spreading to areas of lower development potential.

Zonal Statistics, a process included in the ArcGIS Spatial Analyst toolset, was used to quantify the expected additional development in each watershed and sewershed. The increases in development were used to adjust the watershed/sewershed average curve number by converting assumed forested land into developed land.

RESULTS AND CONCLUSIONS

The SWMM model was developed to evaluate stormwater infrastructure performance under multiple scenarios and multiple timeframes. The design storm of interest was the 25-yr, 24-hr storm. This storm event was modeled under current conditions (2010 land use) with a mean high-high water (MHHW) and a storm surge downstream (tidal)

[3] Methodology is summarized in the memorandum prepared by Geosyntec Consultants, dated 5 February 2014, entitled "*Build-out Analysis Methodology and Results.*"

boundary. The model was also evaluated under a future (year 2040 and 2070) condition paired with coastal storm surges.
The results from the SWMM model simulations are presented in color-coded map format in the Attachment and provide the following information:

1) Time (hours) of flooding at model junctions (i.e. catch basins, manholes);
2) Volume (million gallons (MG)) of flooding at model junctions; and
3) Time (hours) during which both ends of model conduits (i.e. culverts, storm drains) are surcharged.

The color coded maps provide a visual representation of increased potential for flooding during the different model scenarios and provide an understanding of the increased severity with storm surge and future buildout. In addition to these results, hydrographs were developed at key locations, with known flooding, for each scenario. The key locations include:

1) Outfall of the storm sewer system that drains the area around Tan Lane. This branch of the storm sewer network is known to experience flooding problems, and it drains the majority of the downtown area west of the Exeter-Squamscott River.
2) Outfall of the storm sewer system that collects runoff in the area around Linden Street. This section of the storm sewer network has the second largest drainage area after the Tan Lane system.
3) Squamscott River near Wheelwright Creek. This is the farthest downstream point in the model and represents the drainage from the entire Exeter-Squamscott watershed, including upstream of Pickpocket Dam.

Hydrographs for Tan Lane and Linden Street systems (Figures 5 and 6, respectively) demonstrate the behavior of the storm sewer system in Exeter. Under Modeling Scenario 1, which does not simulate backwater conditions in the Little River or Exeter Rivers, for Tan Lane (Figure 5) stormwater runoff drains freely through the system relatively quickly and at high flowrates. When backwater conditions are introduced (Scenario 3), the same precipitation event leads to lower peak flowrates with longer time to drain. In this situation, once the water surface elevation of the receiving water (Squamscott River downstream of Great Dam) exceeds the elevation of the outlet pipe, flowrates decrease and upstream flooding problems take longer to diminish. This effect becomes even more pronounced during the 2040 and 2070 scenarios, when the coastal storm surge elevation is increased (Scenarios 4 and 5, respectively).

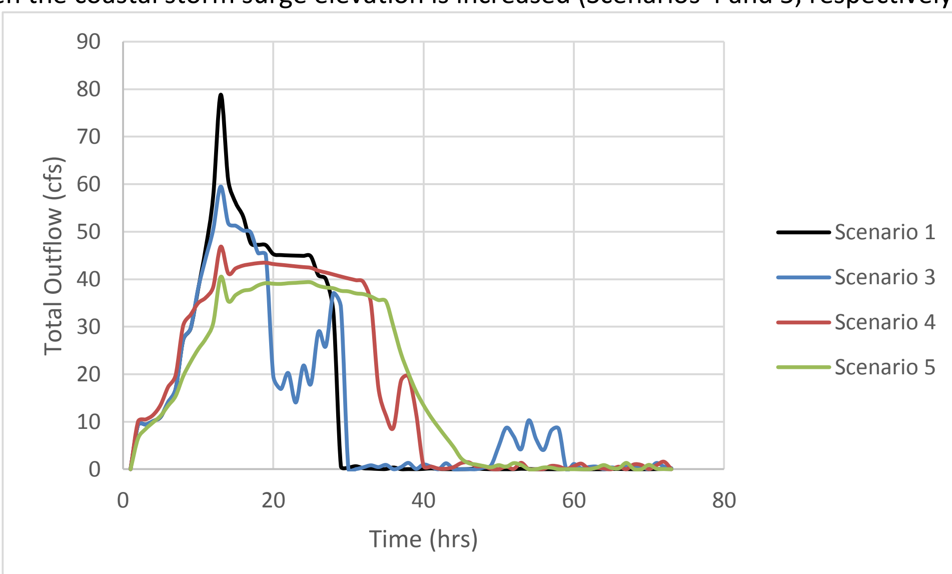


Figure 5. Tan Lane storm sewer system, outflow hydrograph.

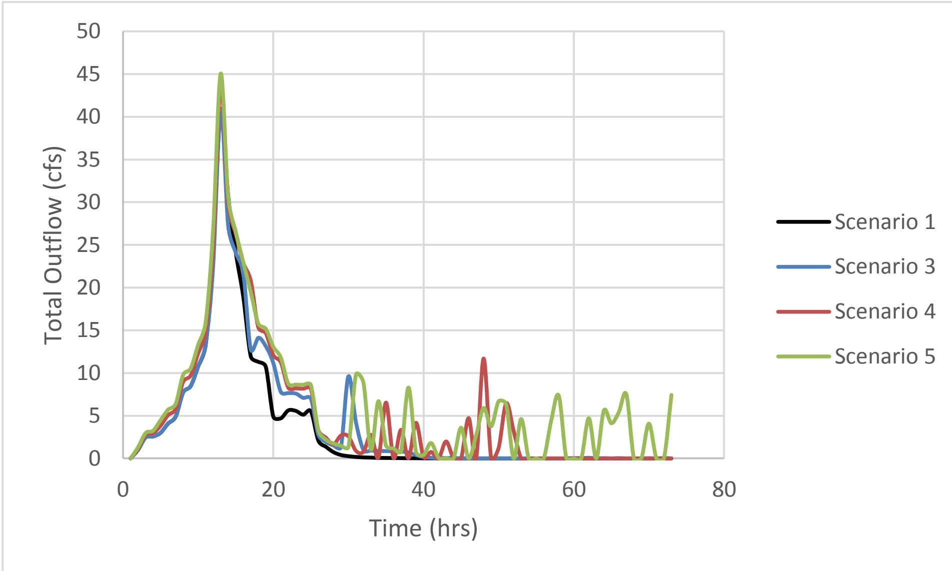


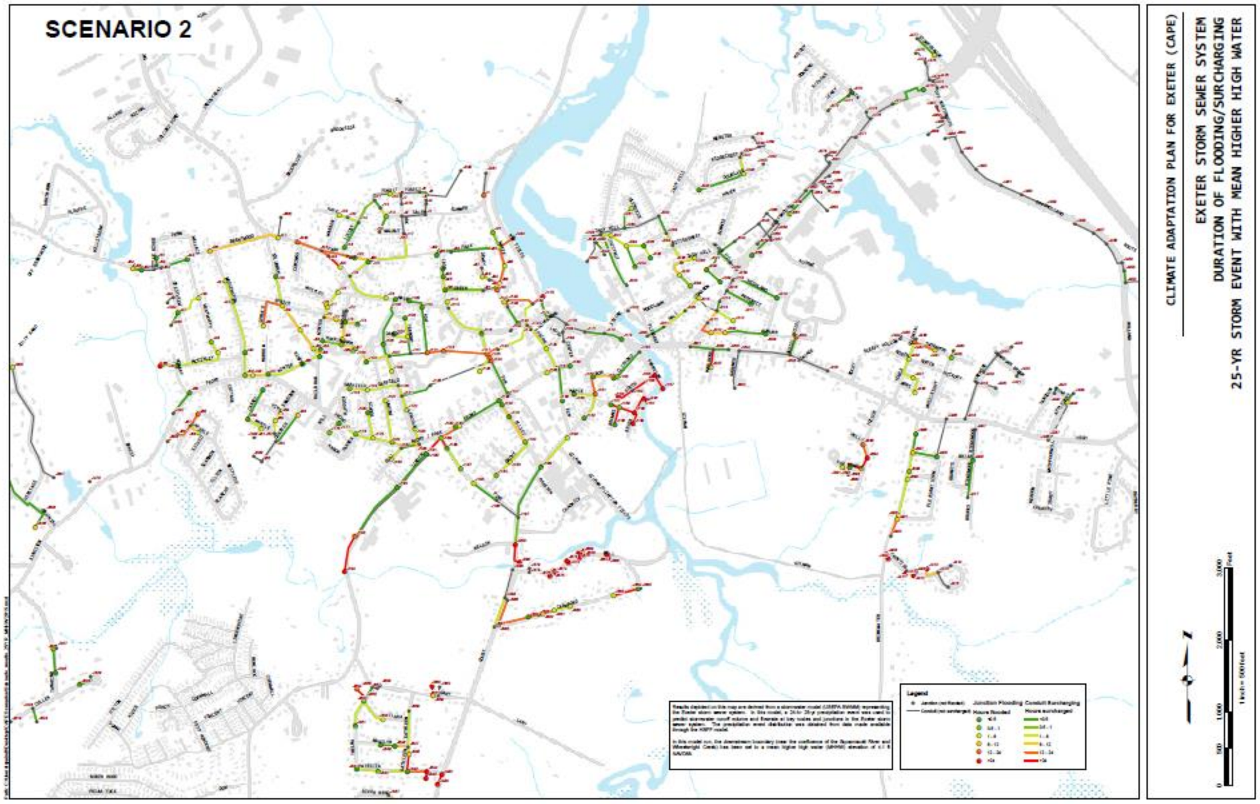
Figure 6. Linden Street storm sewer system, outflow hydrograph.

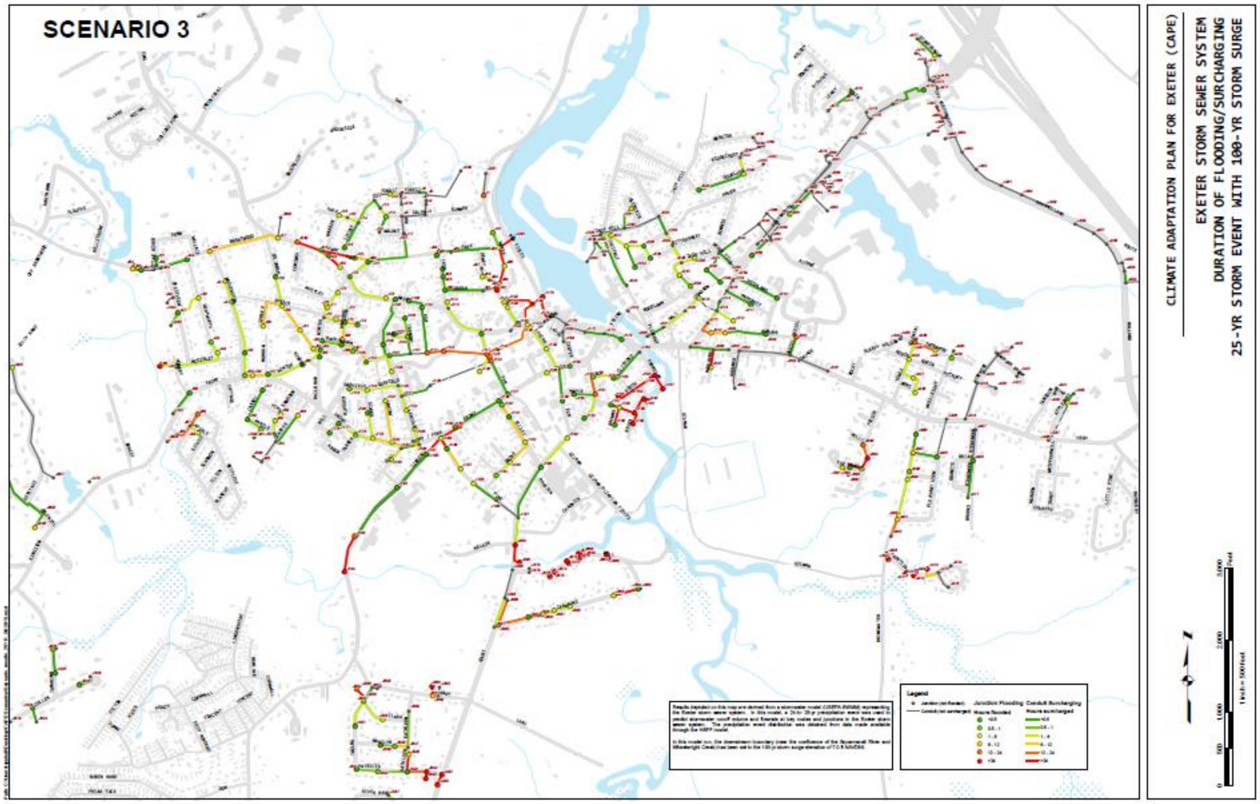
The Linden Street outfall appears to be less effected by the backwater conditions within the Little River. The hydrographs at Linden Street (Figure 6) demonstrates that both flowrate and volume appear to increase in the 2040 and 2070 scenarios, primarily due to increases in precipitation depth.

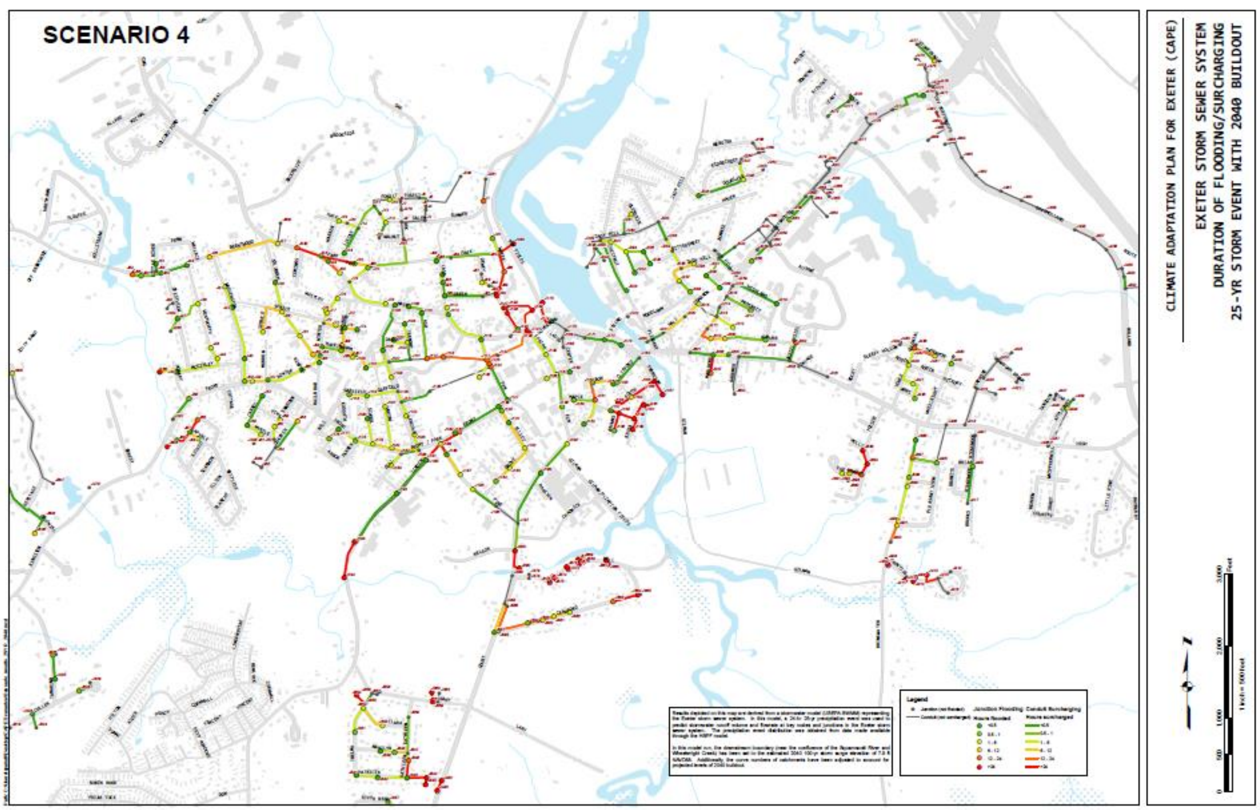
In both the Tan Lane and Linden Street systems, it appears that buildout has little effect on the stormwater runoff volume being generated in these sewersheds. The areas drained by these storm sewer systems is already highly developed and highly impervious, and do not contain much developable land. As a result, new development within these catchments has little effect on the stormwater runoff behavior of these two systems.

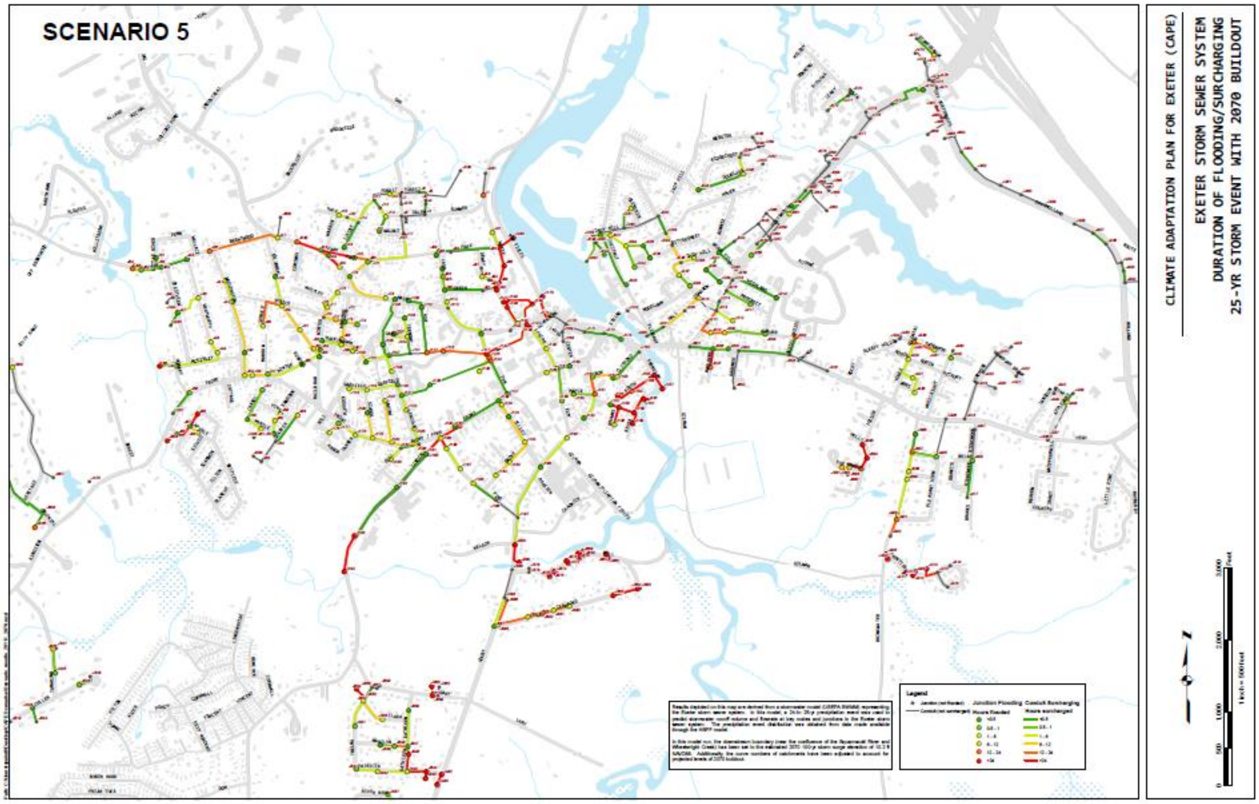
ATTACHMENTS

Sample Model Results




SCENARIO 3
CLIMATE ADAPTATION PLAN FOR EXETER (CAPE)
EXETER STORM SEWER SYSTEM
DURATION OF FLOODING/SURCHARGING
25-YR STORM EVENT WITH 100-YR STORM SURGE


SCENARIO 4
CLIMATE ADAPTATION PLAN FOR EXETER (CAPE)
EXETER STORM SEWER SYSTEM
DURATION OF FLOODING/SURCHARGING
25-YR STORM EVENT WITH 2040 BUILDOUT



Appendix AS9

Vulnerability of Natural Habitats to Climate Change in Exeter

Exeter is a town that was built at the juncture of the Exeter River as it flowed into the tidal Squamscott River. A series of falls at the head of tide mark a narrowing of the Exeter River where bedrock, bridges and the Great Dam constrict flow and result in wide floodplains upstream along the Exeter River. Here, large portions of the downtown commercial zone as well as some outlying neighborhoods were developed over the past several centuries within the active floodplain. Downstream of the falls, the Squamscott River flows north and the narrow tidal floodplain widens appreciably as it flows by the town marina and past armored or bermed shorelines along the Swasey Parkway and Powderhouse Pond. The Exeter community has benefited from its wetlands, both tidal and freshwater, that provided important habitats for fish and wildlife, modulated river flow and improved the quality of life (Table 1).

Categories	Values of Tidal Marshes	Values of Non-Tidal Marshes
Habitat and Biodiversity	Plant growth to support food webs	Plant growth to support food webs
	Secondary production	Secondary production
	Plant structure to provide habitat	Plant structure to provide habitat
	Support of biodiversity	Support of biodiversity
Coastal Protection	Reduce wave height and damage	
	Reduce severity of flooding	Reduce severity of flooding
	Protection from erosion	

Water Quality	Removal of sediments and excess nutrients	Modulate sediment flux, cycle nutrients
Quality of Life	Aesthetic, Recreational & Educational values	Aesthetic, Recreational & Educational values
Climate Change Mitigation	Builds in elevation with sea level rise	
	Long term carbon storage	Stores C, but releases CH_4

Table 1. Values of marshes.

Almost all model scenarios of future climate in Exeter show increased precipitation, with an increase in severe precipitation events. We can expect more frequent and likely greater floods in some years, which will inconvenience some and cause catastrophic damage to private homes, businesses and critical infrastructure for the Town, including drinking water supply and sewage treatment, electricity and roads.

Models based on GCM scenarios show that dam removal in the next decade will result in slightly lower water levels within the river and floodplain upstream of the Great Dam. Lower water levels will open up possible habitat for invasive plants like purple loosestrife and common reed. With increasing temperatures, southern invasive species may invade the area. Invasive plants are likely to adapt to changing climate and the Conservation Commission should develop a plan to identify and control invasive plants along the Exeter River following removal of the Great Dam.

Lower freshwater levels following dam removal will, over time, be offset by greater predicted precipitation /snowmelt driven floods and /or higher water tables from increased sea level by 2070 (Bloetscher et al. 2010, Bjerklie et al. 2012). A comparison of wetland flooding in response to a “10 year storm” for a variety of scenarios has shown slight declines in flooding with the dam out, but by 2070 with severe climate change, the flooding elevations appears similar to current conditions with the dam in place (Figure 1). Similar results were found for flooding in 25 and 100-year storms.

Working in New Haven Connecticut, Bjerklie and colleagues found large portions of the City would experience increased water tables similar to a three foot increase in sea level, especially if modeled with an increase in recharge of 12% over current rates. Ground water levels across most of Exeter are also likely to rise with an increase in sea level. Even with a modest increase of 2 feet of sea level rise by 2070, groundwater levels across the lower portions of town (20 feet above mean high water) are likely to experience significantly greater water tables (1-2 feet).

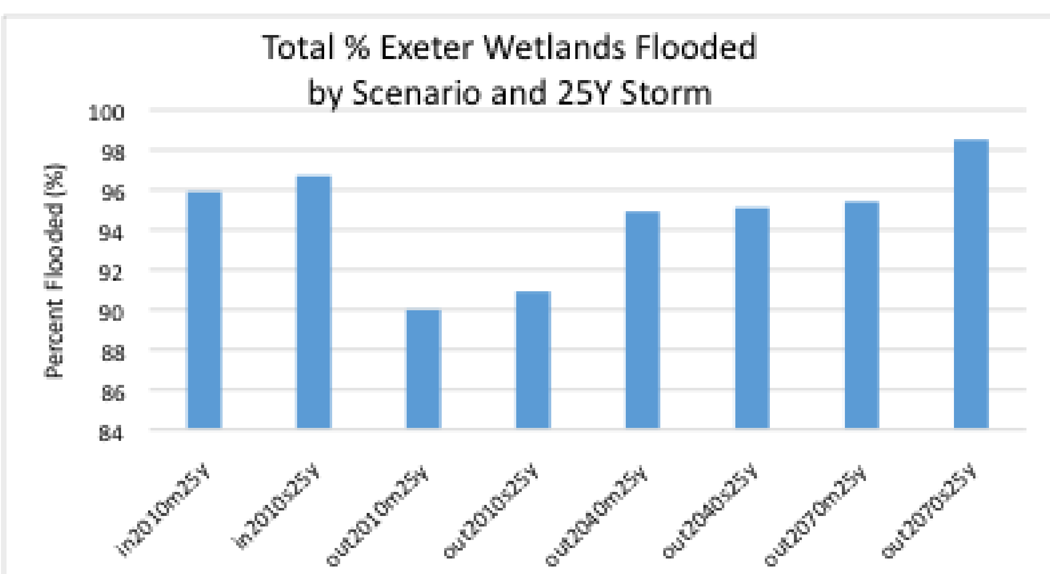


Figure 1. Percentage of wetlands flooded by a 10-year storm under a variety of scenarios. Each scenario is coded in order: 1) in or out refers to the Great Dam, which will be removed soon; 2) year of model run; 3) MHHW (M) or Storm Surge Conditions (S); and 4) return time of storm event used in model.

Downstream along the Squamscott River, fringing brackish marshes that get flooded and exposed up to twice a day line the intertidal portions of the River. These marshes provide habitat for fish and birds that are valued for their cultural significance (the alewife, a migratory herring, is featured on the Town seal). Other ecosystem services provided by salt marshes include erosion prevention, storm surge reduction, biodiversity and habitat, a filter that removes suspended sediments and nutrients such as nitrogen, as well as carbon storage as part of a mechanism that helps marshes grow in elevation as sea level rises (Table 1).

The basis of our understanding of salt marsh ecology is founded on the idea that tidal marshes have developed in New England during the past 4,000 years when sea level has risen slowly (1 mm per year). Flooding waters bring salt and sediments to the marsh, which builds peat from sediment deposition aboveground and organic matter storage belowground (Figure 2). As sea level rose, the marsh expanded landward slowly and once low marsh areas built up to the level of mean high tide, they evolved to high marsh as tall smooth cordgrass was replaced by salt hay.

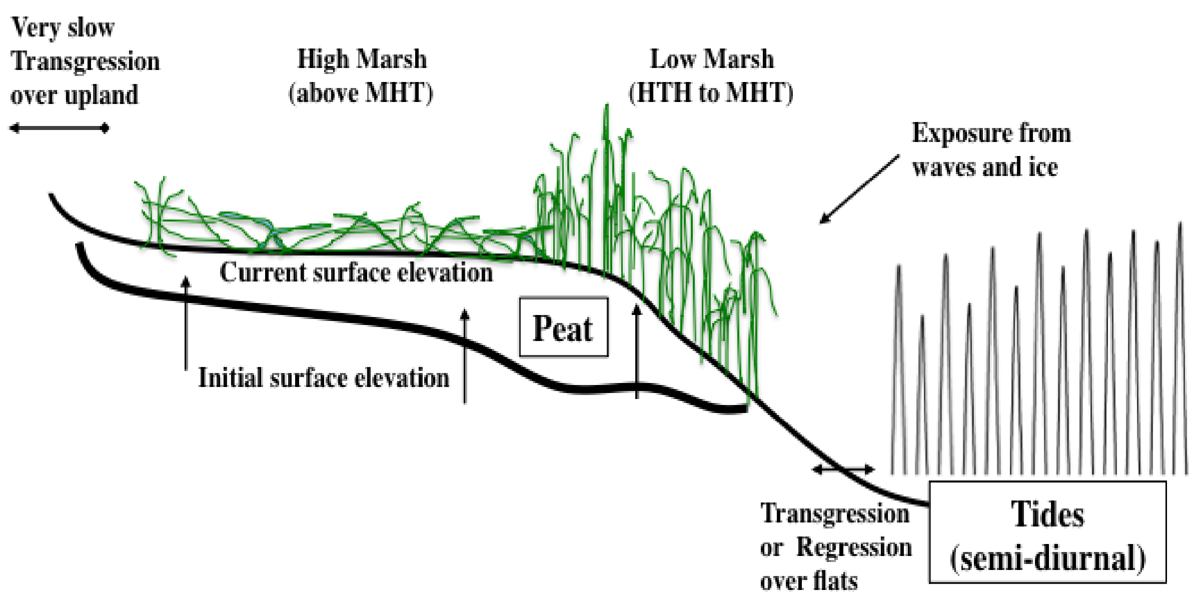


Figure 2. Conceptual model of interactions promoting marsh persistence and loss. As tidal waters flow over the marshes, plants slow floodwaters and suspended sediment drops out or is captured on leaves while peat decomposition is slowed by hypoxic conditions. Storms can be important sedimentation events, as are ice deposits in colder climates. Under slow to moderate Sea Level Rise (1-5 mm/yr) shown here, marshes can maintain relative elevation through accretion of inorganic sediments and organic matter storage; falling sea level results in draining, oxidation of peat, and subsidence (fall in elevation).

Although tidal marshes are highly valued today, past decisions in Exeter have filled marshes to create the wastewater treatment plant, Powderhouse Pond and Swasey Parkway. All of these marsh impacts have been made to provide another service to the town, replacing marsh values with sewage and stormwater treatment areas and a well-used recreational area. Fortunately, over 100 acres of tidal marsh remain and provide a variety of benefits to Exeter.

If we only examine the estuarine wetlands found downstream of the Great Dam, hydrological models based on climate scenarios indicate no impact of dam removal on wetland flooding (Figures 3-4). Instead, flooding of these wetlands is driven by storm surge (about 7 feet NAVD or 2 meters for present 100-year storm) and sea level rise (of 3.2 feet by by 2070 for severe climate change). Thus the area and depth of wetland flooding increases sharply by size of the storm and gradually from sea level rise (Figures 3-4).

Since storms are short-lived and the river is protected from wind-driven waves, storm surges are much more of a human safety risk than a threat to tidal wetlands. Also, the increased flooding from increased sea level would not pose a problem for marsh survival if marshes can build in elevation at a rate similar to sea level rise (Cahoon and Guntenspergen 2010). However, rapid periods of sea level rise will likely occur due to changes in oceanic currents (Goddard et al. 2015), and these periods are likely to exceed the ability of the marshes to build (Kirwan et al. 2010), resulting in the erosion and drowning of low marshes and the conversion of high marsh to low marsh.

As sea levels rise, another process will replace some of our wetlands through a conversion of low-lying uplands into tidal wetlands – a process termed marsh migration (Waterview Consulting 2015). Of course if the natural land slopes steeply or there are artificial barriers, the marshes cannot migrate. Rising temperatures, found for most all the GCM scenario models, may also interfere with marsh building processes and reduce the ability of the marsh to store organic matter (Kirwan and Blum 2011).

Past decisions to fill sections of marsh have reduced marsh area and values, but sea level rise will exacerbate the problem. As sea levels rise, the marsh will erode on its seaward side but will be unable to migrate landward due to the steep shoreline fill used in each case. Human made barriers that prevent marsh migration landward under sea level rise is known as coastal squeeze, as the marsh is squeezed out of existence (Torio and Chmura 2013). Tidal marshes in Exeter are vulnerable to coastal squeeze along the barriers of Swasey Parkway, a section of Route 85 (Water Street) running north just past the parkway, along the WWTP, and the berm surrounding Powderhouse Pond. As marshes are lost through coastal squeeze, there are likely to be negative effects on fish and wetland-dependent birds like herons. Furthermore, structures will be more susceptible to erosion without the protection from the marsh.

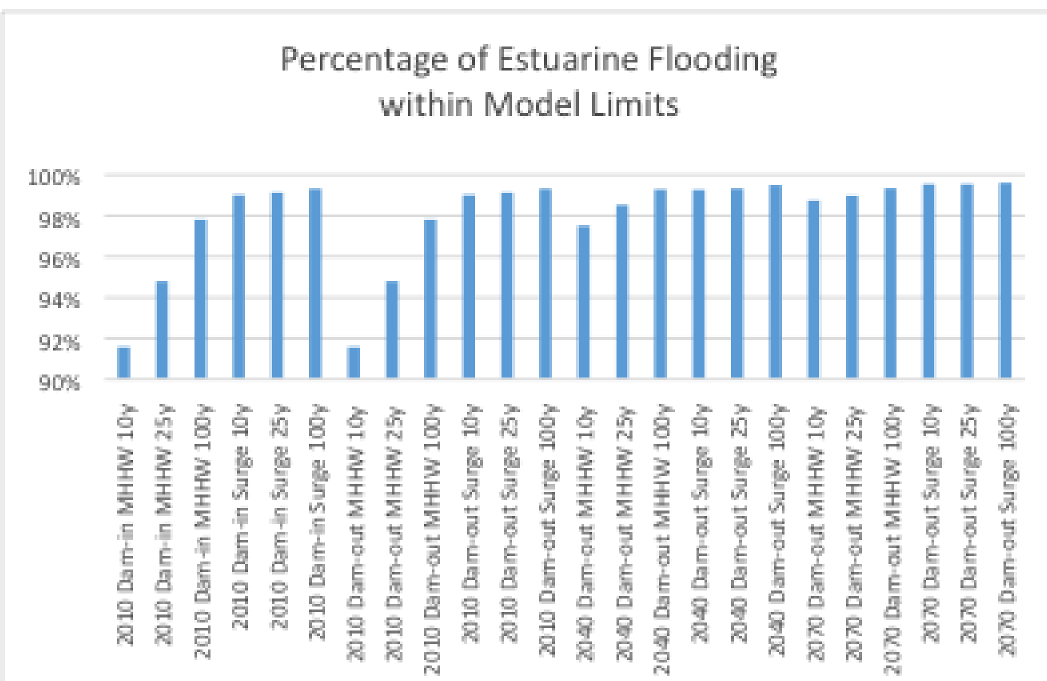


Figure 3. Area of estuarine wetlands flooded for flood scenarios, within model limits (some wetlands to the north and east were excluded from the study area). Codes, reflect scenarios: 1) year of model run; 2) Dam 'in' or 'out'; 3) the tide being only high tide (MHHW) or with a 100-year storm surge; and 4) return time of storm event used in model.

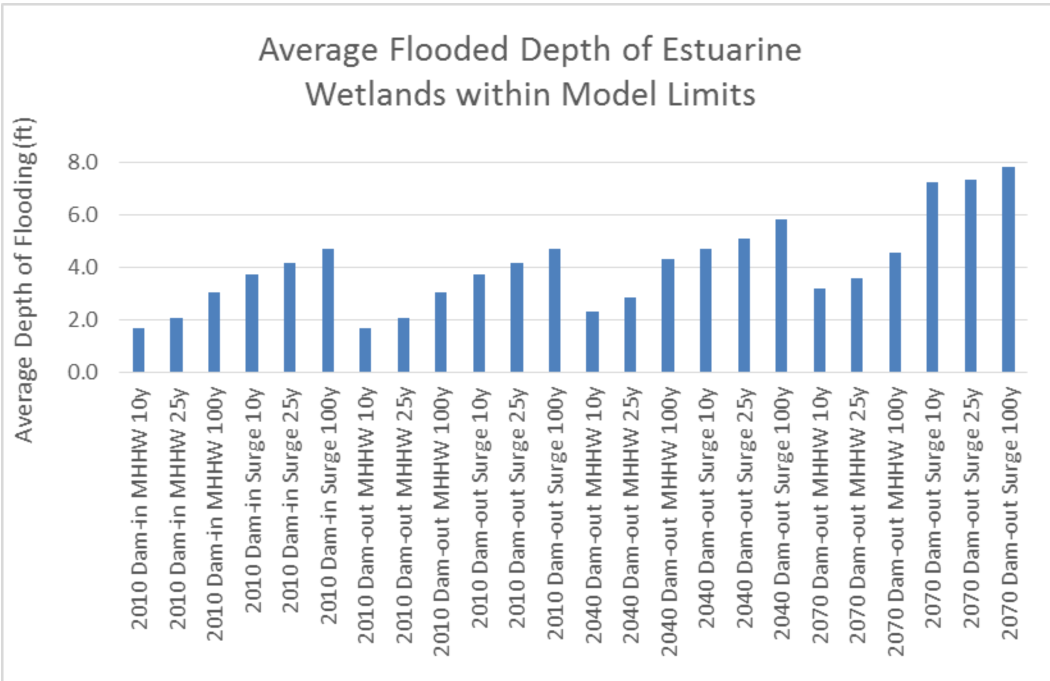


Figure 4. Average flooded depth of estuarine wetlands modeled for GCM scenarios within model limits (some wetlands to the north and east were excluded from the study area). For explanation of codes, see Figure 3.

Recently, the work of several town departments, especially the Conservation Commission, was important in reestablishing an adequate tidal connection to Norris Brook and restoring freshwater wetlands along the section of Brook that runs through Swasey Parkway to the Squamscott River. The result is that the seawall along Swasey Parkway (where the tidal wetlands are subject to coastal squeeze) is interrupted at Norris Brook. This section of the Brook receives daily tidal flow and the freshwater floodplains around it are not subject to coastal squeeze – they can convert to tidal marsh as sea level rises. Norris Brook restoration is one example of steps that can be taken now to improve wetland health and provide space for wetlands to adapt to future climate change.

As described in Appendix A, A Sea level rise 'Walks' with Exeter citizens (November 10th, 2014) discussed characteristics and values (ecosystem services) of tidal marshes and set out flags to show flat water elevations modeled from flood scenarios. The exercise was repeated with sixteen students from Phillips Exeter Academy as part of Climate Change Day on February 11th 2015.

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Appendix A. Materials for Sea Level Rise Activity and Workshop

For CAPE Citizens Working Group November 10, 2014

For PEA Climate Action Day Feburary 11, 2015

PEA Workshop Agenda:

Climate Adaptation Planning for Exeter CAPE

Current and Potential Future Tidal and Storm Surge Water Levels along the Waterfront

For

Climate Action Day – Phillips Exeter Academy

Greeting in Boathouse: David, Alyson and others

Introduce CAPE and the 60 minute workshop

Introduce Tides (banner) at the Boathouse

Semidiurnal 3 meters in height from low to high tides

During the highest tides of each month

Storm Surges - the 100yr (1% chance each year) = 2.9 feet (0.9 m)

Climate Change and Sea Level Rise

Scenario planning

2070 Scenario is 3.2 feet (1 meter)

Salt marshes – one habitat, 'engineered' by plants, that builds itself with sea level rise: Accretion plus Peat Growth

Field Demonstration: High Tides and Storm Tides along the Swasey Parkway

Establish a laser and elevation using storm drain at 6.3' (1.9 m) above MHHW

2015 with 100 year storm (7.0 feet or 2.1 m) Yellow line in Figure 1

2070 – MHHW levels (average high tides reach 7.3 feet (2.2 m) Pink line in Fig. 1

2070 – MHHW plus the 100 year storm (10.2 feet or 3.1 m) Not shown in Figure 1

Discussion:

What does SLR and SS threat mean for the Exeter Community? PEA?

What should the response be? - Seawalls along the shorelines? Other ideas?

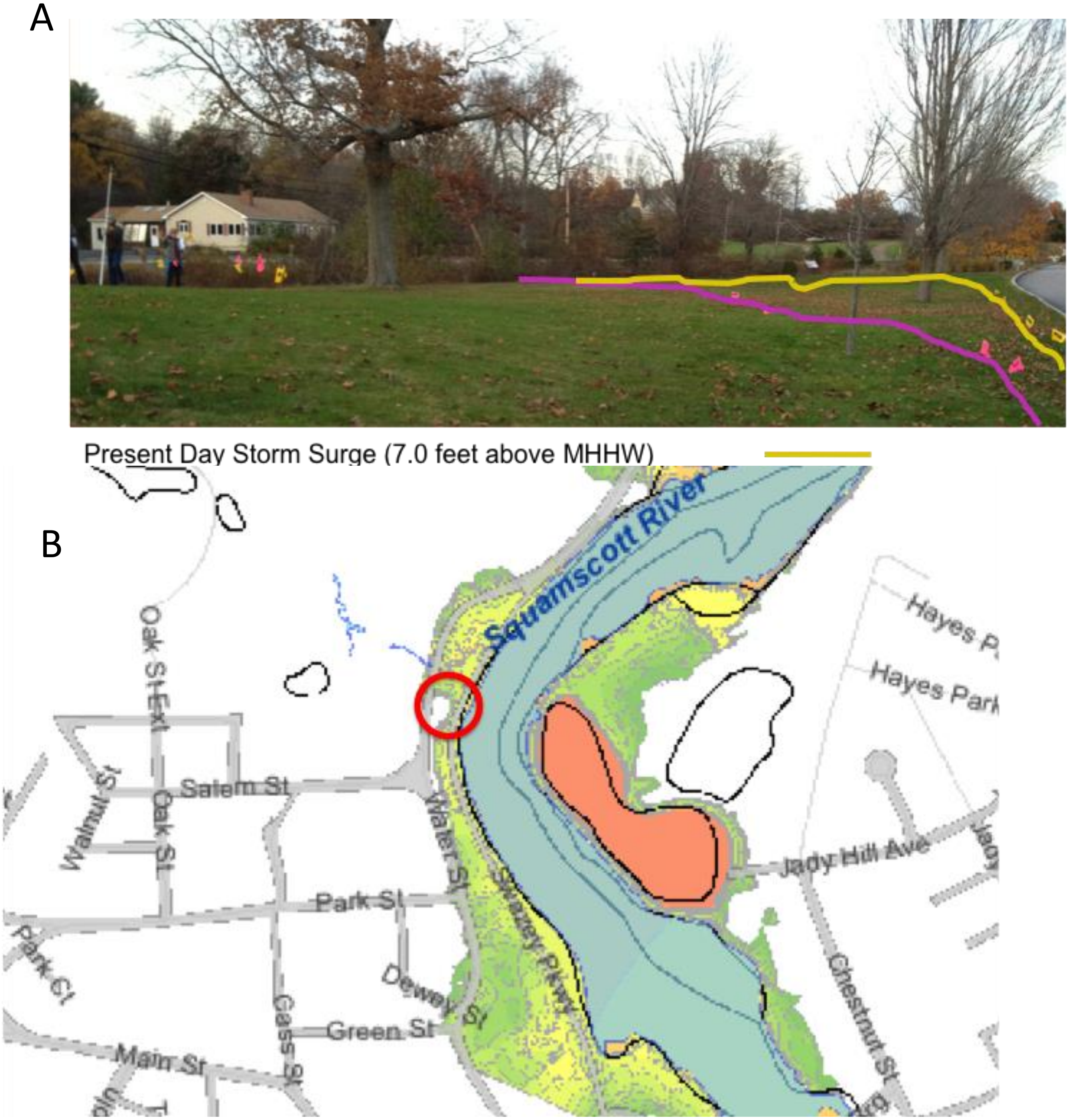

Figure 1. A Participant-mapped flood lines from storm surge (yellow line) in 2014 and normal high tide in 2070 (1 meter increase in sea level, pink line). B. Flooding map of tidal portion of Squamscott River along Swasey Parkway under 100-year storm surge in 2070 with 1 meter of sea level rise. Circle denotes grassy knoll (the top of which remains unflooded) where flooding elevations were mapped by workshop participants.

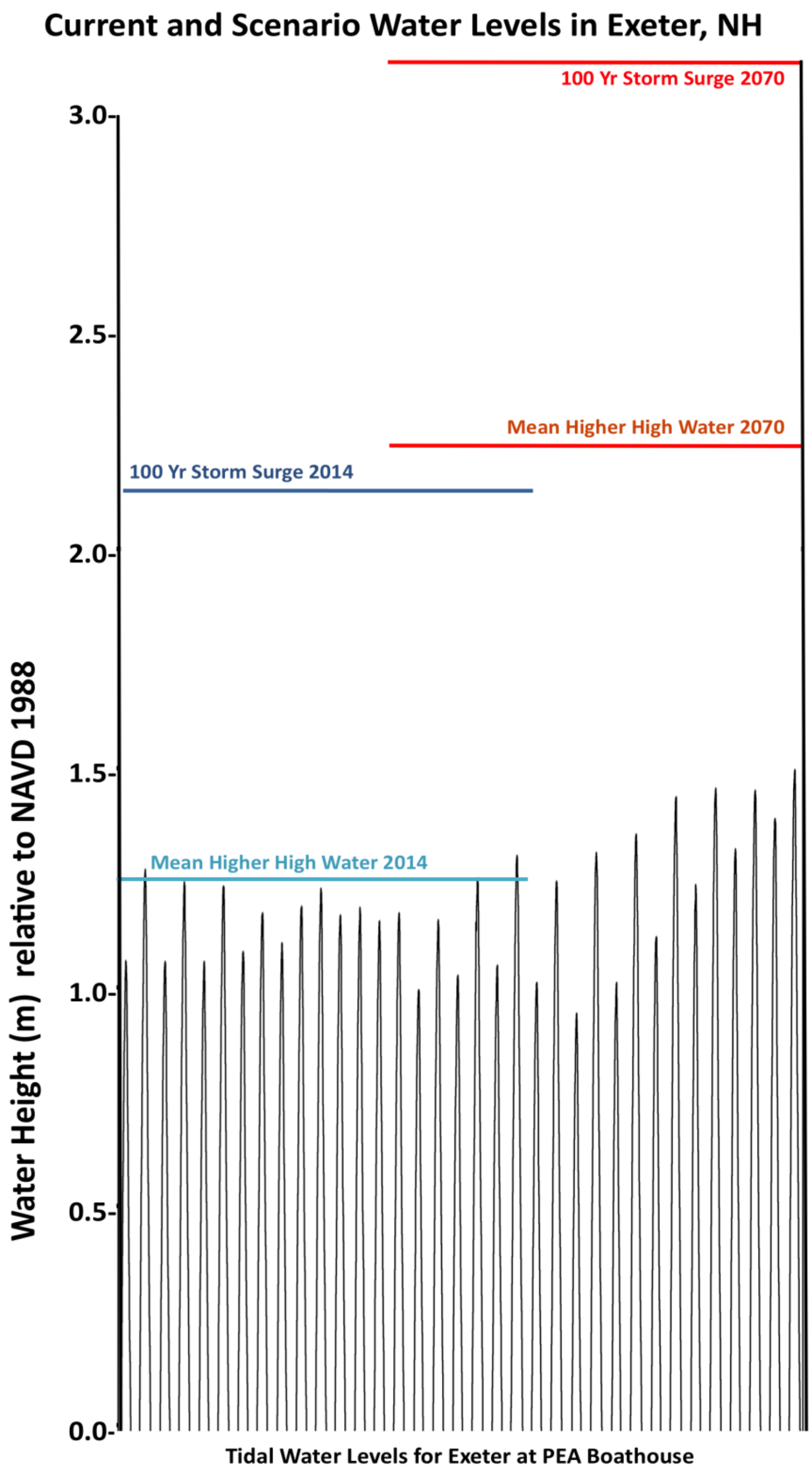

Figure 2. Banner (displayed in ½ scale) used at Phillips Exeter Academy Climate Action Day to illustrate the current tides, mean high tide and storm surge (100 year storm) and comparison to predicted high tide and surge in 2070 under a scenario of severe climate change.

Appendix AS10

Ecosystem Impacts

To help constrain and focus our efforts to assess ecosystem impacts, we constructed an ecological model to represent critical habitats and stressors within the Exeter-Squamscott river watershed related to impacts of climate change, river flow and water quality (Figure 1). The main ecosystem targets of concern are human health, river herring and tidal marshes.

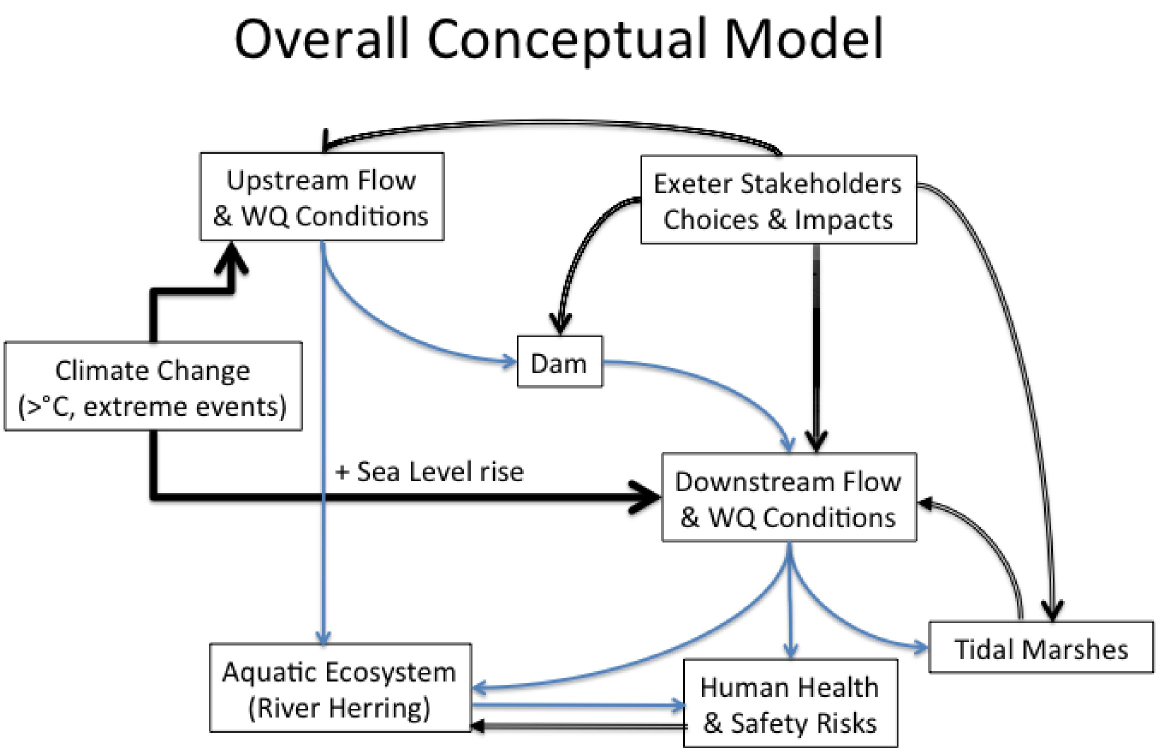

Figure 1. Diagram of ecosystem impacts from a variety of choices made by Exeter stakeholders, including stormwater and NPS pollution management of discharges into the Exeter River (upstream of dam) as well as CSOs and WWTP outfalls to the Squamscott River (downstream of dam), zoning and land use management, dam alternatives, and erection or removal of tidal barriers to marsh migration. Arrows from Tidal Marshes and Human Health Risks are feedbacks to Water Quality and Herring Populations. All ecosystem impacts also feedback to Exeter Stakeholders.

Recent and current ecosystem conditions

Understanding and quantification of recent and current ecosystem conditions are necessary precursors for determining ecosystem impacts of climate change. One comprehensive approach for doing this is to refer to the State of New Hampshire's Surface Water Quality Assessment Program Integrated report (NHDES 2012), that includes a list (303(d) list) of State waters that are impaired by pollutants, and that are not expected to meet water quality standards in the near future. The biennual Integrated Report describes water quality in terms of protection and the potential propagation of fish, shellfish and wildlife as well as recreational activities. The 2012 303-d listings for New Hampshire showed widespread impairments existed at 10 stretches of the Exeter River because of low pH, low dissolved oxygen saturation, fecal-borne bacterial contamination, excess chloride and benthic-macroinvertebrate bioassessments (NHDES 2012). The tidal Squamscott River in Exeter had the same impairments but also included PCBs, dioxin, chlorophyll *a* and total nitrogen. This impairment information directed our efforts to compile pertinent water quality data from ongoing and recent studies to inform the modeling efforts and provide a basis for framing ecosystem conditions and future concerns.

We also compiled specific ecosystem and water quality datasets from individual programs and reports. The data include a wide array of measurements in water and sediments, and come from a range of state, UNH, research and other agency reports and papers (Table 1). Older datasets were also available through various other water quality and fish studies by UNH and the Jackson Estuarine Laboratory. The NH Fish & Game also deployed datasondes below the String Bridge just upstream of the transition from the freshwater Exeter River to the tidal Squamscott River. The data (water temperature, salinity, pH, dissolved oxygen, turbidity) were collected for 4 recent years (2008-11) during the spring, which is a critical time for anadromous fish migrating over the dam to freshwater habitat. All of these data were useful for calibrating model output to reflect actual historical conditions that is critical for developing accurate future scenarios. The site with the most robust and complete data was the Great Dam in downtown Exeter.

	PARAMETERS	
Water temperature	Salinity	Specific conductance
Dissolved oxygen	Fecal-borne bacteria	Nutrients
Suspended solids	Fish run numbers	pH
Chlorophyll *a*	Toxic chemicals	
	DATA SOURCES	
NHDES VRAP Program	NHDES Ambient Tributaries program	NHDES 303(d) list & 305(b) report
NHDES-UNH Squamscott River dissolved oxygen studies	NH Sea Grant Program Coastal Research Volunteer Program	EPA/NHDES National Coastal Condition Assessment Program
NH Fish & Game Dept.	GBNERR System Wide Monitoring program	2011 HydroQual-UNH study

Table 1. Compiled Data Sets

Examination of the compiled data showed several major findings, summarized below and related to human and aquatic ecosystem health.

The CRV storm drain study (Jones 2012) confirmed that elevated levels (in excess of NH State standards) of chloride, bacteria and nitrogen were being discharged to the Exeter and Squamscott rivers from a number of storm drains, thus raising concerns about impacts to human and aquatic ecosystem health linked to predicted increased runoff from both climate change and potential future development that increases impervious surface cover in Exeter. The storm drain water did not have low pH and dissolved oxygen, even though these impairments are widespread in the two rivers. Nitrogen and other nutrients (phosphorus, carbon) once delivered to receiving waters have the potential to cause problems with both pH and dissolved oxygen due to microbial metabolism.

From a human health perspective, water-borne illness and disease (exposure via recreational activities, drinking water contamination, fish consumption) incidence is on the rise in the Northeast due to increasing levels of infectious bacteria and toxic chemicals caused by pollution and climate change factors affecting the region's surface waters. For example, climate change is predicted to increase the prevalence of mosquito vectors of human illnesses like eastern equine encephalitis (EEE) (Armstrong and Andreadis 2013) in the Northeast US, while vibriosis incidence in the Northeast has risen over the past decade and even more sharply since 2010 (Jones 2011; Newton 2014). In addition, historical sources of toxic chemicals are still detectable in the Squamscott River, where sediment levels of PAHs were quite elevated relative to other sites in the Great Bay estuary (http://www.epa.gov/emap/nca/html/regions/ne0006/index.html) due to seepage from a historical gasification coal tar site next to the river. At a series of 6 sites tested as part of the dam removal study, some potentially harmful chemical contaminants were detected in sediments but not at levels that would raise serious issues if the dam were to be removed and some sediment mobilized (VHB 2013). Thus, the current water and sediment quality information suggest that there are some problems, especially microbial contamination from fecal pollution sources, there is the real concern that vector-borne diseases may continue to increase in the area, and even the emergence of tropical diseases is a climate-change related concern. The loading of fecal and toxic contaminants to the rivers will only increase in severity as impervious surface coverage and extreme precipitation in Exeter increases, although some sources have and could be identified and eliminated through shoreline surveys, site investigations, reduction of illicit sources in the Town storm drain system, and installation of low-impact development (LID) and other Best Management Practices (BMP) for stormwater management.

Recent NHDES monthly monitoring data at the Great Dam showed nutrients to be at relatively low levels, with only dissolved organic carbon and nitrogen being elevated compared to levels in other tributaries to the Great Bay estuary (Wood and Trowbridge 2011). This suggests that, given the existing nitrogen impairment, that the watershed and the aquatic ecosystem are susceptible to detrimental nutrient induced impacts.
Annual air temperatures for the 118 years prior to 2013 were compared and 2012 was the warmest, while 2006, 2010, and 2011 were all in the top 8 warmest years in New Hampshire (Stampone, data not shown). A similar pattern has emerged in the Gulf of Maine, where 2012 is the warmest year on record. There have been no studies to directly link higher temperatures with ecosystem changes or human health impacts in the Exeter area over the past five years, but impacts and potential impacts have been documented in this region for a variety of human health issues, including pathogenic vibrios, a naturally occurring set of bacterial species that cause human and fish illnesses in warmer waters (Xu et al, 2015; Newton 2014).

The more integrative water quality and biological measures of ecosystem health include river herring runs, air and water temperature and dissolved oxygen. The recent petition to list alewife and blueback herring as threatened species and to designate critical habitat (NRDC 2011) provides a comprehensive and thorough review of the ecosystem importance of these species and has detailed historical analysis and significance of potential impacting factors. Many factors can affect river herring returns and water quality is one factor that can be locally managed. While modifications to the Exeter River ladder in 2000 had an initial positive impact on river herring usage of the fish ladder, the numbers have continued to drop since 2001 (D. Grout, various NH F&G reports). This indicates that the problem is most likely not with the ladder but with the spawning run, recruitment, water quality, dissolved oxygen levels and possibly flow regime. Herring return numbers and episodic low DO occurrences are indicative of cascading consequences for the totality of environmental and climatic conditions.

As air and water temperatures increase, there are several human and aquatic ecosystem impacts that will occur. Dissolved oxygen saturation and concentration decrease with increasing temperatures, and as ecosystem metabolism increases with temperature, the combined effects will probably result in longer duration and more intensive episodes of low DO levels in the watershed aquatic ecosystem. Higher temperatures also simulate the growth of organisms, and this can result in changes to the community, from microbes to fish. There are many environment-borne human illnesses caused by often-times rapidly growing pathogens that thrive under warmer temperatures that we presently do not experience in the Exeter area, so there are concerns that those microorganisms will emerge as more prominent and frequent members of the ecosystem.

There are multiple sets of evidence that show the episodic occurrence of low dissolved oxygen (DO) levels at sites in the Exeter and Squamscott rivers, including several NHDES-UNH studies and data from the Squamscott River datasonde (Jones 2005; others not cited). More recently, the intensive summer 2011 study (HydroQual 2012) showed frequent low DO episodes of varying length (up to several hours) in the Squamscott River, especially just down river from the Exeter wastewater treatment facility at the Rt. 101 bridge. This is probably due, to a great extent, to effluent from the Exeter wastewater treatment facility, which contains elevated levels of nutrients and plankton generated in the oxidation ponds (Jones and Gregory 2011). The 4 consecutive years that NH Fish and Game monitored DO at the String Bridge showed the typical seasonal decrease in DO from March to June each year as water temperatures increased with measured low (<75% saturation/<5 mg/L) levels except during March of 2010, when extensive low DO was measured following the March 13-15 exceptional rainfall/flooding event. Also, during studies of the effects of passage impediments and environmental conditions on out-migrating juvenile American shad, NH Fish & Game measured levels of dissolved oxygen below 5 mg/L at various sites in the Exeter River. Thus, both warmer temperatures and extreme rainfall events can cause serious and prolonged low DO episodes that can impair health, normal behavior and threaten mortality of herring and other aerobic organisms in the aquatic ecosystem.

Collaborative modeling efforts

We worked with others in model development to assess how climate change scenarios will alter the conditions and/or the loading & concentrations of contaminants, and to interpret modeled projected impacts on ecosystem and human health. The goal of this effort was to address the concerns we heard from residents through the CWG and small and large meetings, in the context of potential future conditions that consider the timing and volume of river and runoff flow through the town, changes in air and water temperature, and the integrated impacts of these factors for wetlands, fish populations and human health.
With all climate change scenarios pointing towards steady and significant increases in both minimum and maximum annual air temperatures and most of them for annual precipitation, these factors can be assessed in terms of potential ecosystem effects. On the other hand, model results from this study for water quality parameters show few consistent increases in total nitrogen and phosphorus loading, so these factors we

assume will not be significantly different in the future, based on the assumptions for all factors used in the models. There will be increased total suspended solids (TSS) compared to current conditions during spring and late summer (July-September), and there appears to be a predicted increase in fecal-borne microbial contaminant loading during autumn (October-November) compared to present conditions (Figure 2).

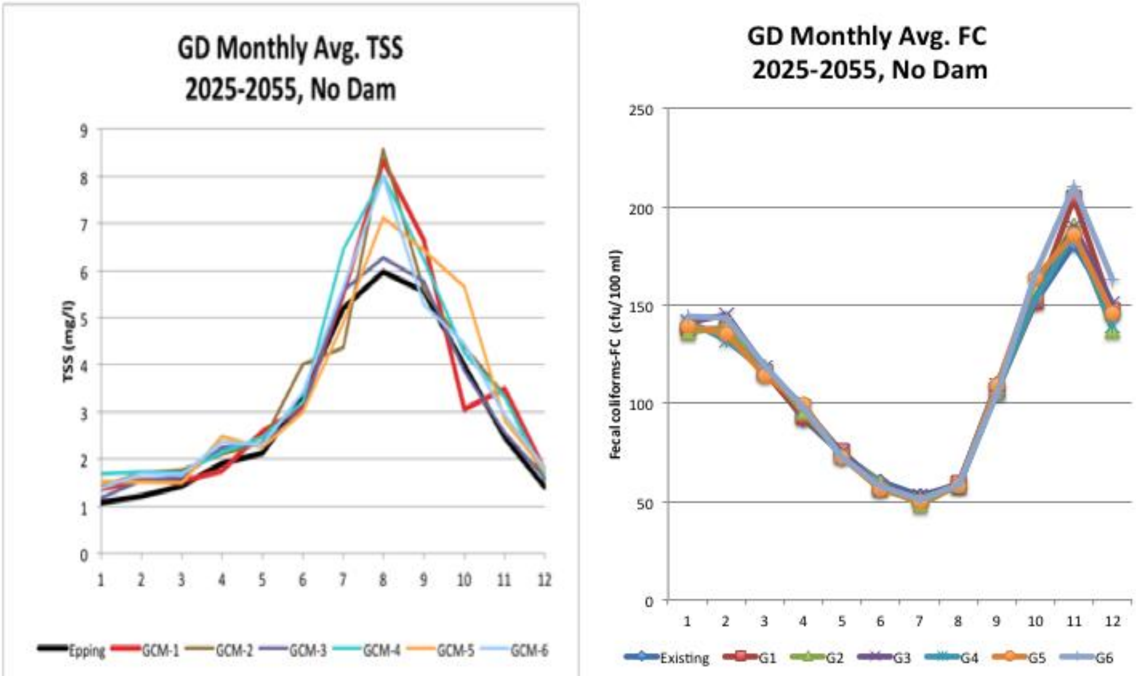

Figure 2. Model-based projections of future concentrations of total suspended solids (TSS) and fecal coliforms (FC) in the Exeter River at the Great Dam (GD).

Low DO can cause stress and mortality in herring, other fish and all aerobic organisms in an ecosystem. DO decreases with increasing temperature and as ecosystem metabolism also increases with temperature, oxygen demand can exacerbate this trend and cause longer duration and more intensive low DO episodes. Thus, future projections of steadily increasing temperatures over the next 50 years suggests that ecosystem conditions will deteriorate for fish and other sensitive species. Suspended solids can also impair fish habitat as it can smother breeding grounds and impair population regeneration. Suspended solids are also vectors for nutrients, toxic chemicals and microbial pathogens, so increases in TSS may also underlie future increases in overall ecosystem toxicity and diseases. Higher concentrations of fecal coliforms suggests increased pollution from human sewage sources and the potential for increased human disease from exposure to contaminated surface waters.

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Appendix AS11

Planning Model Abstract for AGU 2015

Using Minimax Regret Optimization to Search for Multi-Stakeholder Solutions to Deeply Uncertain Flood Hazards under Climate Change – Paul Kirshen, Jory Hecht, Richard Vogel

Prescribing long-term urban floodplain management plans under the deep uncertainty of climate change is a challenging endeavor. To address this, we have implemented and tested with stakeholders a parsimonious multi-stage mixed integer programming (MIP) model that identifies the optimal time period(s) for implementing publicly and privately financed adaptation measures. Publicly funded measures include reach-scale flood barriers, flood insurance, and buyout programs to encourage property owners in flood-prone areas to retreat from the floodplain. Measures privately funded by property owners consist of property-scale floodproofing options, such as raising building foundations, as well as investments in flood insurance or retreat from flood-prone areas.

The objective function to minimize the sum of flood control and damage costs in all planning stages for different property types during floods of different severities. There are constraints over time for flow mass balances, construction of flood management alternatives and their cumulative

implementation, budget allocations, and binary decisions. Damages are adjusted for flood control investments.

In recognition of the deep uncertainty of GCM-derived climate change scenarios, we employ the minimax regret criterion to identify adaptation portfolios robust to different climate change trajectories. As an example, we identify publicly and privately funded adaptation measures for a stylized community based on the estuarine community of Exeter, New Hampshire, USA. We explore the sensitivity of recommended portfolios to different ranges of climate changes, and costs associated with economies of scale and flexible infrastructure design as well as different municipal budget constraints.

APPENDIX C1 –Article in press:

Aytur, S., Hecht, J., & Kirshen, P. (2015). Aligning Climate Change Adaptation Planning with Adaptive Governance: Lessons from Exeter, NH. *Journal of Contemporary Water Research and Education*, *In Press* Special Issue - Water Diplomacy).

(*Note to NERRS: When this article is published, we should probably provide a link to the journal to avoid copyright issues. Contact Semra.Aytur@unh.edu for updates).

Abstract

Adaptive governance has been recognized as an integrative approach for analyzing the social, institutional, ecologic, and economic aspects of decision-making to build resilience against climate change. Although closely aligned with adaptive co-management and ecosystem management, adaptive governance is a distinct framework that explicitly focuses on decentralized decision-making through social processes such as collaborative learning, networking, and the promotion of cross-sectoral partnerships to enhance adaptive capacity.

In this paper, we explore an ongoing engagement process for climate change adaptation planning in Exeter, New Hampshire, and its alignment with key principles of adaptive governance. Climate change poses multiple challenges to Exeter, including increased flooding, reduced low flows, water quality degradation, and associated threats to estuarine ecosystems and public health. Engagement strategies include community conversations, workshops, experiential activities, and a community advisory board comprised of different stakeholder representatives (Citizens' Working Group) collaborating with the scientific team on water resources modeling and scenario analysis. We present important lessons about conveying expectations and timeframes of technical modeling to participants, developing multiple forums for

interaction between researchers and other stakeholders, and making climate change locally relevant to residents by drawing connections to the community's experiences, cultural memory, values, and upcoming decisions. This study contributes to the literature on adaptive governance and climate change adaptation by evaluating stakeholder involvement in a local institutional setting, an important arena where adaptation decisions must be deliberated. It is also among the first studies to evaluate the ways in which a climate change adaptation stakeholder engagement process aligns with adaptive governance principles, particularly through boundary objects and experiences.

Keywords: Community Based Participatory Research, Integrated Water Resources Management, collaborative planning, boundary objects, resilience, flooding, public health, transdisciplinary research

Introduction:

Prior research has described community-based adaptation planning as "a bottom-up strategy that starts with changes and pressures experienced in peoples' daily lives" (Rayner and Malone 1997, 332). Similarly, adaptive governance is a concept that addresses the bottom-up evolution of institutions for the management of shared assets, particularly common pool resources and other forms of natural capital (Hatfield-Dodds et al. 2007). Adaptive governance has been defined as the "evolving and locally context-specific balancing and integration of alternative interests through participatory engagement between governments and communities facilitated by the integration of local and scientific knowledge" (Nelson et al. 2008, 4). It has been recognized as an integrative approach for analyzing the social, institutional, ecologic, and economic aspects of decision-making to build resilience against climate change (Garb et al. 2008; Lynch and Brunner 2010; Raynor and Malone 2000). Although closely aligned with adaptive co-management (Armitage et al. 2007; 2008; Plummer and Armitage 2007) and ecosystem management (Szaro et al. 1998), adaptive governance is a decentralized decision-making process that uses techniques such as collaborative learning, networking, and promotion of cross-sectoral partnerships (Brunner 2010; Kallis et al. 2009). It is a response to the failure of top-down, expert-driven approaches to decision-making to successfully address complex socioecological problems such as climate change. Adaptive governance "suggests factoring the global climate change problem into thousands of local problems, each of which is more tractable scientifically and politically than the global problem" (Lynch and Brunner 2010, 6). Cash and Moser (2000) underscored the critical gap between the top-down assessments of the Intergovernmental Panel on Climate Change (IPCC) that aim to understand large-scale phenomena and the contextualized initiatives that enable local decision-makers to adapt to the local-scale impacts of climate change. They described the need for decision-support processes that provide: "(1) multiple connections between researchers and decision-makers that cut across various levels (polycentric networks)" of governance; and "(2) sustained and adaptive organizations that allow for iterated interactions between scientists and decision-makers" (Cash and Moser 2000, 242).

It is important to emphasize that adaptive governance, like other governance approaches, utilizes science to inform decision-making. However, adaptive governance is distinguished by the *types* of knowledge considered to be policy-relevant and the *engagement processes* through which knowledge is integrated with decision-making (Nelson et al. 2008). Although there is no comprehensive synthesis of best practices for researchers wishing to facilitate adaptive governance through their work, Dietz et al. (2003; 2013) and Nelson et al. (2008) provide guiding principles. These include: 1) clarifying common goals with stakeholders; 2) building on local communication and governance structures; 3) seeking out and integrating local knowledge; 4) balancing complementary knowledge systems (e.g., local knowledge and scientific/external knowledge) to inform planning and policy processes; 5) implementing, evaluating, and refining policy in local contexts; 6) transferring lessons learned across local, regional, and national contexts.

While many studies have explored the viability of an adaptive governance framework for complex and uncertain multi-stakeholder resource management problems, very few studies have evaluated its applicability to community-scale climate change adaptation planning. This study contributes to the literature on adaptive governance and climate change adaptation by evaluating stakeholder involvement in a local institutional setting, an important arena where adaptation decisions must be deliberated. It is among the first studies to evaluate the ways in which a climate change adaptation stakeholder engagement process aligns with adaptive governance principles.

In this paper, we present a case study of an ongoing engagement process developed for the Climate Adaptation Plan for Exeter (CAPE) project. The overall CAPE project objectives are to: (1) develop a science-based, integrated climate change adaptation strategy for Exeter; and (2) implement, evaluate, and document the collaborative planning process and share the project results as a model for other coastal and estuarine communities. In this paper, we focus on the second objective by examining the extent to which our community engagement process aligns with key principles of adaptive governance. We explore adaptive governance as a framework for adaptation planning because stakeholders themselves identified several principles of adaptive governance as valued outcomes of the CAPE project (e.g., bringing together diverse stakeholders, connecting scientists with citizens and community groups, meeting regularly with citizens, and sharing knowledge). Specifically, we address the following research questions in this paper: 1) what were the challenges and opportunities associated with aligning these engagement strategies with adaptive governance principles, and 2) what lessons were learned that might enhance future adaptation planning efforts in community contexts? Documenting our engagement process in a case study format aids in clarifying the social relationships and institutional factors that will influence the final outcomes of the CAPE project, including which climate change adaptation strategies are ultimately pursued by the community.

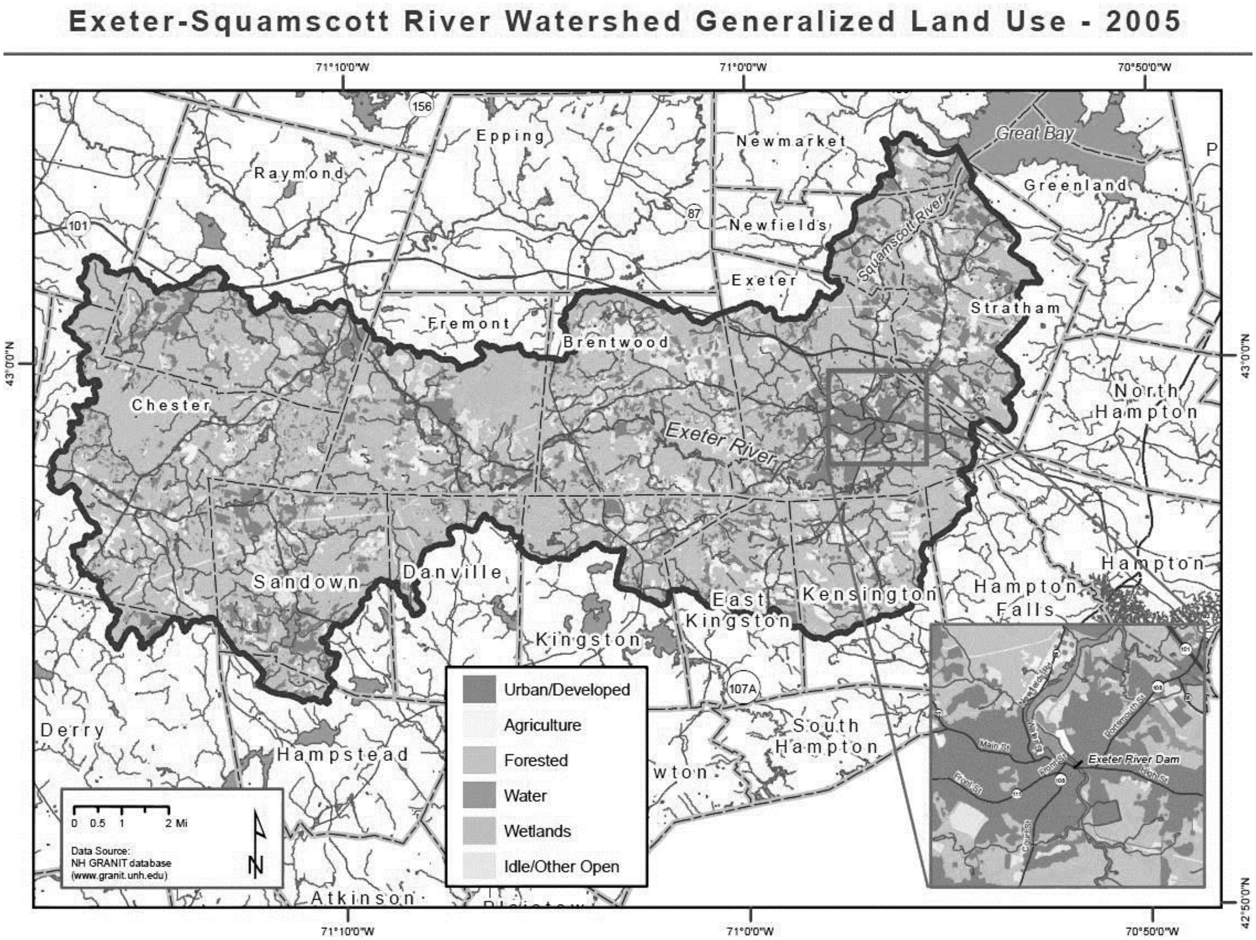
Case Study:

The Great Bay National Estuary Research Reserve (GBNERR) is located in southeastern NH and includes 20,172 acres of open water, wetlands, and upland zones. The 1,084 mi^2 watershed that drains into the reserve is heavily forested and has extensive wetlands, but is also becoming increasingly urbanized (currently 9% of the watershed area) (Mills 2009). The major climate change stressors in the region include increases in air and water temperatures, sea level rise, and changes in precipitation and runoff patterns, including larger storms and floods.

Our transdisciplinary team comprised of social and biophysical scientists, engineers, and town staff, is undertaking a collaborative planning effort to develop an integrated climate change adaptation strategy for one of the towns situated on a river that drains into GBNERR in order to develop a prototype for managing the developed portions of the watershed under climate change. Specifically, the case study area is the portion of the Town of Exeter in the Exeter/Squamscott River Basin, which includes most of the town's area and is located just upstream of Great Bay (Figure 1). The Squamscott River, tidal in nature, is located downstream of the dam in the center of the downtown.

(Insert Figure 1-Map of area here)

Caption: Figure 1- Map of study area



Exeter's population is approximately 14,000 with over 18% of the population over the age of 65 (U.S. Census 2010). The median household income is $72,231, although there is diversity in socioeconomic status and housing conditions. For example, there are approximately 876 manufactured housing units, many of which are highly vulnerable to flooding.

Climate change will exacerbate Exeter's present challenges related to: 1) tidal and non-tidal river flooding, 2) stormwater drainage, 3) nonpoint source pollution and water quality, and 4) the protection and restoration of downstream marshes and fisheries. These challenges were identified in the proposal phase by reviewing recent studies for the area (Mills 2009) and consulting with town officials. These stressors related to climate change also have the potential to significantly impact public health (e.g., injuries and illnesses associated with flooding and exposure to contaminated water, the stress associated with possible evacuation, and the risk of being stranded in flooded neighborhoods without access to medical and social services). Since the water-related stressors in the case study area are interconnected, they can be most effectively managed in an integrated fashion. To help translate climate changes and sea level rise into impacts on the community, the team employed flood, stormwater, hydrologic and water quality simulation models. Additionally, they developed a flood adaptation decision-support tool and an ecosystem process model.

Alignment of Engagement Strategies with Adaptive Governance

To examine the alignment of our engagement strategies with adaptive governance, we will review how each of these strategies functioned as a **boundary object** and/or a **boundary experience**. A **boundary object** is typically described as a product (e.g., map, model, field notes, images, and other types of information) that different stakeholder groups can use in different ways to share knowledge (Bowker and Star 1999) and interact with the study team (Cash et al. 2002; 2006). Boundary objects aid in the translation of information by providing common points of reference for dialogue (Chrisman 1999) and drawing attention to different interpretations and meanings (Fischer and Reeves 1995). Boundary objects can aid decision-making in situations of incomplete knowledge, nonlinearity, and diverse interests (Mollinga 2008; 2010). They can also include intermediate versions of a product that stakeholders can react to and agree upon before the final version is developed (Marick 2014; Star and Griesemer 1989; Wenger 1998). For example, in the CAPE project, several iterations of GIS maps showing locations that were vulnerable to flooding under different climate change scenarios were shared with town staff and other stakeholders. The map content and format were adjusted to reflect stakeholder input, so that the final versions were acceptable to town staff, researchers, and other community members. Boundary objects are flexible enough to adapt to local needs, but retain enough immutable content to maintain integrity across applications (Star and Griesemer 1989; Wenger 1998).

The role of boundary objects in adaptive governance has been widely discussed in the literature (Carlile 2002; Folke et al. 2005; Garb et al. 2008; Fuller 2009; Brunner and Lynch 2010; Crona 2012). Boundary objects are used to develop a shared language that enables stakeholders to cross disciplinary or cultural barriers (Carlisle 2002, 446). They also offer stakeholders a new vocabulary to discuss problems and a foundation for re-framing concepts to align with multiple perspectives (Fuller 2009, as cited in Kallis et al. 2009, 637; Lejano and Ingram 2009). Importantly, this new vocabulary helps to facilitate conversations between scientists and other stakeholders.

A **boundary experience** is a term developed by our engagement team to explicitly call attention to the dynamic and iterative process through which groups of stakeholders share knowledge and co-produce boundary objects with the project team. While this procedural component has been implicit in prior scholarship pertaining to boundary objects (Carlile 2002; Lejano and Ingram 2009; Munaretto et al. 2014), we contend that it is helpful to recognize it explicitly so that the dynamic interplay between process and product – the essence of transformative social learning (Pelling et al. 2008; Parkins and Mitchell 2005) - can be more critically evaluated. We found that some of the greatest challenges and opportunities of our engagement process were situated at this nexus.

Engagement Process

In transdisciplinary research on community resource management problems, there is a growing expectation for community members to be actively engaged in the research process (Commonwealth of Australia, 2008). The CAPE project utilized a Community Based Participatory Research (CBPR) approach (Israel et al. 2005), in which community stakeholders partner with the research team on all aspects of the project including clarifying goals, refining the methodology, and interpreting results. While CBPR is widely utilized in public health to improve the adoption, implementation, and sustainability of community-based interventions, its application to adaptive governance and its relevance to promoting specific researcher-stakeholder interactions supportive of democratic decision-making remains unexplored. Thus, we chose CBPR over other approaches to examine its application to a climate change adaptation planning process, and to enable researchers and stakeholders from different disciplines to learn about how engagement approaches commonly used in public health may translate across sectors to inform water-related decisions.

Specific engagement activities utilized during the first 18-month phase of the project included community conversations, workshops, and experiential activities (e.g., walking groups and field tours). In addition, we created a Citizens' Working Group (CWG) that provided direct feedback to the scientific team on water resources modeling and scenario analysis. Details about specific engagement strategies are described below (Table 1).

(Insert Table 1 here)

Community Conversations

The first community-wide CAPE engagement event was held in the spring of 2013, at Exeter High School. This was a "community conversation" in which our team members from New Hampshire Listens (NH Listens) designed a deliberative dialogue entitled "Floods, Rains, and Rivers" to explore the community's values and perceived vulnerabilities associated with climate change. NH Listens works with local and statewide partners to bring people together for productive conversations that complement traditional forms of government meetings, such as town hall or school board meetings (NH Listens 2014). Recruitment was conducted through email, announcements at public meetings, advertisements, and personal contact. Additionally, project staff met with several key *communities of interest* prior to the event. ***Communities of interest*** are a community of people who share a common interest, goal, or knowledge about something—a common bond or interest (Henri and Pudelko 2003). These included a local retirement community, a resident owned manufactured housing community, high school students, conservation groups, and a group of mothers with young children. In addition, staff of NH Listens trained a group of high school students as facilitators who helped to lead each small group discussion.

The participants (n=63) were split into nine groups, each of which was led by a facilitator from NH Listens and a youth facilitator to explore different issues and challenges facing the Exeter community. This event was designed as an opportunity for stakeholders to clarify goals, identify local assets, and discuss ideas to effectively plan for a changing climate. The narratives from the conversation were analyzed qualitatively and grouped into themes. Evaluation surveys indicated that the community conversation served as an effective boundary experience in terms of enabling participants to consider different perspectives and become better informed about local climate change issues. Over 75% of respondents (n=40) reported that they would participate in another community conversation.

Another activity initiated at this event was a mapping exercise in which participants identified "areas of importance" or locations where they perceived vulnerabilities for people, infrastructure, and natural resources. Participants marked these locations on large paper maps, which were subsequently developed into a GIS. This activity provided a visual snapshot of town assets and resources that could be impacted by flooding, and also generated a discussion in which at-risk populations (e.g., older adults) who might suffer stresses associated with extreme weather events were identified.

These tangible products served as starting points for developing indicators such as the location, depth, and areal extent of flooding of infrastructure, natural resources, and community places to inform the flood modeling. They have also proven useful as boundary objects because they translate local knowledge that the technical team can incorporate into scientific modeling efforts. The technical models have provided quantitative details about severity, depth, and damages caused by present and potential future flooding that augment this qualitative local knowledge.

This dynamic interplay of knowledge was iteratively improved through subsequent meetings and field tours with town staff. Other locations in the town where flood damages occur or could occur were identified, enabling the list of vulnerabilities to be continuously expanded and specified. For example, some of these additional locations included sewage pump stations, recreation areas, several culverts, and the new Gilman Pond well. Town emergency management staff identified areas that are cut off from emergency services during flood events. The team also mapped wetlands that will be threatened by flooding and permanent sea level rise. Additional indicators of flood damages under present and future climates include the direct expected value of property and content damage costs to buildings, as well as indirect costs, such as evacuation expenses and lost work time.

Citizens' Working Group (CWG) - The CWG is a local stakeholder advisory board (n=20) designed to meet with the CAPE team on a regular basis. It includes representatives from the Exeter Select Board, local businesses, non-profits, faith-based organizations, the Exeter River Study Committee, and residents of various neighborhoods. Residents from manufactured housing communities, among the most vulnerable to flooding, are also represented. Participants were recruited at our community conversation; anyone interested was invited to join. Additional members were recruited through the University's Cooperative Extension program.

This citizen input group was designed to enable the CAPE modeling team to develop products that are legitimate, credible, and salient for the community in order to align with the functions of boundary objects described by Cash et al. (2002). This resulted in boundary products that were useful for priority audiences - the town's decision-makers and the town boards that advise them. Nine meetings were held over the first 18 months of the project. Evaluation surveys demonstrated that the overall response to the CAPE team's preliminary models was good; the team scored an average of '4' on a scale ranging from 1 (poor) to 5 (best). Notably, participants reported substantial improvement in the researchers' use of clear language over the 18 months (e.g., less technical jargon, more understandable words). Prior research has shown that clear language is a key feature of successful boundary objects (Clark et al. 2011). Respondents commented that the information being produced by the CAPE project was extremely important to the town.

Workshops with Town Staff

In 2012 and 2013, the CAPE team held meetings with town staff and CWG members. The 2012 meeting provided an opportunity for stakeholders and researchers to interact and discuss prior research about the impacts of climate change to the region. In 2013, the CAPE team hosted a half-day meeting at Exeter Town Hall to present the project's progress during first year. This included reviewing the first year's engagement activities, discussing preliminary findings, and envisioning next steps. The primary audience was town officials, staff, and civic leaders, with approximately 25 people attending each workshop. Survey data (n=18) indicated that participants felt the meetings were successful overall. For example, using an ordinal rating scale, participants at the 2013 meeting reported that CAPE was very successful at promoting greater communication between groups in Exeter, increasing awareness of natural resources and how they relate to climate change impacts, and improving communication between scientists and citizens. Survey results also indicated that the workshop enabled participants to better comprehend both technical and outreach components of the project. When asked, "How can CAPE help you do your work/become a more informed citizen?", common themes among answers were to provide more information about the effect of climate change on natural resources such as tidal marshes, as well as the economic and social costs of storm impacts. Participants also wrote in suggestions for improving graphs and educational presentations that the team has since adopted. Another outcome has been growing involvement of other town staff (such as emergency services personnel) fostered through informal networking opportunities at these workshops.

(Insert Figure 2 here) Caption. Figure 2. The CAPE team delivers a Year 1 in Review presentation to the town on December 12, 2013.

Experiential Activities

Aligning with Lejano and Ingram's (2009) view that successful collaboration depends upon continuous trust-building activities (Lejano and Ingram 2009), the CAPE team engaged in several activities to connect climate change to local experiences, cultural memory, and values. Two examples are described below.

a) ***Tour of Vulnerable Locations with Exeter Assistant Fire Chief*** **-** In August 2014, the Exeter Town Planner arranged a tour of the town with the Assistant Chief of the Exeter Fire Department to review vulnerable flooding locations. The group spent several hours identifying roads and homes that had experienced flooding since 1995. This tour was very valuable to the technical team because it enabled them to ground-truth the model results regarding the extent and depth of floods. Additionally, this tour provided important information about the flood response actions of residents that informed the development of an adaptation decision-support tool that the team is currently completing. For instance, the tour revealed some home flood-proofing measures that residents had adopted (e.g., sump pumps), which can be incorporated into the tool as an adaptation option. In addition, the tour enabled the project team to learn what emergency services the town provides during floods, such as boats, rafts, swift-water rescue operations, and a limited number of generators to deal with power cuts that often coincide with flood events. During recent storms, residents living in certain neighborhoods have been stranded due to flooding of surrounding roads.

   (Insert Figure 3 here)

   Caption. Figure 3. Emergency personnel on Court Street during the March 16, 2010 storm.

These images and narratives help capture the town's 'cultural memory' of these events. The experiences and images shared by the Assistant Fire Chief during the tour are types of boundary objects that will enable diverse stakeholders and the modeling team to consider how climate change may directly impact residents' daily lives.

b) ***Marsh Walk for Flood Elevations*** In November 2014, the CAPE team led a walk with the CWG at a community park along the tidal Squamscott River to mark flood elevations with different colored flags representing three different sea level rise and coastal flooding scenarios.

(Insert Figure 4 here)

Caption. Figure 4. The CAPE team and CWG members mark current and future flood heights elevations associated with different climate change scenarios at Swasey Parkway.

This activity served as a very meaningful boundary experience. Several CWG members commented on the importance of being together outdoors, sharing knowledge about the importance of the marsh for ecosystem health, and using the flags to visualize the effects of different scenarios on this critical community resource. This activity not only helped the team to connect with the CWG, but also created an interactive process that reinforced the community's values. During the initial community conversations, residents emphasized the importance of the marsh ecosystem as a nursery for fish and other wildlife (including the alewife, the town's symbol) and identified Swasey Parkway as an important place to exercise, spend time outdoors, and enjoy nature. Evaluation of experiential activities was conducted using visual analysis methods (Knoblauch et al. 2008) in which photographs were interpreted by participants and members of the research team.

Modeling and Scenario Analysis

As described previously, several hydrologic, hydraulic, water quality and ecosystem models are being developed by the CAPE team with input from CWG members and town staff to describe present conditions and how they might change under various climate and land use change scenarios (Figure 5). The models will also be used to explore adaptation strategies that the town can employ to respond to changes in climate and land use in the Exeter-Squamscott River watershed over time.

During the first 18 months of the project, the CWG was primarily involved with evaluating outputs from the models that predict the riverine and coastal flooding, urban drainage, water quality, and ecosystem consequences of climate change without any additional control or adaptation measures. Figure 5 displays the modeling sequence employed to determine climate change impacts to Exeter and the linkages with a decision-support tool to guide adaptation decisions. Since few municipal-scale climate-change adaptation projects have integrated models of flooding hazards of riverine, stormwater and coastal origin combined with water quality, land use, and ecological sub-models, our analysis of stakeholder participation throughout the modeling process is critical for guiding subsequent integrated modeling efforts.

Insert Figure 5 here.

Caption: Simulation and decision-support modeling flow chart. CMIP = Coupled Model Intercomparison Project; HSPF = Hydrological Simulation Program – Fortran; HEC-HMS = Hydrologic Engineering Center – Hydrologic Modeling System; SWMM = USEPA Stormwater Management Model; HEC-RAS = Hydrologic Engineering Center – River Analysis System

The involvement of the CWG and other local experts (such as the town's engineer, planner, and public works staff) in the model review process enabled discrepancies in the model results to be identified and corrected. For instance, these consultations prompted the team to collect water surface elevation data in the tidal Squamscott River as well as use a different hourly rainfall distribution for the 24-hour design storms used to simulate flooding from extreme precipitation events under different climate change scenarios. While this complex integrated modeling approach helps to provide credible scientific inputs to the adaptation planning process, delays in the modeling process have also made the engagement process more challenging.

Discussion

Several important lessons from this ongoing study could benefit future climate change adaptation studies at the community scale. For example, various actions could have been taken earlier to better manage stakeholder engagement during the intensive modeling process. Since our initial framing of the CWG's role emphasized the simulation modeling component, many stakeholders came to view the completion of modeling as a necessary condition for any meaningful dialogue about the project. In addition, many CWG members perceived their primary role to be verifying the models and interpreting the results, thus limiting their participation in other aspects of the project in which their contributions would have been beneficial. Because of this perception, when model results were not still complete by the fall of 2014 due to the complexity of model integration and calibration, the CWG requested that meetings be suspended until results were complete.

An important lesson from this experience was that we unintentionally focused on a particular set of boundary objects (the models) to such an extent that they became barriers to designing boundary experiences instead of enabling them. Notably, neither the tour with the Assistant Fire Chief nor the flood elevation walk were predicated on complete model results, and these types of boundary experiences could have been intentionally designed into the engagement process from the beginning.

A related issue is that although the town's interest in scientific models was a catalyst for bringing stakeholders together, it was sometimes challenging to engage the CWG and other stakeholders in sharing their local knowledge and cultural memories. In accordance with adaptive governance principles (Dietz et al. 2003; Nelson et al. 2008; Nilsson and Swartling 2009; Simonsen 2010; Brunner 2010), the CAPE team believed that local knowledge and shared experiences would be essential to the development and implementation of the adaptation plan. However, as observed in other studies (Dietz 2013; Dietz et al. 2003), stakeholders may have been more familiar with a top-down, expert-driven process in which scientific outputs are viewed as a panacea for resolving complexities and reducing uncertainties, rather than as inputs for analytic deliberation.

Other scholars provide valuable lessons pertaining to the challenges inherent in aligning collaborative planning with adaptive governance in local contexts (Porthin et al. 2013; Proctor and Drechsler 2006, Simonsen, 2010; Lynch and Brunner 2010, Borisova 2012). For example, Bronen and Chapin (2013) examined governance and institutional strategies for climate-induced community relocations in Alaska. They learned that community residents and government agencies concurred that relocation was the only adaptation strategy that can protect lives under extreme environmental threats. The authors identified policy changes and components of a toolkit that could facilitate community-based adaptation when environmental events threaten people's lives. Policy changes included the creation of an adaptive governance framework to offer communities a continuum of responses ranging from protection in their current location to relocation to new sites. In alignment with adaptive governance, key components of the toolkit included local leadership and integration of social and ecological well-being into adaptation planning.

Similar findings have been reported internationally (Kallis et al. 2009). For example, in a study of adaptive governance in Pakistan, Mian (2014) noted that overall flood governance may not improve unless there are better cross-linkages between key actors and networks across the disaster prevention - management continuum. The authors noted the importance of strong leadership from a local champion for promoting adaptive governance in communities. We learned a similar lesson in the CAPE study, as the Town Planner and the Assistant Fire Chief played critical roles in facilitating linkages between various stakeholder groups and the research team.

Young and Lipton (2006) studied social relationships and civic participation in an Andean community facing climate change impacts to their agricultural livelihoods. They found that participation in local institutions was invaluable for both individual households and the community's social capital (Young and Lipton 2006; Mayer 2002). Furthermore, they found many informal institutions operating within the community through personal ties and mutual assistance. High levels of civic participation and informal ties were also found in the CAPE project, as evidenced by the high number of community organizations in which the stakeholders participated (including town government, conservation committees, religious groups, youth leadership organizations, higher education, and emergency response). Research suggests that this capacity for collective action through community institutions may play an important role in plan implementation and compliance (Robbins 1998).

In a study focused on developing a water management plan in Florida, Borisova et al. (2012) designed a collaborative process to build a better understanding of stakeholder perceptions of water quality problems and water policy. The authors found that stakeholder conflicts were associated with perceived flaws in the structural and procedural characteristics of the stakeholder engagement process (e.g., suboptimal watershed stakeholder representation on committees, limitations in information sharing between stakeholder groups). Notably, the CAPE project achieved good representation from town staff and certain community groups initially, but faced similar challenges and trade-offs in sustaining participation from these groups while simultaneously trying to extend outreach efforts to other groups (such as local businesses) who were under-represented.

Mollinga (2008; 2010) and White et al. (2008) emphasize that transdisciplinary research projects require the integration of modeling, mapping, and communication products to support adaptive governance, and that such integration requires a concerted, long-term effort. Although the CAPE team made concerted efforts to develop these different types of boundary objects concurrently, it was a challenge to do so within a two-year time frame given the complexity of the modeling process.

Lastly, we turn to the question of transferring lessons learned from the CAPE project to other contexts. Although Exeter is a relatively small community, there is a diversity of stakeholder interests including homeowners and businesses with waterfront properties, other large land owners, conservation groups, citizen cooperatives, and manufactured housing communities. Thus, many of the lessons learned from the CAPE project may apply to other communities with similar interest groups. However, one group that is notably absent in CAPE is the agricultural sector, which can be a powerful voice in other communities (Young and Lipton, 2006) and would have added complexity to the outreach process. Similarly, we did not face challenges associated with non-English speaking populations or other literacy barriers, which would require additional resources.

Another benefit of working in a geographically small community that may limit the transferability of our experiences to other contexts is that the travel time required to meet with different stakeholder groups is minimized. The CAPE team was able to visit different locations easily, and the community has a distinct town center that provides accessible meeting places for engagement activities. In larger or more dispersed communities, this may be significantly more challenging.

To facilitate learning across contexts, the CAPE team participated in a Science Collaborative Transfer Project workshop funded by NOAA's National Estuarine Reserve Research System (NERRS). One of the key lessons shared was the importance of making climate change locally relevant (e.g., using boundary objects and experiences to draw connections to local decisions and values). However, we also learned that it is important to be sensitive to possible negative connotations that can arise from media portrayals of "flood-impacted communities" and potential economic losses in real estate value.

One strategy that can be helpful regardless of community size is to seek out individual "point-persons" who are trusted members of the community and/or represent particular stakeholder interests. We recommend taking adequate time at the beginning of a project to identify important social networks and point-persons, so that engagement resources can be targeted towards cultivating these relationships. For example, in the CAPE project, the Town Planner, the CWG, clergypersons, Cooperative Extension professionals, and representatives of manufactured housing communities played critical roles in extending outreach efforts.

Conclusions:

The CAPE project generated many learning opportunities for both stakeholders and the project team due to the complex subject matter and the necessity of coordinating intensive technical modeling with community engagement. The engagement process aligned with several important principles of adaptive governance, including clarifying common goals with stakeholders, building on local communication and governance structures, and balancing the informational needs of different stakeholders through boundary objects and experiences that integrate complementary knowledge systems. Other adaptive governance principles, such as implementing, evaluating, and refining policy in local contexts and transferring lessons learned across contexts, were not as evident during the first phase of project and will require more time to assess as the project evolves.

In summary, lessons learned from the CAPE project underscore the importance of having contingency plans to keep participants engaged if models are delayed, creating multiple forums for interaction between researchers and community members, and making climate change locally relevant through a dynamic interplay between boundary objects and boundary experiences (e.g., drawing connections to local experiences, cultural memory, values, and upcoming decisions).

By developing a more comprehensive portfolio of boundary objects, as well as emphasizing the importance of designing boundary experiences for analytic deliberation, our team can better support Exeter in its climate adaptation planning efforts while simultaneously enabling other communities to learn from this process.

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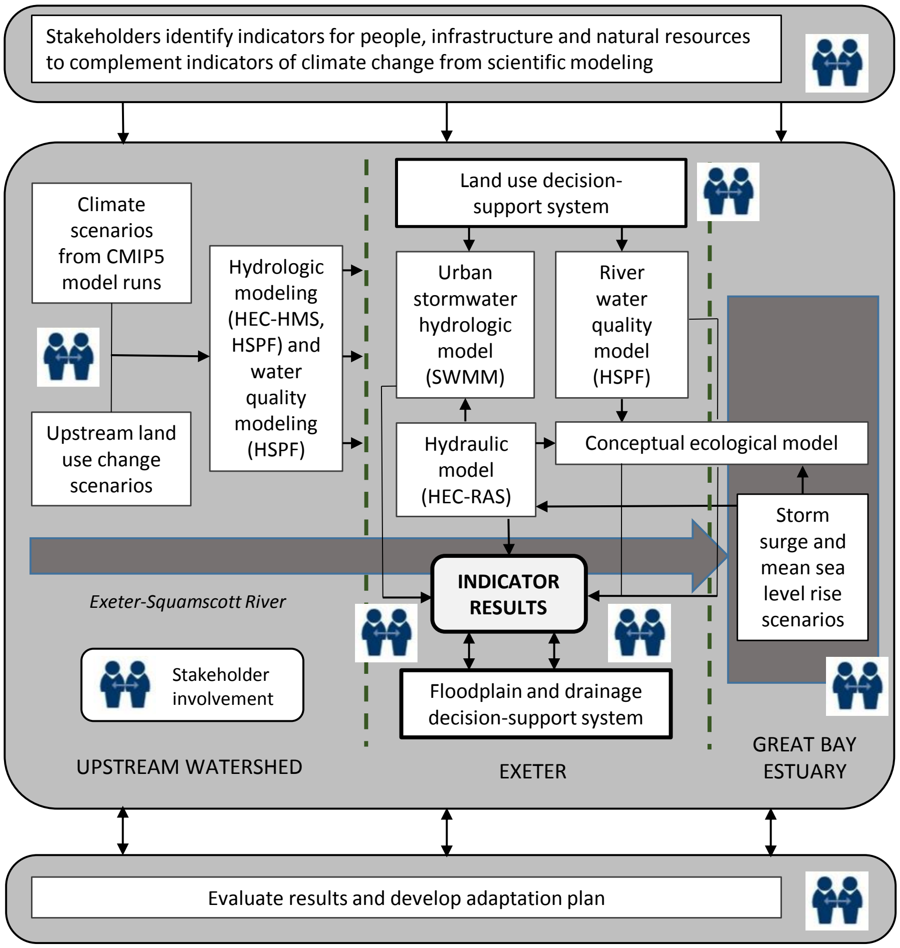
Table 1. Summary of lessons learned regarding engagement strategies, their function as boundary objects/experiences, and alignment with adaptive governance principles

Engagement Strategy	Role as Boundary Object /Boundary Experience	Alignment with Adaptive Governance Principles
Community Conversations	●Explores the community's values and perceived vulnerabilities associated with climate change. ●Provides a forum for stakeholders to share perspectives, identify local assets, needs, and ideas to effectively plan for a changing climate ●Generates interest in more sustained participation for subsets of stakeholders (e.g., Citizens' Working Group). ●Promotes inter-generational dialogue ●Initiates co-production of boundary objects such as maps, narratives, and inputs for models	●Clarifies common goals with stakeholders ●Promotes collaborative learning and networking ●Develops a foundation for analytic deliberation (structured dialogue involving scientists, end-users, and interested citizens, informed by analysis of key information about socio-ecological systems (Dietz 2003, 2013)
Workshops with town staff	●Enables the team to check in annually with town decision-makers, and to identify individuals who wish to be more involved in certain stages of the modeling process (e.g., checking discrepancies) ●Provides a mechanism for piloting and refining boundary objects (e.g., testing educational materials, explaining preliminary model results). ●Promotes opportunities for the CWG and the research team to interact with town leadership	●Builds on local governance and communication structures ●Enables climate change adaptation planning to be linked to specific local decisions ●Supports multiple connections between researchers and decision-makers ●Helps to ensure that scientific outputs will be viewed as credible, legitimate, and salient (Cash et al., 2002)

Experiential Activities	●Connects technical and non-technical stakeholders ●Provides a 'bridge' to link various boundary objects (e.g., by connecting scientific information with community values and cultural memories; creating a diverse portfolio of activities that are not entirely dependent on model results ●Aligns with Carlile's (2002) pragmatic view of boundary objects as a means of representing, learning about, and transforming knowledge to support a public policy process	●Integrates complementary knowledge systems (e.g., local knowledge and scientific/external input) to inform planning and policy processes ●Promotes collaborative learning and networking ●Supports iterative interactions between scientists and decision-makers
Citizen's Working Group (CWG)	●Provides a forum for 'vetting' boundary objects and experiences and tailoring them for different groups ●The CAPE CWG expressed interest in learning about what other communities in the state are doing in terms of hazard mitigation and climate adaptation planning. For example, other communities have enrolled in the National Flood Insurance Program's Community Rating System, which reduces insurance premiums in jurisdictions in which flood hazard mitigation activities are implemented (FEMA, 2014),	●Clarifies common goals ●Builds on local communication and governance structures ●Facilitates connections between researchers and decision-makers across institutional levels (e.g., Board of Selectmen, Town Staff, clergy, representatives of manufactured housing communities). ●Integrates complementary knowledge systems ●Supports transfer/exchange of knowledge with other communities
Modeling and Scenario Analysis	●Provide a scientific basis for adaptation planning; highly valued by stakeholders ●Models may be communicated and shared with diverse groups by 'nesting' them within a portfolio of boundary	●Integrates complementary knowledge systems ●Provides a foundation to support policy implementation

experiences (e.g., community conversations, experiential activities, workshops) and linking them to other boundary objects, such as a decision support tool ●Nesting may support adaptive governance by allowing stakeholders to connect *future* scenarios to past and present experiences, cultural memories, and town values.	and evaluation

Figure 5. Stakeholder involvement with simulation modeling and decision-support tools



3-16-2010: Court St.

2007 Patriots Day Storm: Swasey Parkway


3-16-2010: 61 and 63 Linden St.


3-16-2010: Unitil Sub-Station on the Exeter River

3-16-2010 Court St. Sewer Pump Station

Caption: Flood elevation mapping

Citizens use flags to visualize the effects of different climate change scenarios and flood elevations on critical community resources.

Reference: Photo Elicitation and Visual Analysis in Evaluation: Knoblauch, H., A. Baer, E. Laurier, S. Petschke, and B. Schnettler. 2008. Visual analysis. New developments in the interpretative analysis of video and photography. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, 9(3), Art. 14, Available at http://nbn-resolving.de/urn:nbn:de:0114-fqs0803148 Accessed April 11, 2015.

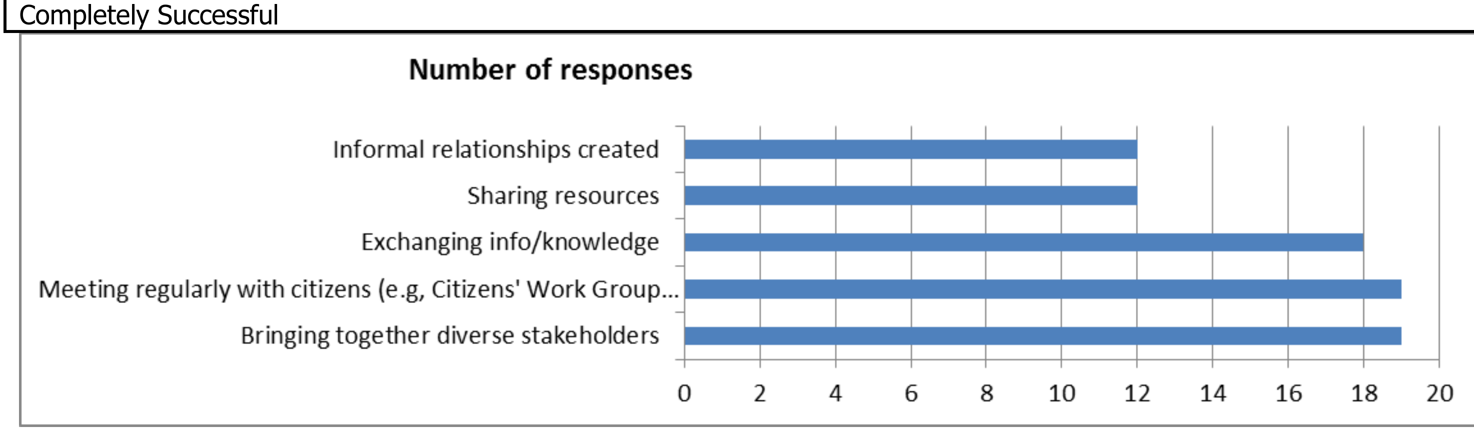
APPENDIX C2 – SUMMARY OF EVALUATION RESULTS FROM PAST YEARS

EVALUATION RESULTS FROM PRIOR YEARS

Evaluation Results from Meetings with Town Staff (2013)

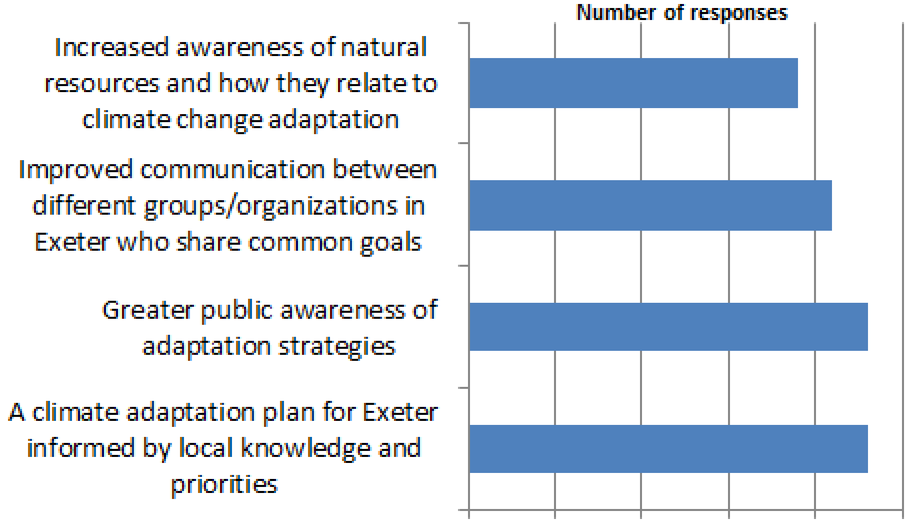
Question: How successful has CAPE been at reaching its goals this year?

Answers	***No re***
Not Successful	
Somewhat Successful	
Successful	
Very Successful	
Completely Successful	



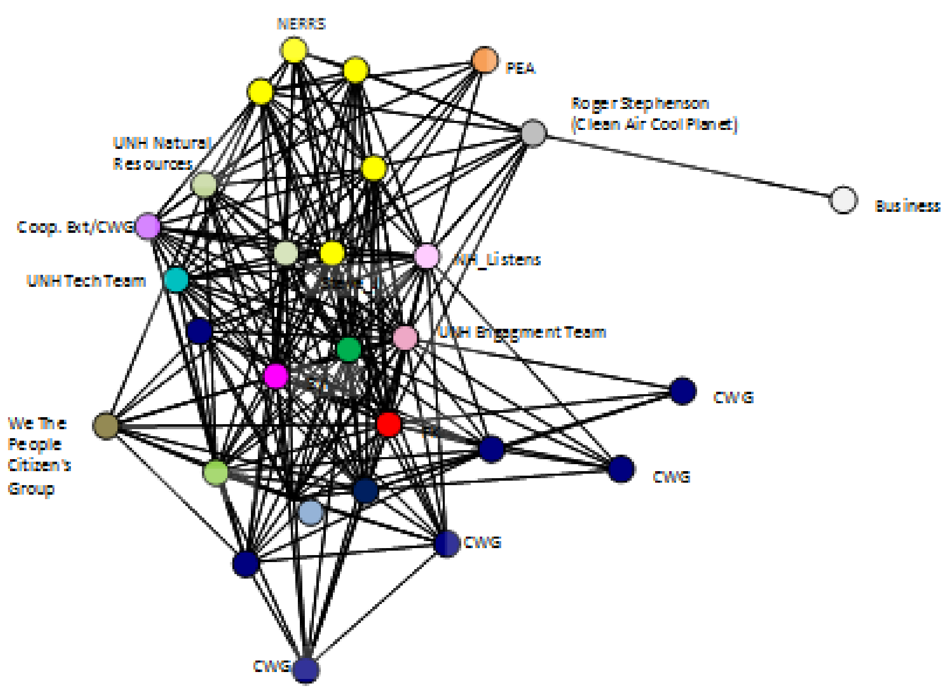
What we learned from 12/12/13 Town Staff Meeting:

Which outcomes of CAPE are most important to Exeter?



Source: CAPE PARNER survey (n=23)

Social Network Map (Year 1)



Social Network Metrics:

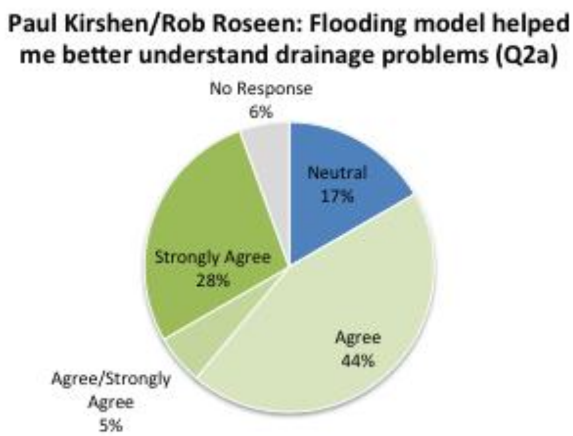
- Trust: 79% (out of 100%)
- Degree Centralization: 53.8% (The lower the centralization score, the more similar the members are in terms of their number of connections to others (e.g. more decentralized). The score of 53.8 indicates a moderate level of decentralization among those stakeholders who responded to the survey.

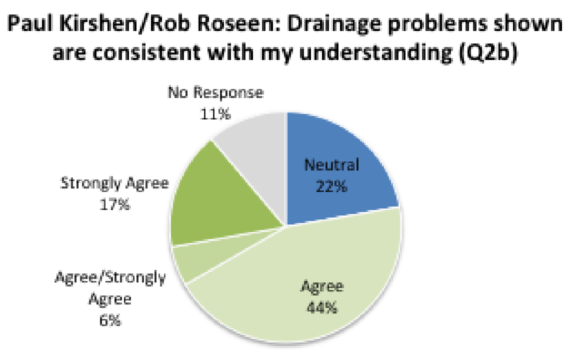
Overall Summary-Meeting with Town Staff 2013

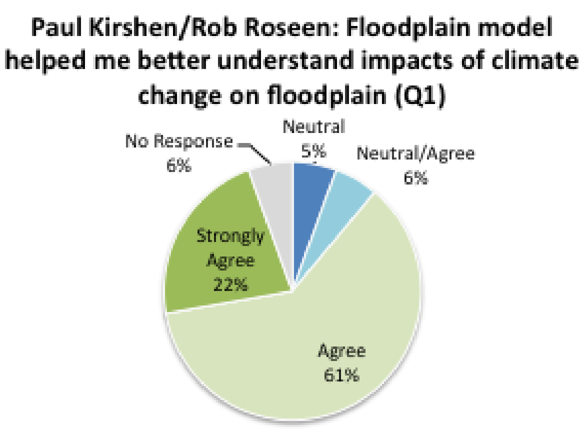
(Source: 'CAPE DEC 12 2013 Evaluation raw frequencies2' & from database)

N = 18

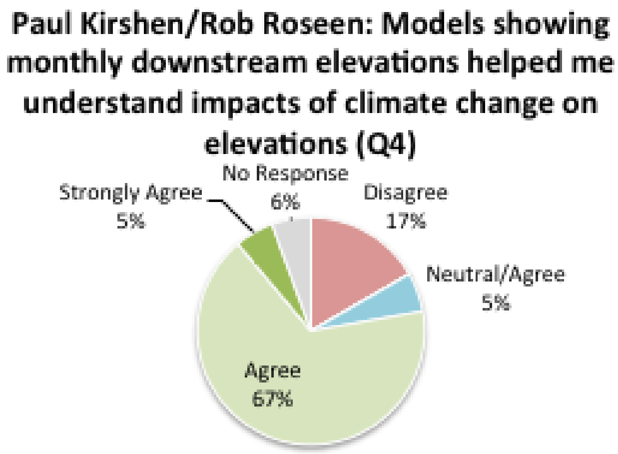
Compiled by: Lisa Graichen, TIDES student

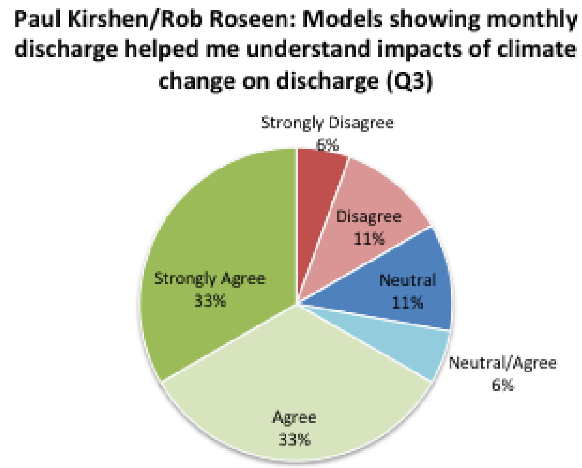






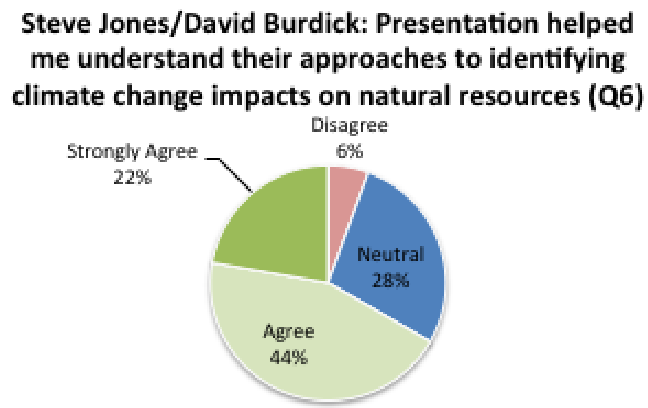
Summary: Overall, many participants agreed that the models shown in this presentation helped them better understand the impacts of climate change. Almost all participants agreed or strongly agreed that the floodplain model and flooding model helped them better understand the issues. Two-thirds of participants agreed or strongly agreed that the drainage problems shown in the presentation were consistent with their understandings of the problem in Exeter (almost a quarter of participants were neutral). Half of participants were neutral about whether the model calibration was consistent with their experiences in Exeter. Another third of participants agreed or strongly agreed that it was consistent. A third of participants strongly agreed and another third agreed that the monthly discharge models helped them understand the impacts of climate change on discharge. A few participants disagreed or strongly disagreed. Two-thirds of participants agreed that the models showing downstream elevations helped them understand the impacts of climate change. One strongly agreed, one responded neutral/agree, and two disagreed.





NATURAL RESOURCES PRESENTATIONS

Summary: Two-thirds of participants agreed or strongly agreed that this presentation helped them understand the approaches to identifying the impacts of climate change on natural resources and ecosystems. One disagreed, and the remaining participants were neutral.



Suggestions for Improvement

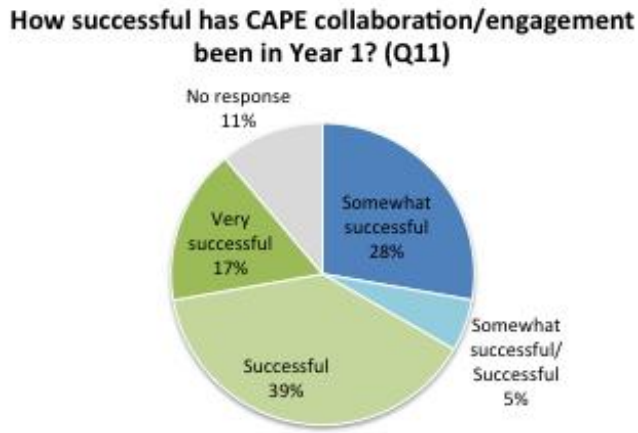
- Presentations need to be sharpened for a more general audience
- Don't zigzag all over with the pointer
- For conveying results, pictures, maps, and even conceptual models are more helpful than graphs
- More detail
- Hold the Q&A until the end. Perhaps have extended Q&A in separate rooms for people who want in depth conversations.
- Need more context at the beginning
- Smaller group meetings all around town presenting the basics! Answer questions and show 1) How it impacts me, 2) What changes must I make.
- Provide a printout of the slides

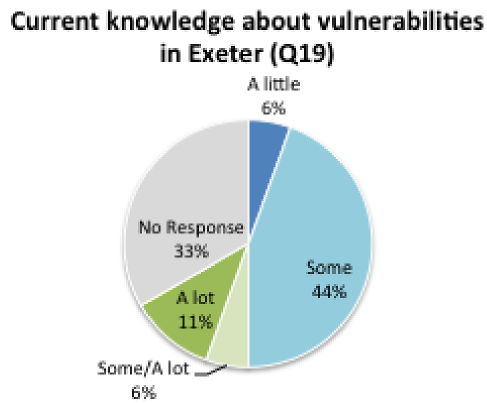
ENGAGEMENT PROCESS

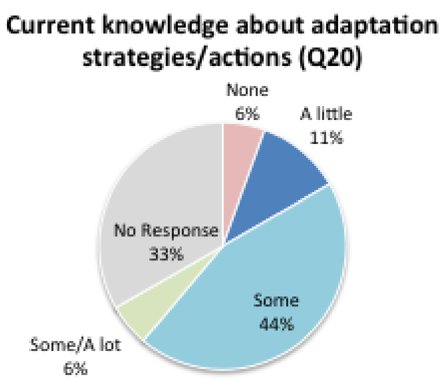
Summary: Half of participants agreed or strongly agreed that this presentation helped them understand the connections between CAPE's collaboration and evaluation process and the goals of the project. A third of participants were neutral.

Over three-quarters of participants agreed or strongly agreed that this presentation ("What Other Towns are Doing" with respect to climate change adaptation and preparing for flooding) increased their support for the CAPE project. Two individuals were neutral and two did not respond.

Over half of the respondents rated CAPE's collaboration/engagement in Year 1 as successful or very successful. Another third rated it as somewhat successful or somewhat successful/successful (two did not respond). Half of participants said they had some or some/a lot of knowledge about the vulnerabilities in Exeter. Two have a lot of knowledge and one has a little (a third did not respond). Half of participants have some or some/a lot of knowledge about adaptation strategies that could be used. Two have a little and one has none (a third did not respond).





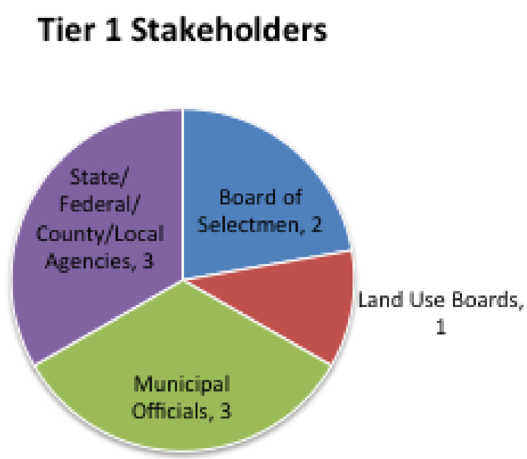


OVERALL MEETING

Summary: Half of participants agreed that overall, the presentation of material was effective. Two were neutral, one disagreed, and a third did not respond. Half agreed that the time frame was appropriate. One participant strongly agreed and one disagreed (over a third did not respond). A third agreed that the content was engaging, two strongly agreed, and three were neutral (over a third did not respond). Almost half agreed or strongly agreed that the language of the presentation was easy to understand.

Tier 1 Stakeholders

(Tiers were identified via a Communications Planning process that took place in 2013)



EVALUATION OF MODEL PRESENTATIONS

Model of the 100-year floodplain:

- One member of the **Board of Selectmen** agreed that this model helped him to understand the impacts of climate change on the floodplain in Exeter at high tide with storm surge (1 was missing).
- One representative of the **land use boards** agreed that the model helped her better understand the impacts of climate change on the floodplain in Exeter.
- The three **municipal officials** agreed that this model helped them understand the impacts of climate change on the floodplain in Exeter. One commented, “It appeared the holding ponds were underwater in a climate change scenario. This should be highlighted.” Another commented, “I didn’t understand the high tide and storm surge parts.”
- Among the representatives from **state/federal/county/local agencies**, one strongly agreed, one agreed, and one responded neutral/agree that this model helped them understand the impacts of climate change on the floodplain in Exeter. The neutral/agree responder commented, “I think this is the red/blue overlay slide. Could have used more info or visualizations of change in depth and how that impacts people, NR, and infrastructure.”

Model of flooding at manholes and surcharging in the system:

- One **Selectman** agreed that this model helped him understand the drainage problems (1 was missing).
- The representative from the **land use boards** group was neutral about whether this model helped her understand the drainage problems in Exeter. She commented that seasonal occurrence was not emphasized.
- Among the **municipal officials**, one member strongly agreed, one agreed, and one was neutral about whether these models helped them understand the drainage problems in Exeter. The official who was neutral commented, "Slide was too fast for comprehension."
- Two participants from the **state/federal/county/local agencies** strongly agreed and one agreed that these models helped them understand the drainage problems in Exeter. The one who agreed commented, "would have benefitted from context."

Drainage problems:

- One of the **Selectmen** agreed that the drainage problems were consistent with his understanding of the problems in Exeter (1 was missing).
- The participant from the **land use boards** agreed that the drainage problems shown were consistent with her understanding of these problems in Exeter.
- Among the **municipal officials** present, one agreed and two were neutral about whether the drainage problems shown were consistent with their understanding of the problems in Exeter.
- Of the representatives from the **state/federal/county/local agencies**, one agreed and one strongly agreed that the drainage problems shown are consistent with their understanding of these problems in Exeter (1 was missing)

Model calibration/validation:

- One **Selectman** agreed and the other strongly agreed that the model calibration/validation was consistent with their experience living in Exeter.
- The representative from the **land use boards** was neutral about whether or not the model calibration/validation was consistent with her experience.
- The three **municipal officials** were neutral about whether the model calibration/validation was consistent with their experience.
- Of the representatives from the **state/federal/county/local agencies**, one strongly agreed and one was neutral that the model calibration/validation was consistent with their experience.

Model of present average monthly discharge at Great Dam and elsewhere:

- One **Selectman** disagreed that this model helped him understand the potential impacts of climate change on monthly discharge. He said he did not understand the slides. The other member strongly agreed that the models helped, but commented that "the effect of the Great Bridge on flood height was not really made clear."
- The representative from the **land use boards** agreed that these models helped her understand the potential impacts of climate change on monthly discharges. She commented that she was surprised there was not more change.
- Two of the **municipal officials** strongly agreed that the models helped them understand the potential impacts of climate change on monthly discharges. One commented, "Told me what was probably going to happen, but didn't totally figure that out yet." The third member disagreed, but commented that the verbal summary helped.
- Of the representatives from the **state/federal/county/local agencies**, one member strongly agreed, one responded neutral/agree, and one strongly disagreed that these models helped them understand the potential impacts of climate change on monthly discharges. The one who responded neutral/agree commented that the graphs and explanation were a little confusing. The member who strongly agreed commented "This info is incredibly important to the Town right now and has a lot of implications for the dam removal in Town. We need

a better way to share the info with the public than the charts (the info in the slide was good but the graph was not). The graphs are definitely too complicated. Pictures are good!"

Model of present average monthly elevations downstream of Great Dam:

- One **Selectman** disagreed that this model helped him understand the impacts of climate change on monthly downstream elevations, commenting again that he did not understand the slides. The other member responded that she already knew most of the information shown in the models.
- The representative from the **land use boards** agreed that these models helped her understand the potential impacts of climate change on mean monthly downstream elevations.
- Two of the **municipal officials** agreed that these models helped them understand the potential impacts of climate change on monthly downstream elevations. One commented that he was confused about whether it was average elevation change or change at low or high tide. The third member disagreed, commenting again that the verbal summary was helpful.
- Of the representatives from the **state/federal/county/local agencies**, one strongly agreed, one responded neutral/agree, and one disagreed. The member who responded neutral/agree commented, "I found the graphs and explanation a little confusing. Questions and comments in the room were helpful." The one who disagreed commented, "The narrative information was helpful but the graphs were not."

Summary of Natural Resource Presentations:

- One member of the **Board of Selectmen** was neutral about this presentation, commenting that he wanted more detail. The other member strongly agreed that this presentation helped her understand their approaches to identifying climate change impacts on natural resources and ecosystems. What stood out most to one of these Selectmen included the costs of future property damage, possibility of increased pollutants, the need to prepare (infrastructure, drainage), and preservation of historical features.
- The representative from the **land use boards** was neutral about this presentation, commenting, "Still in development stage, so I'm awaiting this!"
- Two **municipal officials** agreed that this presentation helped them understand these researchers' approaches to identifying climate change impacts on natural resources. The third was neutral, commenting that it was "too quick." The comments about what stood out most to this group included: losing road access, reducing fertilizer use, the impacts of low dissolved oxygen on fish, the capacity of infrastructure to deal with stormwater, worsening floods, and changing seasons.
- Of the representatives from the **state/federal/county/local agencies**, one strongly agreed, one agreed, and one disagreed that this presentation helped them understand the approaches to identifying climate change impacts on natural resources. The member who disagreed commented that there was not enough detail. What stood out most to this group included the need for the community to understand the risks, the need to restore wetlands, and the impacts of bridges and the dam.

<u>COLLABORATION, ENGAGEMENT, AND EVALUATION PRESENTATIONS</u>

Summary:

- The member of the **land use boards** agreed that this presentation helped her understand the connections between CAPE's collaboration process and the goals. She commented, "I wish we had more time for this."
- Two **municipal officials** agreed this presentation helped them understand how CAPE's collaboration process relates to the goals. The third member was neutral.

"WHAT OTHER TOWNS ARE DOING" PRESENTATION

Summary:

- One **Selectman** agreed that this presentation increased his level of support for CAPE (1 was missing).
- The participant from the **land use boards** agreed that this presentation increased her support for CAPE, commenting, "I wish we had more time for this."
- Two **municipal officials** agreed and one strongly agreed that this presentation increased their support for CAPE. One commented, "Good to hear what other communities are doing."
- Two representatives from **state/federal/county/local agencies** strongly agreed and one agreed that this presentation increased their support for CAPE.

OTHER COMMENTS FROM STAKEHOLDERS

- One **Selectman** responded that CAPE collaboration/engagement has been somewhat successful and the other rated it as very successful. For suggestions to help reach the goals, one commented that the outcomes need to be tied together (1 missing). To improve collaboration/engagement, one suggested that it should be stressed that working with others takes a lot of time.
- The representative from the **land use boards** rated CAPE collaboration/engagement as somewhat successful. For suggestions to help reach CAPE's goals, this member commented, "These presentations focused on pulling all the areas of the study together. Will help the program move forward."
- All three **municipal officials** rated the CAPE collaboration process as successful. One member suggested offering childcare to help reach CAPE's goals.
- Two representatives from **state/federal/county/local agencies** rated CAPE's collaboration/engagement process as successful, and the third said it's been very successful. One member commented that CAPE has been somewhat successful at building greater public awareness and very successful at promoting greater communication between groups in Exeter, improving communication between UNH scientists and citizens, and increasing awareness of natural resources and how they relate to climate change adaptation. To improve collaboration/engagement, one member suggested setting up a table to talk to the community at convenience stores to expand the demographic, and also to offer onsite childcare and dinner to help get the young family demographic involved.

<u>OVERALL EVALUATION OF TODAY'S MEETING</u>

Summary:

- One individual would like "greater detail about what climate change really means to storm impacts in Exeter." The other commented that "this may help in the dam discussion – recognizing that results are preliminary." Both members stated that they have a lot of knowledge about the vulnerabilities in Exeter and some knowledge about strategies or actions that could be taken.
- The participant from the **land use boards** agreed that the presentation was effective and the time frame was appropriate. She also agreed that the pictures, graphs, and data were engaging, and that the words/language were easy to understand. She would like more information about the effects on natural resources. This participant responded that she has some current knowledge about the vulnerabilities in Exeter and about the strategies or actions that could be used to deal with these vulnerabilities.
- One **municipal official** agreed that the presentation of material was effective and strongly agreed that the time frame was appropriate. This member strongly agreed that the pictures, graphs, and data were engaging and agreed that the words/language were easy to understand (2 missing). This official responded that she has some knowledge about current vulnerabilities and no knowledge about strategies that could be used.
- Two representatives of **state/federal/county/local agencies** agreed that the presentation was effective and the time frame was appropriate. One agreed and another was neutral about whether the pictures, graphs, and data were engaging. One strongly agreed and another agreed that the words/language were easy to understand (1

missing). One suggested that the presentation could be improved by adding context at the beginning, such as "here are the questions we are trying to answer, and here is how those questions are related to decisions towns will need to make." Two members responded that they have some current knowledge about the vulnerabilities in Exeter and about the strategies that could be used.

Tier 2 Stakeholders

<u>EVALUATION OF MODEL PRESENTATIONS</u>

Summary:

Model of the 100-year floodplain:

- Of the participants from the **general public**, two strongly agreed, one agreed, and one was neutral that this model helped them understand the impacts of climate change on the floodplain in Exeter.
- Of the participants with **unknown occupations**, three agreed and one strongly agreed that this model helped them understand the impacts of climate change on the floodplain in Exeter.
- Both members of the **environmental group** (one is also counted in the land use boards group) agreed that this model helped them understand the impacts of climate change on the floodplain in Exeter.

Model of flooding at manholes and surcharging in the system:

- Of the participants from the **general public**, one strongly agreed, one responded agree/strongly agree, one agreed, and one was neutral about whether this model helped them understand the drainage problems in Exeter.
- Of the participants with **unknown occupations**, three agreed and one strongly agreed that this model helped them understand the drainage problems in Exeter.
- One member of the **environmental group** agreed and the other was neutral about whether this model helped them understand the drainage problems in Exeter. The one that agreed wrote, "Don't use words like surcharging – use a term the public can understand." The other wrote, "Seasonal occurrence not emphasized."

Drainage problems:

- Of the participants from the **general public**, one strongly agreed, one responded agree/strongly agree, one agreed, and one was neutral about whether the drainage problems shown were consistent with their understanding of these problems in Exeter.
- Of the participants with **unknown occupations**, two agreed and one strongly agreed that the drainage problems shown were consistent with their understanding of these problems in Exeter. The fourth member was neutral.
- The two members of the **environmental group** agreed that the drainage problems shown were consistent with their understanding of these problems in Exeter.

Model calibration/validation:

- Of the participants from the **general public**, two agreed and two were neutral about whether the model calibration/validation was consistent with their experience in Exeter.
- Of the participants with **unknown occupations**, two strongly agreed and two were neutral about whether the model calibration/validation was consistent with their experience in Exeter.
- One member of the **environmental group** was neutral about whether the model calibration/validation was consistent with their experience in Exeter (1 missing).

Model of present average monthly discharge at Great Dam and elsewhere:

- Of the participants from the **general public**, one strongly agreed, two agreed, and one was neutral about whether this model helped them understand the potential impacts of climate change on monthly discharges.
- Of the participants with **unknown occupations**, one strongly agreed and two agreed that these models helped them understand the potential impacts of climate change on monthly discharges. The fourth member was neutral.
- Both members of the **environmental group** agreed that this model helped them understand the potential impacts of climate change on monthly discharges.

Model of present average monthly elevations downstream of Great Dam:

- All four participants from the **general public** agreed that this model helped them understand the potential impacts of climate change on downstream elevations.

- All four participants with **unknown occupations** agreed that these models helped them understand the potential impacts of climate change on monthly downstream elevations.
- Both members of the **environmental group** agreed that the models helped them understand the potential impacts of climate change on downstream elevations.

<u>Natural Resources Presentations</u>

Summary:

- Three members of the **general public** agreed and one strongly agreed that this presentation helped them understand the approaches to identifying climate change impacts on natural resources. What stood out most to this group included transportation systems, infrastructure, risk of housing flooding, threats to the Exeter River and wildlife, road runoff, the dam, and a lack of awareness about these issues among the community.
- Of the participants with **unknown occupations**, one strongly agreed, one agreed, and two were neutral about whether this presentation helped them understand the approaches to identifying climate change impacts on natural resources. One commented, "They didn't really say how they were going to do it, just what issues they will be looking at." What stood out most to this group included the extent of flooding, the Great Dam, the wastewater treatment plant, drinking water, public health impacts, downtown businesses, and the problem of informing people in Exeter.
- One member from the **environmental community** agreed and one was neutral about whether this presentation helped them understand the approaches to identifying climate change impacts on natural resources. One member suggested emphasizing that the probability of a 100-year storm happening tomorrow is 1% and that the Great Bay is a global ecological resource.

<u>COLLABORATION, ENGAGEMENT, AND EVALUATION</u>

Summary:

- Three participants from the **general public** agreed that this presentation helped them understand how CAPE's collaboration process relates to the goals (1 missing).
- Both members of the **environmental group** agreed that this presentation helped them understand how CAPE's collaboration process relates to the goals.
- Two members of the **general public** agreed and one strongly agreed that the presentation of "What other Towns are Doing" increased their support for CAPE
- Both members of the **environmental group** agreed that this presentation increased their support for CAPE.

- Suggestions to help reach CAPE's goals included having meetings in larger rooms with chairs in a circle, and also including churches, schools, ESLAC, seniors, high school teachers, and PEA faculty.
- Suggestions to help reach CAPE's goals included meeting in smaller groups and "going to them rather than expecting them to come to you"
- One commented, "These presentations focused on pulling all the areas of the study together. Will help the program move forward."

- Both members of the **environmental community** agreed that the presentation of material was effective, the time frame was appropriate, and the content was engaging. One agreed that the language was easy to understand and the other member was neutral. One commented that she is awaiting more information about the effects of natural resources. One member of this group has some knowledge and the other has some/a lot of knowledge about the vulnerabilities in Exeter and about the strategies that could be used.

CAPE APRIL 10, 2013 COMMUNITY CONVERSATION
EVALUATION SURVEY RESULTS – THEMES (n=31)

Summary:

● All respondents (100%) reported that providing clean water for drinking, recreation, and ecosystems was "extremely important"

● Over 87% of respondents reported that providing protection against river and street flooding was "extremely important" (35%) or "very important" (52%).

● When asked, "Do you have someone you trust that you could call to help you in an emergency or extreme weather event?" 89% said yes; 11% said no.

● When asked, "Have you worried about getting your medication or getting to a doctor's appointment (for yourself or a family member) during an extreme weather event?",
24% said yes; 76% said no.

●Over 70% believed that water quality in Exeter's streams and rivers is fair to poor. Ten percent believed it was good to excellent.

● Over 2/3 of participants described their current level of knowledge about the impacts of a changing climate in Exeter as "a lot" (35%) or "some" (32%). Thirty-nine described their current level of knowledge as "a little" or "none".

● Approximately 1/3 of participants reported that they had little to no knowledge about *strategies/actions* that can be used help protect people, infrastructure, and natural resources from the impacts of flooding and extreme weather events. Fifty-five percent said they had some knowledge, and 10% said they had a lot of knowledge.

Readiness for Action:

● Half of the participants said that they were already participating in Town adaptation planning-related discussions/activities (such as through membership on the River Study Committee, the Planning Board, or through their church or school).

Another 20% said that they would consider participating within the next 30 days, and 25% said they would consider participating within the next 6 months.

● Over 2/3 of participants said that they had already made some personal behavioral changes (such as changing their lawn care practices, water and energy usage, recycling, and composting). Another 18% said they would consider making changes within the next 30 days, and 14% said they would consider making changes within the next 6 months. In sum, this was a highly motivated group.

Q16. What aspects of this Community Conversation were most valuable to you?

Q16_Most_valuable	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Community involvement	1	6.25	1	6.25
Community participation	1	6.25	2	12.50
Group work	1	6.25	3	18.75
Just the fact that there was a high level of interest and involvement was encouraging.	1	6.25	4	25.00
Learning	1	6.25	5	31.25
Multiple perspectives	1	6.25	6	37.50
Seeing and meeting different people of different ages and connections to Exeter coming together.	1	6.25	7	43.75
Small group environment.	1	6.25	8	50.00
Some of the questions - clarified my own thinking.	1	6.25	9	56.25
The dialogue with a diverse group.	1	6.25	10	62.50
The discussion of potential implications to Exeter.	1	6.25	11	68.75
The guided discussion and facilitation	1	6.25	12	75.00
The large map and the printed materials	1	6.25	13	81.25
The potential flood zones that we should focus on	1	6.25	14	87.50
The small group conversation set up was very comfortable and inviting.	1	6.25	15	93.75
The table conversations because it was amazing to hear other perspectives on the issue.	1	6.25	16	100.00

COMMENTS:

Q. What was one new thing you learned today?

Common concerns about climate change.
How big the water problems are
My neighborhood floods!

How prone and vulnerable Exeter is to flooding
I learned more about where Exeter's vulnerable
Issues with the dam and sewer system
Much more familiar with vulnerable locations in
Specific flood areas
That funds allocated for sewer plant update are in adequate
Vulnerability of Exeter to regional development

Q12_Other_Important Issues That Were Not Discussed:	Frequency	Percent	Cumulative Frequency	Cumulative Percent
CO2 mitigation	1	20.00	1	20.00
Federal funding-the link of national to public government	1	20.00	2	40.00
Not much discussion of nearby Seacoast issues	1	20.00	3	60.00
people adapting to changes	1	20.00	5	100.00

Descriptive Statistics Supporting the Survey Summary Statements-

1. **Q: Please rate the importance of providing clean water for drinking, recreation, and ecosystems ?**

   1=Extremely important
   2=Very important
   3=Somewhat important
   4=Not important

● All respondents (100%) reported that providing clean water for drinking, recreation, and ecosystems was "extremely important"

2. **Q: Please rate the importance of providing protection against river and street flooding?**

Pre_Q2a	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Extremely (1)	11	35.48	11	35.48
Very (2)	16	51.61	27	87.10
Somewhat (3)	4	12.90	31	100.00

● Over 87% of participants reported that providing protection against river and street flooding was “extremely important” (35%) or “very important” (52%).

Q18. Do you have someone you trust that you could call to help you in an emergency or extreme weather event?

***Eighty-nine percent said yes; 11% said no.**

Q18	Frequency	Percent	Cumulative Frequency	Cumulative Percent
No (0)	3	10.71	3	10.71
Yes (1)	25	89.29	28	100.00

Frequency Missing = 3

Q19. Have you worried about getting your medication or getting to a doctor's appointment (for yourself or a family member) during an extreme weather event?

***Twenty-four percent said yes; 76% said no.**

Q19	Frequency	Percent	Cumulative Frequency	Cumulative Percent
No (0)	22	75.86	22	75.86
Yes (1)	7	24.14	29	100.00

Frequency Missing = 2

Q20. In my opinion, the water quality in Exeter's streams and rivers is:

1=Excellent 2=Good 3=Fair 4=Poor

Over 70% believed that water quality in Exeter's streams and rivers is fair to poor. Ten percent believed it was good to excellent.

Q20_water_quality	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Excellent (1)	1	3.33	1	3.33
Good (2)	2	6.67	3	10.00
Fair (3)	15	50.00	18	60.00
Poor (4)	6	20.00	24	80.00
Don't Know (88)	6	20.00	30	100.00

Q1: Which of the following best describes your current knowledge about the impacts of a changing climate in Exeter?

Pre_Q1	Frequency	Percent	Cumulative Frequency	Cumulative Percent
None (1)	2	6.45	2	6.45
A little (2)	8	25.81	10	32.26
Some (3)	10	32.26	20	64.52
A lot (4)	11	35.48	31	100.00

● Over 2/3 of participants described their current level of knowledge about the impacts of a changing climate in Exeter as "a lot" (35%) or "some" (32%). Thirty-nine described their current level of knowledge as "a little" or "none".

Q3: Which of the following best describes your current knowledge about *strategies/actions* that can be used help protect people, infrastructure, and natural resources from the impacts of flooding and extreme weather events?

(1) None (2) A little (3) Some (4) A lot

Pre_Q3	Frequency	Percent	Cumulative Frequency	Cumulative Percent
None (1)	4	12.90	4	12.90
A little (2)	7	22.58	11	35.48
Some (3)	17	54.84	28	90.32
A lot (4)	3	9.68	31	100.00

● Approximately 1/3 of participants reported that they had little to no knowledge about *strategies/actions* that can be used help protect people, infrastructure, and natural resources from the impacts of flooding and extreme weather events. 55% said they had some knowledge, and 10% said they had a lot of knowledge.

STAGES OF CHANGE/READINESS FOR ACTION QUESTIONS:

Q. COLLECTIVE ACTION: I rate my readiness to participate in future Town adaptation planning discussions/activities as:

1= I'm not interested

2= I would consider participating within the next 6 months

3= I would consider participating within the next 30 days

4= I am already participating

Q23_Collective_Change	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Not interested (1)	1	3.57	1	3.57
I **would consider participating within the next 6 months (2)**	7	25.00	8	28.57
I would consider participating within the next 30 days (3)	6	21.43	14	50.00
I am already participating (4)	14	50.00	28	100.00

Frequency Missing = 3

● Half of the participants said that they were already participating in Town adaptation planning discussions/activities. Another 20% said that they would consider participating within the next 30 days, and 25% said they would consider participating within the next 6 months.

Q23_Types of Collective Action	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Exeter River Study Committee Member	1	16.67	1	16.67
I feel I'm already doing a good job. I am interested in what they do and will keep abreast	1	16.67	2	33.33

Q23_Types of Collective Action	Frequency	Percent	Cumulative Frequency	Cumulative Percent
I'm a student at UNH and take part in exercises like this for my major and I'm interested in this	1	16.67	3	50.00
Planning Board member	2	33.33	5	83.33
Through my church.	1	16.67	6	100.00

Frequency Missing = 25

Qb. I rate my readiness to take <u>personal</u> actions (such as properly maintaining my septic system and considering my lawn care practices) as:

1= I'm not ready to make any changes

2= I would consider making changes within the next 6 months

3= I would consider making changes within the next 30 days

4= I have already changed my personal behavior

● Over 2/3 of participants said that they had already made some personal behavioral changes. Another 18% said they would consider making changes within the next 30 days, and 14% said they would consider making changes within the next 6 months. In sum, a highly motivated group.

Q22_Personal_change	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Would change in 6 mo. (2)	4	14.29	4	14.29
Would change in 1 month (3)	5	17.86	9	32.14
Already changed my behavior (4)	19	67.86	28	100.00

Frequency Missing = 3

Q22_What kinds of personal changes did you make?	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Advocating for the River	1	12.50	1	12.50
Already feel I'm fairly responsible in dealing with personal actions. Have public sewer and use organic fertilizer on lawn and gardens sparingly.	1	12.50	2	25.00

Q22_What kinds of personal changes did you make?	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Changed my water use and power use habits; drive a hybrid car; less driving; local foods	1	12.50	3	37.50
Drive a Prius; LED lighting; recycling	1	12.50	4	50.00
Generator	1	12.50	5	62.50
I focus on recycling through use of less packaging and composting. I plant with native plants primarily and I'm always trying to make energy saving improvements where I live.	1	12.50	6	75.00
Maintenance of property and lawn.	1	12.50	7	87.50
Solar water heater is a consideration; we already are diligent about maintaining our septic system and careful about water use; we don't use chemicals on our lawn.	1	12.50	8	100.00

Frequency Missing = 23

DEMOGRAPHICS
N=31 (*Exeter Residents only included in this report. We received 9 other surveys from people who did not live in Exeter).

MEDIAN AGE: 61.5

Age_groups	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Age 15-25	11	35.48	11	35.48

Age_groups	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Age 26-64	8	25.81	19	61.29
Age >=65	12	38.71	31	100.00

Frequency Missing = 3

GENDER	Frequency	Percent	Cumulative Frequency	Cumulative Percent
F	16	53.33	16	53.33
M	14	46.67	30	100.00

OCCUPATION	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Accountant	1	3.45	1	3.45
Air craft manufacturing	1	3.45	2	6.90
Barista	1	3.45	3	10.34
Civil Service Employee and Student	1	3.45	4	13.79
Community development; YMCA	1	3.45	5	17.24
Computer consultant	1	3.45	6	20.69
Management Consulting	1	3.45	7	24.14
Part-time employee	1	3.45	8	27.59
Realtor	1	3.45	9	31.03
Retired	12	41.38	21	72.41
Self employed	1	3.45	22	75.86
State Rep	1	3.45	23	79.31
Student	5	17.24	28	96.55
Teacher	1	3.45	29	100.00

Frequency Missing = 2

EMPLOYMENT categories: 1=employed full-time 2=employed part-time 3=unemployed 4=retired 5=student

EMPLOYMENT	Frequency	Percent	Cumulative Frequency	Cumulative Percent

EMPLOYMENT	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	6	20.00	6	20.00
2	3	10.00	9	30.00
3	1	3.33	10	33.33
4	13	43.33	23	76.67
5	7	23.33	30	100.00

Education Level: 1=High School 2=Some College 3=College Graduate

4= Post-Graduate /Professional Degree

EDUCATION	Frequency	Percent	Cumulative Frequency	Cumulative Percent
High School (1)	1	3.33	1	3.33
Some College (2)	5	16.67	6	20.00
College Grad (3)	10	33.33	16	53.33
Post-Graduate Degree (4)	14	46.67	30	100.00

- Over 80% of the participants had a college degree (33%) or higher (47%).

POST_EVALUATION QUESTIONS:

Q9: The conversation helped me to become better informed about

the about the impacts of a changing climate in Exeter
(*Over 75% agreed or strongly agreed)

Q9	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Disagree (2)	1	3.45	1	3.45
No opinion (3)	6	20.69	7	24.14
Agree (4)	13	44.83	20	68.97
Agree Strongly (5)	9	31.03	29	100.00

Q10: The conversation helped me to better understand the

Climate Adaptation Plan for Exeter (CAPE) project and how I can get involved

Q10	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Disagree (2)	3	10.34	3	10.34
No opinion (3)	9	31.03	12	41.38
Agree (4)	13	44.83	25	86.21
Agree Strongly (5)	4	13.79	29	100.00

Frequency Missing = 2

● Approximately 59% agreed or strongly agreed that that the conversation helped them to better understand the Climate Adaptation Plan for Exeter (CAPE) project and how I they could get involved. Thirty-one percent had no opinion, and 10% disagreed.

Q11: Because of this conversation, I had a better understanding of

people who I disagree with and their opinions.

Q11	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Disagree (2)	3	14.29	3	14.29
No opinion (3)	11	52.38	14	66.67
Agree (4)	7	33.33	21	100.00

Frequency Missing = 10

- Note: Several people commented 'n/a' because there were no disagreements at their table.

Q21.Which of the following best describes what happens during a heavy rain at your residence? (question taken from Exeter's "Think Blue" survey):

1=Almost all of the water soaks into the ground and does not leave the property.
2=Some water may soak in but most flows into storm drains and moves untreated into local waters.
3=Some water may soak in but most flows into storm drains where it is cleaned before flowing into local waters.
4=Some may soak in but most flows into the sewer system and is treated at the waste water treatment plant before flowing into local waters.
5=I don't know where the rain water goes.

Q21_heavy_rain	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	7	29.17	7	29.17
2	10	41.67	17	70.83
3	3	12.50	20	83.33
4	3	12.50	23	95.83
5	1	4.17	24	100.00

Frequency Missing = 7

Q24_ Comments	Frequency	Percent	Cumulative Frequency	Cumulative Percent
An exciting experience-moving forward in Exeter feels wonderful!	1	16.67	1	16.67
I think the time was well-spent and I'd like to have covered the topic much more than the time	1	16.67	2	33.33
I wish we could have read the materials prior to the discussion instead of during the session.	1	16.67	3	50.00
Lengthy agenda; could be 1 page	1	16.67	4	66.67
The program was well thought-out and graciously hosted. I'd have been more comfortable had I u	1	16.67	5	83.33
Would need more info in order to consider CWG	1	16.67	6	100.00

Themes from Community Conversation, 2013

[1] Folke, C., T. Hahn, P. Olsson, and J. Norberg. 2005. Adaptive governance of social-ecological systems. *The Annual Review of Environment and Resources* 30:441-473.

Hatfield-Dodds S., R. Nelson, and D. Cook. 2007. Adaptive governance: An introduction and implications for public policy. In: *Australian Agricultural and Resource Economics Society, 2007 Conference (51st)*, Queenstown, New Zealand, No. 10440.

Appendix C3

Community-based Climate Change Adaptation: Workshop for Delaware and New Hampshire Practioners

Participant Agenda

New Hampshire and Delaware may be hundreds of miles apart, but coastal communities in each state face similar challenges in adapting to the impacts of climate change. This interactive workshop is designed to engage the professionals who support these communities as they plan and work toward greater resiliency. It will combine interactive group activities and dialog with case studies of innovative approaches to engaging communities throughout the adaptation process—from the articulation of values and needs to fostering long-term collaborative relationships that are built on trust and focused on mutual goals. Many thanks to the New Hampshire and Delaware professionals who provided input on the focus and design of the day's agenda!

8:30 am Registration & Coffee

9:00 am to Noon (*The morning will include a 15-minute break.)*

Welcome & Introductions
Dover meet Dover! Brief activity to help us get acquainted and share personal goals for the day.

Starting with Values
A value-based approach to climate change adaptation uses a community's social and economic challenges and resources to frame the planning process. Such an approach can increase the likelihood that communities will make the best decisions possible with the resources available. Through a series of "ignite" style case studies, you will hear from fellow practitioners as they share different techniques they have used to characterize and prioritize community values, why they chose these methods, what worked well, and what they would do differently in the future. This session includes a group activity in which you will be able to share your experiences and learn more about techniques of particular interest.

Moving From Values to Action
When you understand what different stakeholders in the community care about, what then? How do values translate into priorities and actions? This session will combine case study presentation with an interactive group activity to explore participatory approaches to identifying, planning, and implementing climate change adaptation actions that have the support of critical partners and stakeholders.

12:00 pm Lunch Take a break or use this opportunity to dig into burning questions sparked by the morning dialog with colleagues from near and far.

1:00 to 4:30 pm (*The afternoon will include a 15-minute break.)*

Going the Distance Community-based climate change adaptation is a long-term, iterative process that not only requires practitioners to build and sustain partnerships with communities, but also with other agencies and organizations with similar goals. Using case studies and dialog, this session will focus on opportunities and barriers to developing partnerships that support specific planning projects, as well as the challenges and benefits of building a community of practice for climate change adaptation among practitioners.

Finding a Common Language The ability for experts and stakeholders to communicate clearly and openly is at the heart of a values-based, collaborative approach to helping communities plan for climate change. Experts need to be prepared to share their work in a clear, transparent way that reinforces trust among stakeholders and is relevant to their values and needs. Using case studies and dialog, this session will focus on best practices and pitfalls of communicating the local effects and concerns of climate change among stakeholders, practitioners, and experts in community-based climate change adaptation.

Wrap up, Evaluation, and Social

Appendix C4

Working Collaboratively and Engaging Stakeholders

A Community Climate Adaptation Planning Case Study and Learning Exchange

Wednesday, May 20, 2015, 8:30 am – 4:00 pm
Save The Bay, Providence, RI

Goal: Increase the use of effective engagement techniques to ensure the active participation of residents and community groups in the decision-making process.

Primary Audience: Those responsible for initiating, facilitating, and managing work with communities (municipal staff and officials, state and federal agency personnel, non-profit organization representatives, and other interested parties)

Objectives:
Participants will increase their knowledge of how to:

- Identify and build on local partnerships;
- Seek out and integrate homegrown knowledge, stakeholder concerns, and values;
- Integrate values, stakeholder experience, and scientific input; and
- Build in evaluation results throughout the life of the project

Time **Speaker/ Facilitator**	**ACTIVITIES and OBJECTIVES**	**Set up and materials**
8:00	**Sign-in and refreshments** **Total: 30 minutes**	Sign-in sheet, name tags
8:30 **Jen**	**Welcome and Introductions** <u>Objective:</u> Participants will understand the objectives of the workshop and learn about fellow attendees <u>Activities:</u> 1. Explain why the workshop was created and its objectives, overview of materials, tell them everything will be available online after the workshop, acknowledge presenters/sponsors; logistics- food, bathroom,	Folder of materials - agenda - evaluation - CTP fact sheet - speaker bios - attendee list - key terms/ def - Top Ten (NH list) - Group Agreements

Michele	breaks, exits, cell/computer protocol, etc. *(10 min)* 2. Hellos and standing circle: participants introduce themselves and their affiliation(s), share why they came and what they hope to learn *(20 min)* **Total: 30 minutes**	- Summary report from conversation - 2 pg engagement report - activity form
9:00 **Jen** **Steve** **Jen**	**Overview of the CAPE project** <u>Objective:</u> Participants will learn about the overall goal and structure of the CAPE project <u>Activities:</u> 1. Introduce speaker, topic, and context *(5 min)* 2. PowerPoint presentation *(15 min)* • Background: Basic "blueprint" of the project (e.g., a diagram that provides context, highlights players/organizations involved (collaboration and partnerships across agencies- public staff, science and social science team, etc.)) • The Engagement and Research Plan(s) Dance • Brief intro of CAPE team roles and diversity of the team (and CAPE people in the room) 3. Clarifying questions about CAPE *(10 min)* **Total: 30 minutes**	PowerPoint Have CAPE magnets, pencils, and posters in the room
9:30 **Jen** **Semra** **Jen**	<u>Evaluating your Efforts: Starting with the end in Mind</u> <u>Objective:</u> Participants will understand the various approaches for evaluating their engagement efforts <u>Activities:</u> *1.* Introduce speaker, topic, and context *(5 min)* *2.* PowerPoint presentation *(15 min)* • The variety of evaluation methods and how they shaped the project • Which evaluation components were applied to which engagement activity(ies) • What we learned and how we know • How do we know how we are doing • When and how to explain the science • End of project key messages and audiences • When to use what techniques in your tool box *3.* Clarifying questions *(10 min)* 4. Learning exchange/activity *(15 min)*	PowerPoint Semra

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<tr><td></td><td>Total: 45 minutes</td><td></td></tr>
<tr><td>10:15</td><td>BREAK
Total: 15 minutes</td><td></td></tr>
<tr><td>10:30

Jen

Sylvia

Michele

Steve

Jen</td><td>Responding to a Concern and Developing a Strong Engagement Plan
Objective: Participants will understand how to develop a strong engagement plan based in community interest and readiness

Activities:

Introduce speaker, topic, and context (5 min)
PowerPoint Presentation: Building the Team (10 min)

Building the team from the beginning to increase likelihood of collaboration
Identifying who to work with and why at municipal level (grassroots interest from Exeter/interested community)
Identifying key stakeholders, including primary, secondary and tertiary audiences (a la communications plan)
Relationships, relationships, relationships and CHAMPIONS

PowerPoint Presentation: Engaging the Public (10 min)

PR vs. public engagement vs. communication
Outline of the engagement plan
Community readiness – tools and how
Communities of Interest
Communities of Place
Engagement – who to engage with, stakeholders, and why
What was proposed in the plan vs. what was actually done (order and priority changes)

PowerPoint Presentation: Forming a Citizen Working Group (CWG) (10 min)

Structure and process
Engaging political and civic leaders (mention and cover in next section)

Clarifying questions (10 min)
Learning exchange/activity (25 min)

Individually: participants select something they want to accomplish in the next year, then identify all of the stakeholders they will need to engage (10 min)
In pairs: participants share an insight, reflection, idea, etc. with another (5 min)
Large group conversation/pop ups (10 min)

</td><td>Community readiness/How to do it

“If you are affected by a decision, you are a stakeholder”

Jen will make worksheet</td></tr>
</table>

	Total: 60 minutes	
11:30 **Jen** **Sylvia** **Jen**	Identifying Community Values and Concerns Objective: Participants will understand various approaches for assessing stakeholder/community member values and concerns Activities: *1.* Introduce speaker, topic, and context *(5 min)* *2.* PowerPoint presentation: Experiential Activities *(20 min)* • Techniques/methods/best practices for assessing values and concerns o Use of maps, concrete and effective categories o Iterative contact with stakeholders to ground truth data – municipal employees o Sitting down with staff (go to them- no doodle!), use of town staff o Fostering cross agency collaboration and communication o Public health and emergency preparedness o Staff response to flooding maps 1. Clarifying questions *(10 min)* 2. Learning exchange/activity *(15 min)* **Total: 30 minutes**	PowerPoint A few experiential exercises, maps, stories Bring our maps to show Need a flooding map Syl will bring in power point Michele bring maps
12:00	LUNCH **Total: 45 minutes**	
12:45 **Jen** **Steve**	Stay Flexible and Adapt! (Adaptive Collaboration for Adaptive Management) Objective: Participants will understand how to anticipate investments of time for collaboration and how to adapt along the way. Activities: 1. Introduce speaker, topic, and context (*5 min*) 2. Group Discussion: Overview of Adaptive Management and Collaboration (*20 min*) • Adaptive collaboration for adaptive management- adapting the team, recognizing when you need different	"Know the plan. The plan will change."

<table>
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<td>Sylvia

Michele

Jen</td>
<td>

skills/input/organization
The collaborative process: by nature you will change what you have designed
Iterative evaluation processes; getting feedback, testing assumptions

3. Stories and Discussion: Insights and Adaptations (3 snapshots) (20 min)

Realizing that not all CWG team members could understand the technical nature of the “ground truthing models” task that was put before them; realizing that some “review” (of models, etc.) is more efficiently accomplished through face-to-face meetings with Town staff (such as the Town Engineer)
The evolution of 12/12/12 meetings and Sylvia’s presentation guidelines – x and y axis!!! Sylvia on coaching presenters on power point and accessibility, watch short video
How the focus was originally on “the community” and then became “priority audiences” after the communications plan was developed by Dolores

4. Clarifying questions (10 min)
5. Learning exchange/activity (10 min)

Participants reflect on a “hindsight is 20/20” experience they’ve had with a project and share with the larger group (pop ups)

Total: 60 minutes
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<td>Sylvia coaching Paul video (Michele has it)</td>
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<td>1:45</td>
<td>BREAK
Total: 15 minutes</td>
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<td>2:00

Jen

Michele</td>
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Engaging Stakeholders and Holding Great Events

Objective: Participants will understand the various approaches for engaging stakeholders/community members in, and designing and executing, successful project events

Activities:
3. Introduce speaker, topic, and context (5 min)
4. “Ignite” PowerPoint presentation (10 min)

The various engagement techniques used, from least to most resource-intensive (meetings, workshops, experiential activities, etc.); highlight:

Festivals and public art
Use of Photos
Youth engagement
Use of high school students as facilitators
Hawk Tawk
Collaborative meetings and outreach
Community Conversation
Summer student GIS maps from April 10 (digital formatting of maps)

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<td>PowerPoint

Pictures and stories

(one of Semra’s slides)</td>
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Michele **Jen**	○ Early Tour and Flood spots tour with Fire Department ○ Experiential activities/Dave B ○ Working with Elected leaders 5. PowerPoint presentation *(10 min)* • Getting them there - How to get the word out/attract people to your events (basic marketing strategies) • Meeting basics (e.g., 80% of time spent on prep/outreach, 20% on the event itself) • Top Ten Tips for Hosting 6. Clarifying questions *(10 min)* 7. Learning exchange/activity *(20 min)* • In pairs: participants share an activity in which they took part where they were really engaged and inspired, and identify activities they think would be appropriate for their project (identified in first activity) *(10 min)* • Large group conversation/pop ups *(10 min)* **Total: 60 minutes**	
3:00 **Jen**	**Wrap up and Evaluations** Activities: 1. Final thoughts, Q& A, CAPE Panel *(15 min)* • Potential questions for panelists: has the project resulted in new partnerships, unanticipated opportunities/outcomes/other projects, etc? 2. Thank presenters, participants, etc. *(5 min)* 3. Complete evaluation *(10 min)* Total: 30 minutes	Evaluations
4:00 pm	Adjourn	

Appendix C5

Public Meeting Facilitation Laboratory

Wednesday, August 12, 2015; 12:00 pm – 3:00 pm
Warwick Public Library, 600 Sandy Lane, Warwick, RI

EVALUATION

# of participants: 27 *completed evals: 23*

1. Participating in this event was a good use of my time:

__**18**___ Strongly agree __**4**___ Agree __**1**___ Neutral ______ Disagree ______ Strongly disagree

Comments:

- Really useful
- It was interesting to see the different scenarios that could be played out
- Great fun. Good stuff.

2. How much did this workshop increase your knowledge of the topic presented?

__**9**___ A great deal __**10**___ A lot __**2**___ Some __**2**___ A little ______ Not at all

Comments:

- The actors were great and true to form
- Thoughts for going ahead in similar situations

3. Did you learn something that you will apply in your work or future decisions?

__**21**___ Yes ______ No ___**1**__ Maybe __**1**___ Prefer not to answer/not applicable

Comments:

- Active listening, controlling emotions, strategies from audience
- Gave me a nice flavor of tactics I could utilize
- Good demonstration of active listening
- I received good strategies to use, the interactive nature of the workshop meant helpful learning
- I was hoping for more specific examples/techniques

4. Are there any other issues/topics on which you would like information/training that might help you in your work or decision-making?

- There are important things that I learned from the meeting (ground rules, Roberts Rules of Order, etc!)
- More on process and less on outright conflict management
- Maybe an overview of different decision-making processes (when to use what process)
- I would like to know how or if rules differ due to location and (?) when it comes to public forums
- Active listening techniques
- More capacity building like this
- More on science for the public
- Active listening

5. Any additional comments?

- More situations with public Q&A would be helpful
- Very interesting. More like that!
- Great job. Liked the live actors, made the presentation more enjoyable
- Good work!
- This was great!

- Thanks! Great format for learning and pulling lessons learned from audience
- Great event!
- This was a fantastic training that we need to replicate! How can we get these people back down here?!
- GREAT!
- Great workshop!
- Thanks as always Jen!
- Enjoyed immensely- would attend again!!
- I wish we had a worksheet at the beginning of the workshop to help get a baseline of what is going on (e.g., characters, scenarios) to help facilitate discussion better. And to take notes on!
- Great job thanks!