Climate Trends in Massachusetts and Its Impact on River Flood Behavior

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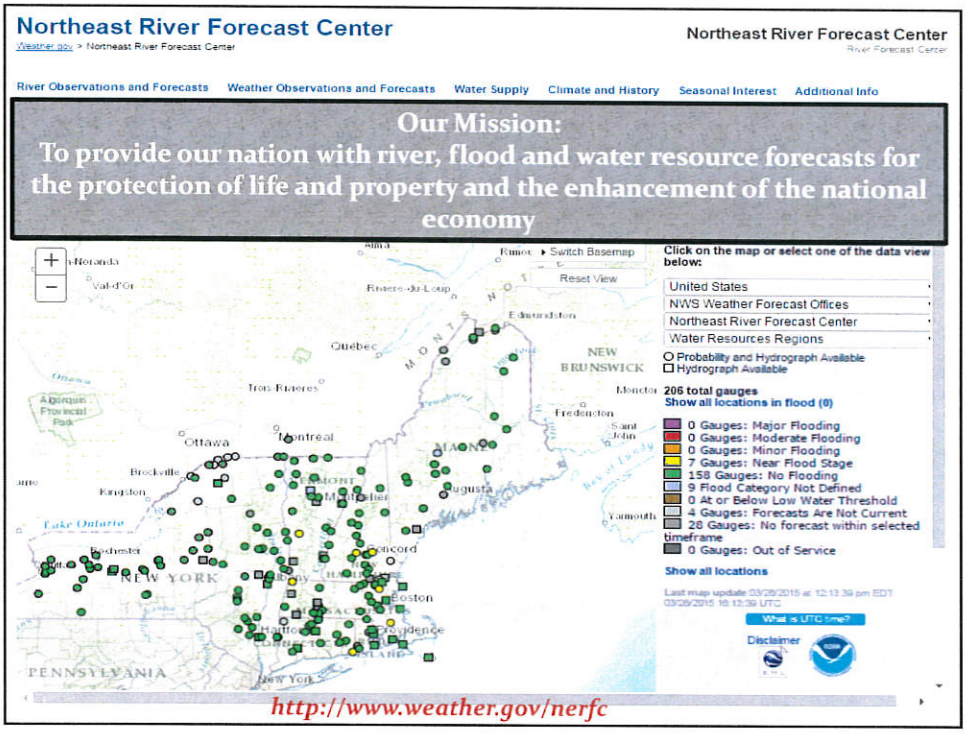
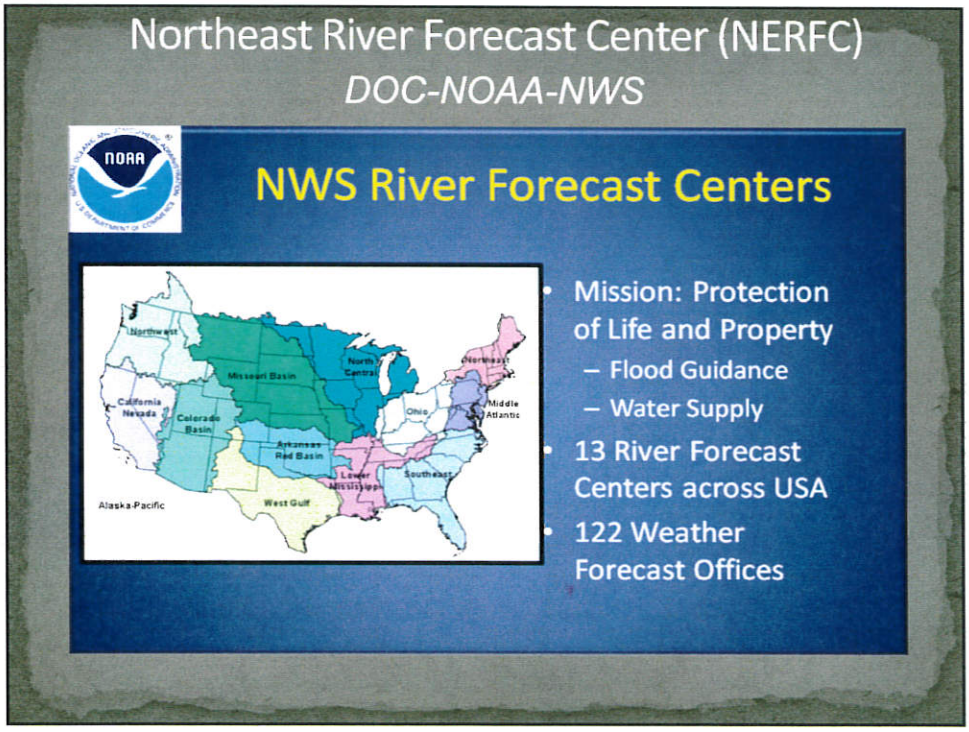
Providence Street – West Warwick, RI at 1030 am Wednesday 3/31/10

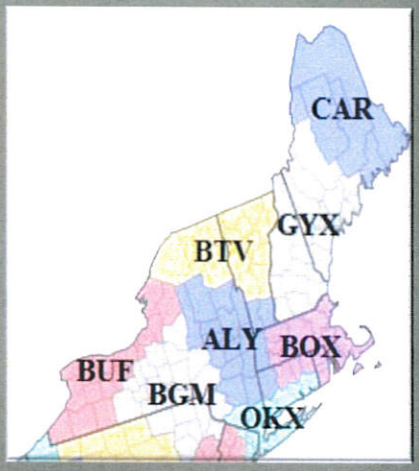


http://www.weather.gov/nerfc



Weather Forecast Office
New York/New England Service Areas

- WFO Caribou, ME
  - Northeast Maine counties
- WFO Gray, ME
  - Southwest Maine and all of New Hampshire
- WFO Burlington, VT
  - Northern 2/3rds of VT
- WFO Albany, NY
  - Srn 1/3 of VT, Berkshire, MA, Litchfield, CT
- WFO Taunton, MA
  - Rest of MA, all of RI, and the northern 2/3rds of CT
- WFO Upton, NY
  - All coastal CT Counties
- WFO Binghamton, NY
  - Finger Lakes region
- WFO Buffalo, NY
  - Buffalo Creeks, Genesee and Black



Weather Forecast Office Responsibilities
Weather Ready Nation

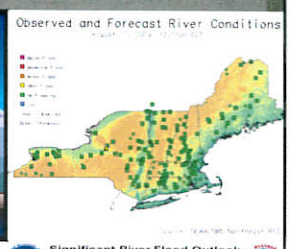
- Watch/Warning responsibilities
  - Public, Marine, Aviation, Fire Weather, Coastal Flooding, River and Flash Flooding, Fire Weather
  - Issue and coordinate all watches/warnings with local interests
    - Conference calls with State EMA
    - Media through NWSChat
  - Define forecast service requirements
  - Establish new forecast requirements
- Provide Decision Support Services to the Decision Makers in the region

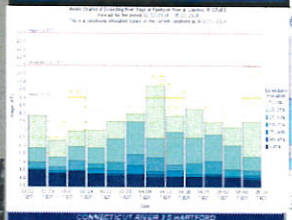
River Forecast Center Responsibilities

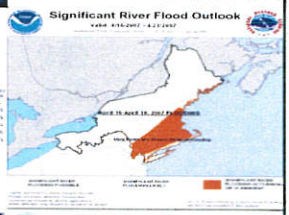
Calibrate and implement a variety of hydrologic and hydraulic models to provide:

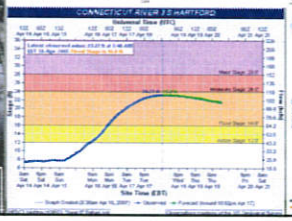
- River flow and stage forecasts at 180 locations
- Guidance on the rainfall needed to produce Flash Flooding
- Ensemble streamflow predictions
- Ice Jam and Dam Break support
- Water Supply forecasts
- Partner with NOAA Line Offices to address issues relating to Hazard Resiliency, Water Resource Services, Ecosystem Health and Management, and Climate Change

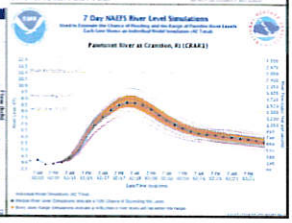
Moderate flooding - Connecticut River at Portland, CT











Forecast Services

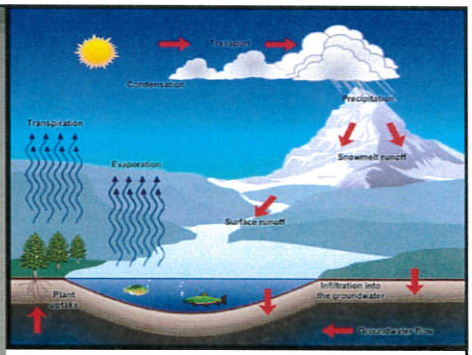
On A Watershed Scale

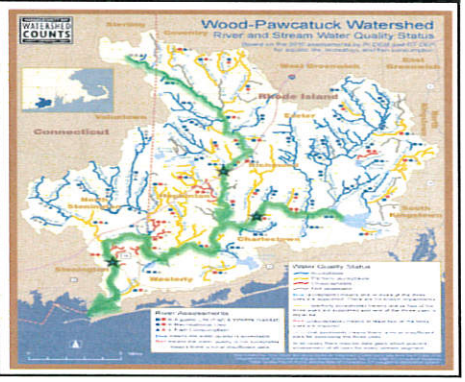
Requirements:

- Observed precipitation & temperatures
- Observed streamflows (USGS)
- Forecast temperatures and precipitation
- **Drainage area ≤ 100 sq mi**

Our models help us forecast:

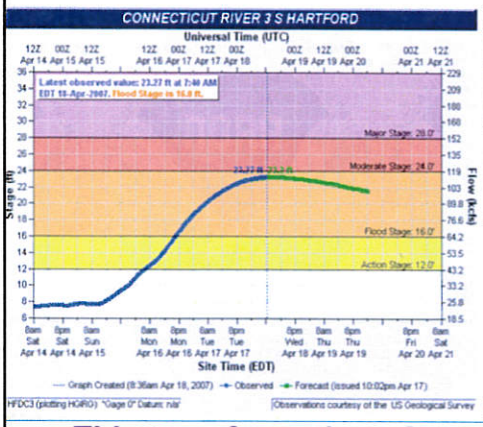
- The volume of water in the river & that's converted to stage/elevation
- Time of the peak elevation & duration
- Soil moisture & Snow melt
- Unit hydrograph theory
- Reservoir Operations
- Hydraulics (HES-RAS) for complex river systems
  - Tidal reaches
  - Lake Champlain, Farmington River
  - Combines tidal/storm surge with fresh water runoff on 5 tidal rivers

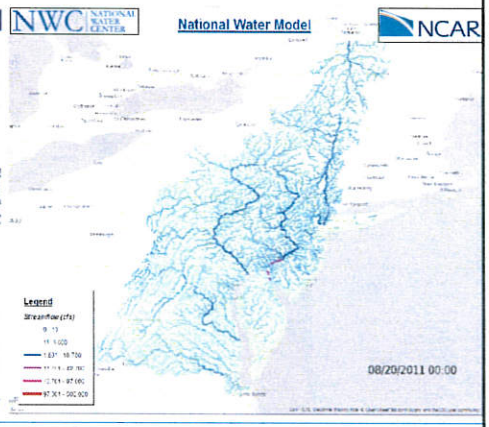




A Look At Current & Future Water Prediction Services:

Moving from Point Specific to Street Level Hydrologic Forecasting



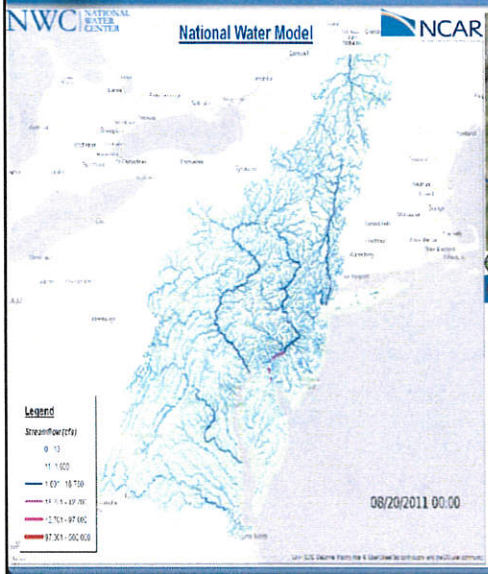


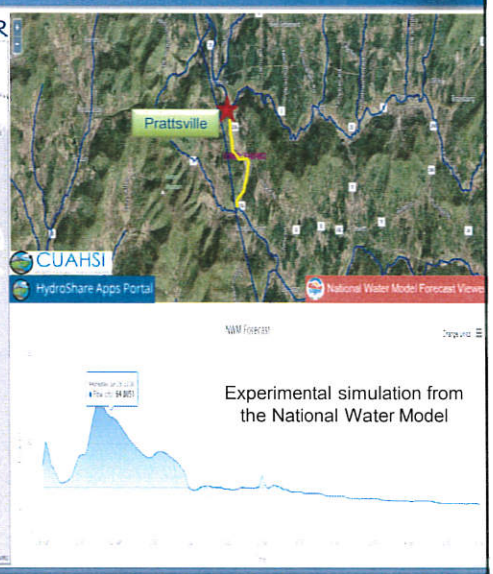
This transformation of our services is the result of the development of the new National Water Model

Building a Weather-Ready Nation

But it truly is a matter of scale

Tomorrow's Scale – 1 km or less!

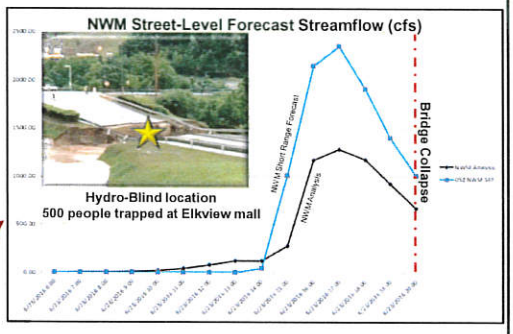


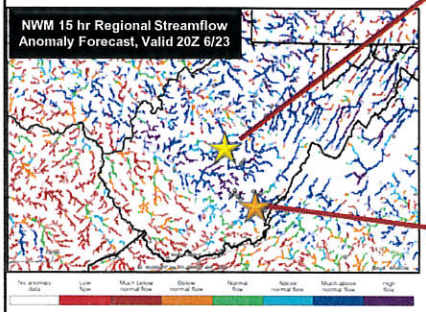


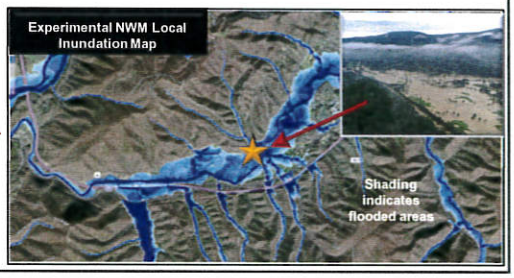
Building a Weather-Ready Nation

NWM-Based Street Level Hydrologic Prediction
Record Setting West Virginia Flood Event, June 23rd 2016

- Thousands of homes damaged or destroyed, $111+ million in FEMA aid
- NWM allows users to drill down from regional to local to street scale
- Information complements hydrologic guidance at existing forecast locations and provides new insight at millions of hydro-blind locations







http://www.water.noaa.gov/map

Our changing climate:

- From a "Practitioner's Perspective"
- Rainfall/Temperature trends
- Changes in flood & drought behavior
- Challenges going forward

A few caveats

- Neither Ed nor I are climate scientists!
  - We are practitioners
- We have the benefit of living in this part of the country – i.e.: *we are locals!*
  - It's different now – beyond temps & precip
  - Changes in vegetation, insects, bird life & ***river response***
  - Sea level rise
- The mission: Develop a better understanding of the current regime vs. the old & what that means to how we model our rivers
  - "Accumulation of Ingredients" – not one single "source"
  - Where we are headed: that's the million $$ question!

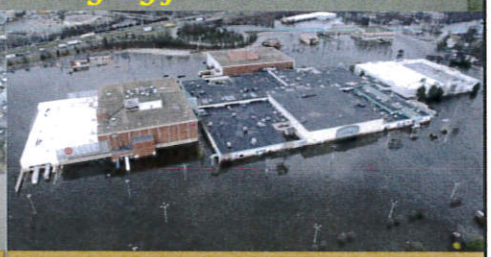
My "religious experience":

Takes on a whole new meaning when it hits your hometown…

Providence Street – West Warwick, RI at 1030 am Wednesday 3/31/10

I've been a little busy these past 10 years!
Job Security in the face of changing flood behavior!!

Record flooding along the Fish and Saint John Rivers – northeast Maine, 4/30/2008



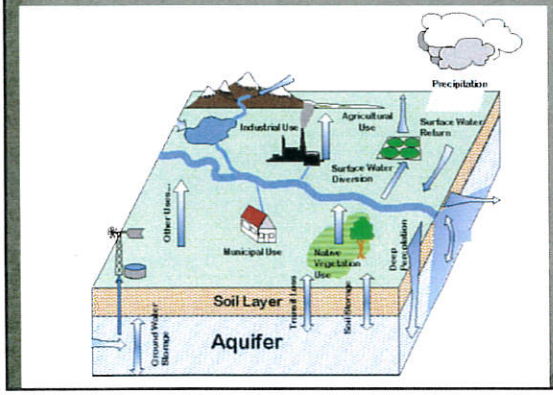
Providence Street – Warwick, RI at 1030 am Wednesday 3/31/10

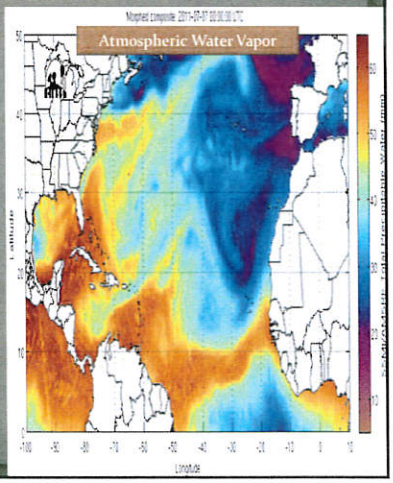
Home washed off its foundation on the Schoharie Creek, Prattsville, NY – Tropical Storm Irene

Record Flash Flooding in Utica, NY, July 1st, 2017
Photo courtesy of Jill Reale (WKTV)

Is there a common theme to recent ?

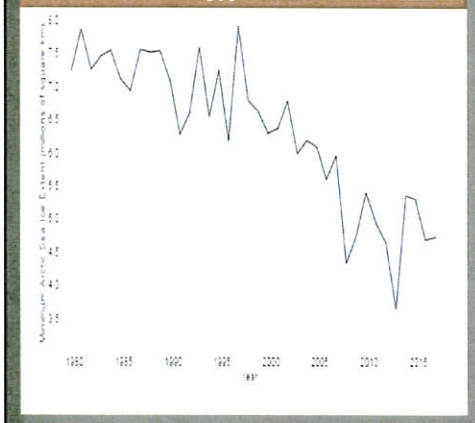
- Several:
  - Slow moving weather systems – a blocked up atmosphere
  - Multiple events in close succession or 1 or 2 slow movers
  - Resulted in saturated antecedent conditions
  - Each fed by a "tropical connection"
    - Plumes of deep moisture





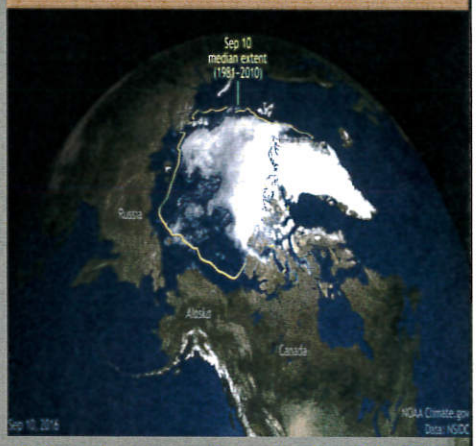
A warming planet and shrinking Arctic Sea ice

September Minimum Sea Ice Cover 1979-2016



This graph shows the average area covered by sea ice during September each year. Minimum sea ice extent has decreased 12% per decade since 1979. Data provided by the National Snow and Ice Data Center.

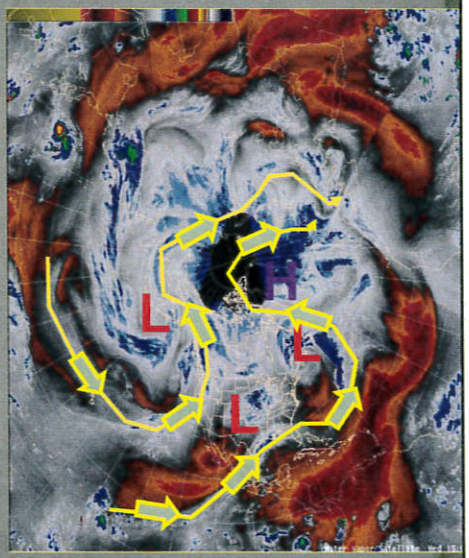
2016 Arctic Sea Ice Summer Minimum



Arctic sea ice concentration on the date of the 2016 minimum extent, September 10, 2016. NOAA Climate.gov image based on NOAA and NASA satellite data from NSIDC.

Is there a plausible "Climate Hypothesis"?

- Modest changes in air & sea temperatures = atmosphere can hold more moisture
  - New England is in close proximity to the ocean and the Gulf & Atlantic moisture streams
  - Affected by dual storm tracks and blocking high pressure over Greenland
  - These ingredients offer us more "opportunities" to latch onto these plumes
- Reduction of sea ice changes upper level wind flow
  - Blocked up pattern induces slower moving storms or back-to-back-to back events



The Changing Climate

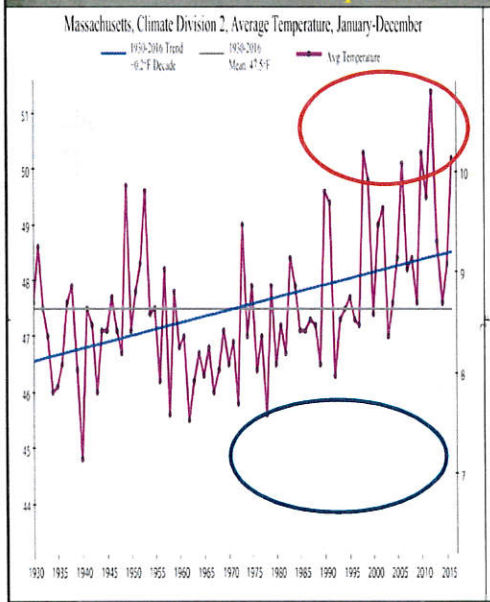
- Common themes across New England:
  - Increasing annual precipitation
  - Increasing frequency of heavy rains
  - Warming annual temperatures
  - Wildly varying seasonal snowfall
- Shift in precipitation frequency (50, 100 yr – 24 hr rain)
- For smaller (<800 sq mi) basins – trend toward increased flood magnitude and/or frequency
  - Most pronounced where significant land use change and/or urbanization has occurred

Flooding along the Sudbury River in Wayland, MA, March 31st 2010. Photo: NERFC

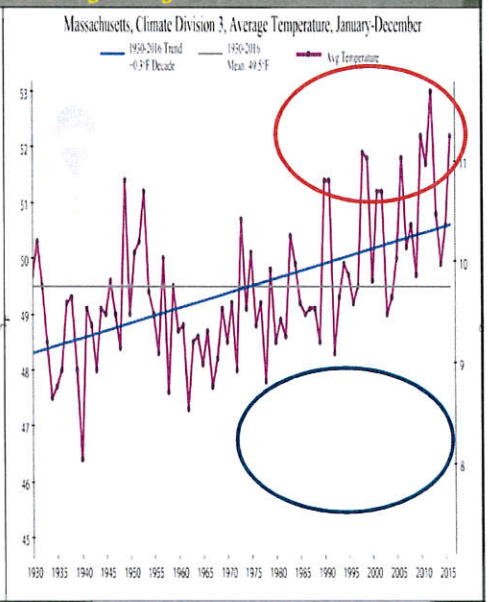
The Eagle-Tribune had it correct: "River Raging" – May 15th, 2006

A Look at Temperature Trends

http://www.ncdc.noaa.gov/cag



CT Valley to Merrimack Valley

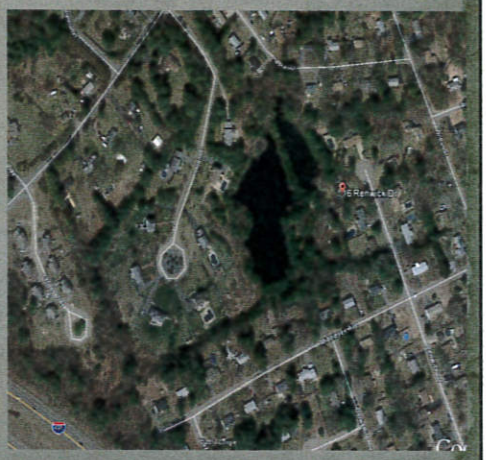


Eastern/Coastal Massachusetts

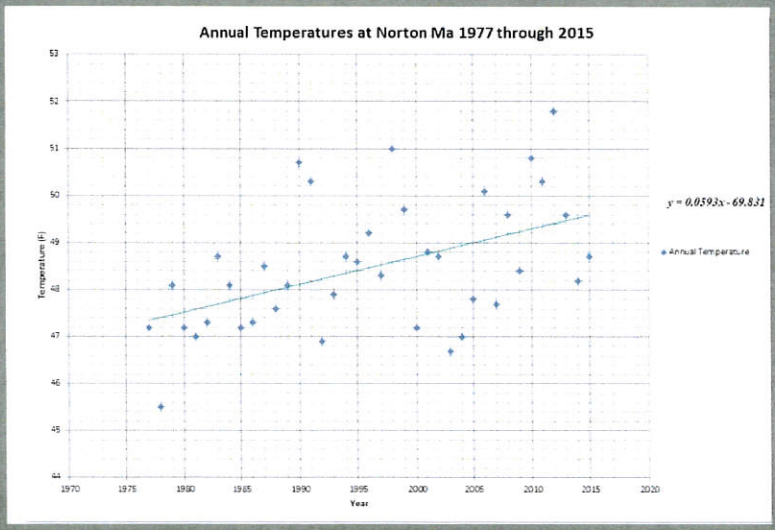
NWS Norton Coop Station Temperatures Vegetation Issues affect Climate Station

1995

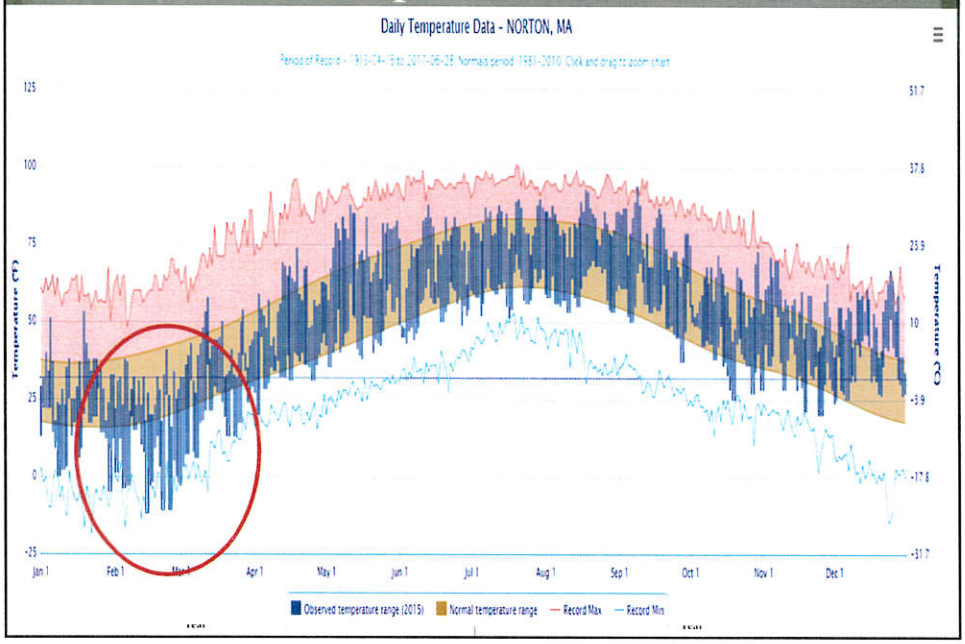
2017



A Norton NWS Station Perspective on Temperatures since 1976



A Look at Temperature Trends



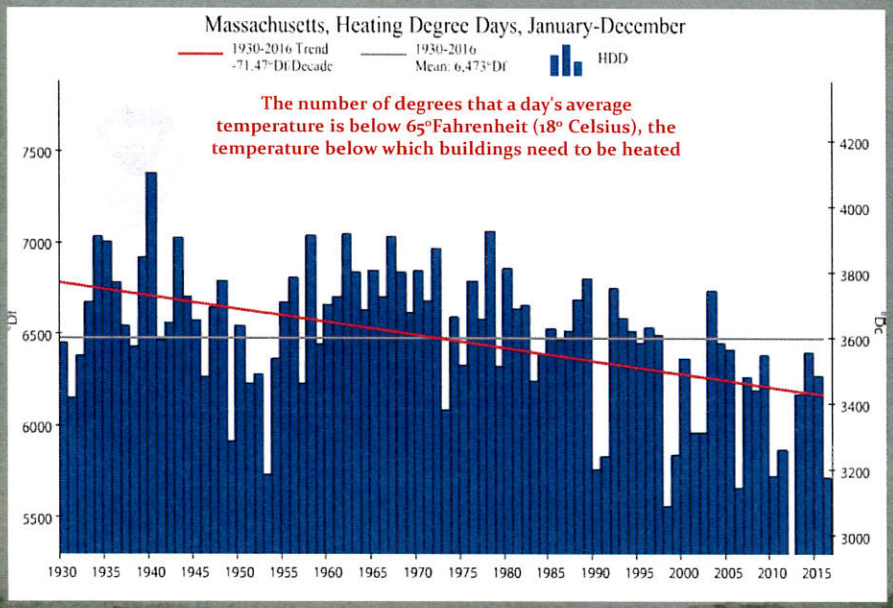
Period of Record Cold – Norton

Climatological Data for NORTON, MA - February 2015

Click column heading to sort ascending, click again to sort descending

	Max Temperature	Min Temperature	Avg Temperature	Avg Temperature Departure	HDD	CDD	Precipitation	Snowfall	Snow Depth
2-01	22	1	11.5	-15.3	53	0	T	T	16
2-02	31	1	16.0	-10.9	49	0	0.33	3.9	16
2-03	32	12	22.0	-5.0	43	0	0.55	6.6	25
2-04	23	-4	9.5	-17.6	55	0	0.00	0.0	24
2-05	38	-4	17.0	-10.2	48	0	T	T	23
2-06	37	-3	17.0	-10.3	48	0	0.05	1.0	24
2015-02-07	21	-3	9.0	-18.5	56	0	0.00	0.0	24
2015-02-08	26	19	23.5	-4.1	41	0	0.24	2.9	24
2015-02-09	32	15	23.5	-4.3	41	0	0.27	2.9	26
2015-02-10	23	15	19.0	-8.9	46	0	**0.78**	10.5	30
2015-02-11	31	17	24.0	-4.1	41	0	T	T	28
2015-02-12	23	10	16.5	-11.8	48	0	0.04	1.0	27
2015-02-13	32	8	20.0	-8.4	45	0	0.02	0.4	27
2015-02-14	18	**-12**	3.0	-25.6	62	0	0.00	0.0	26
2015-02-15	27	**-12**	7.5	-21.3	57	0	0.56	**11.1**	35
2015-02-16	20	-3	8.5	-20.5	56	0	0.08	2.0	34
2015-02-17	20	-2	9.0	-20.2	56	0	0.00	0.0	33
2015-02-18	23	9	16.0	-13.4	49	0	0.10	3.0	34
2015-02-19	32	13	22.5	-7.2	42	0	0.11	2.6	35
2015-02-20	28	3	15.5	-14.4	49	0	T	T	33
2015-02-21	18	-11	3.5	-26.6	61	0	0.00	0.0	32
2015-02-22	33	-11	11.0	-19.4	54	0	0.54	1.7	31
2015-02-23	**41**	26	33.5	2.9	31	0	0.02	0.2	29
2015-02-24	26	-11	7.5	-23.4	57	0	0.00	0.0	28
2015-02-25	16	-11	2.5	-28.6	62	0	0.14	3.9	31
2015-02-26	34	5	19.5	-11.9	45	0	0.00	0.0	29
2015-02-27	25	0	12.5	-19.2	52	0	0.01	0.2	29
2015-02-28	28	-2	13.0	-19.0	52	0	0.00	0.0	29
Sum	762	65	-		1399	0	3.84	54.1	-
Average	27.2	2.3	14.8	-14.1	-	-	-	-	26.0
Normal	40.1	17.8	28.9		1009	0	3.76	10.1	-

Impacts on Energy to Heat or Cool



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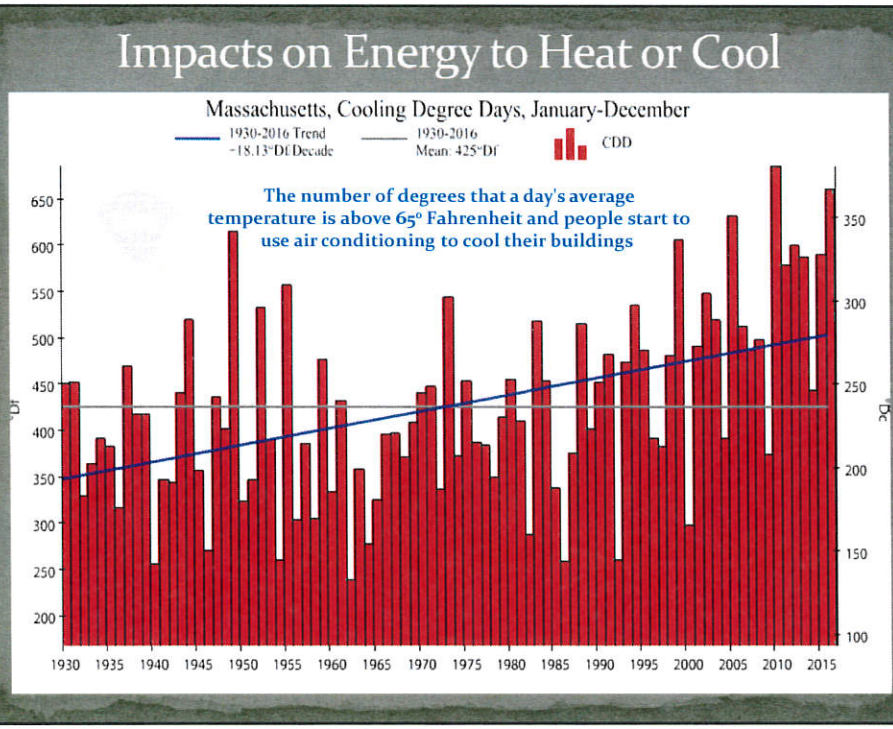
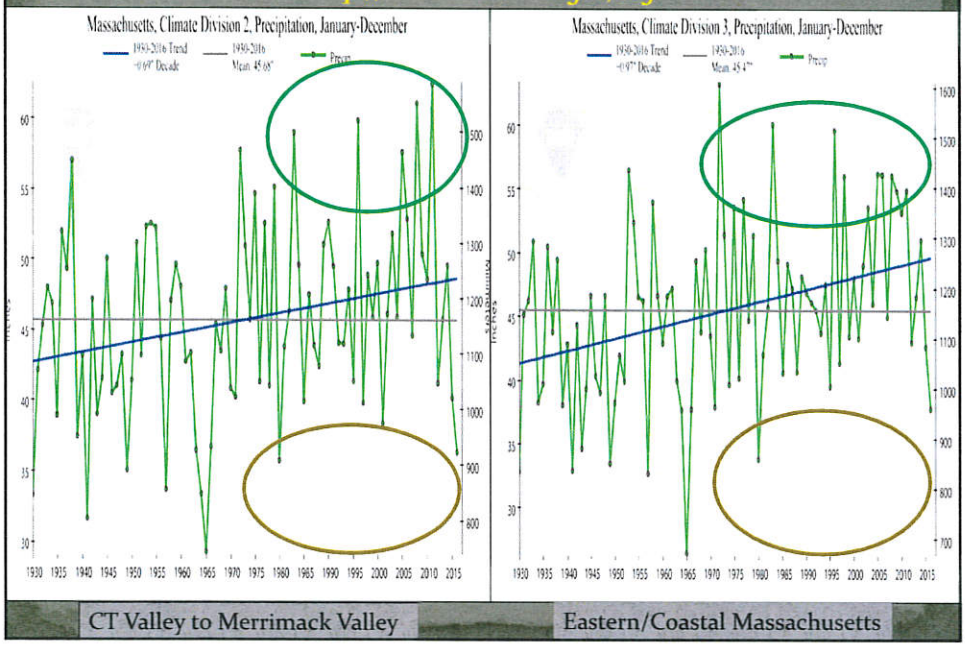


A Look at Precipitation Trends

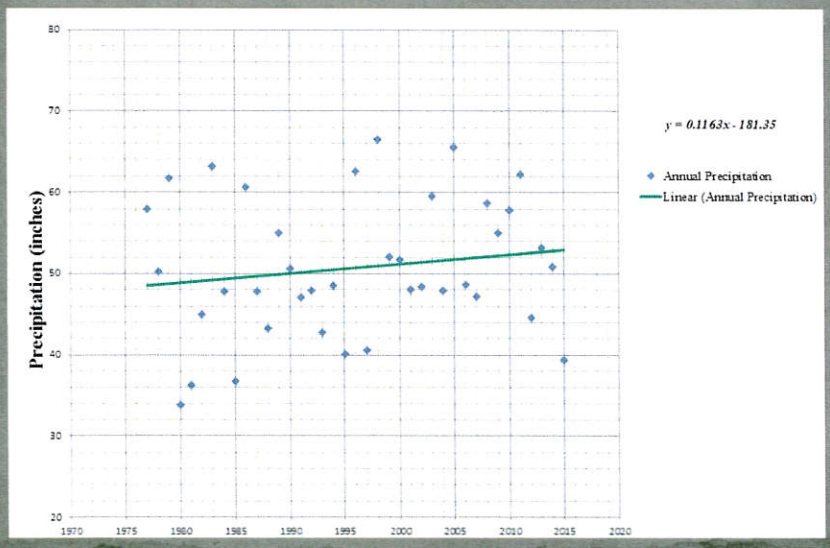
http://www.ncdc.noaa.gov/cag



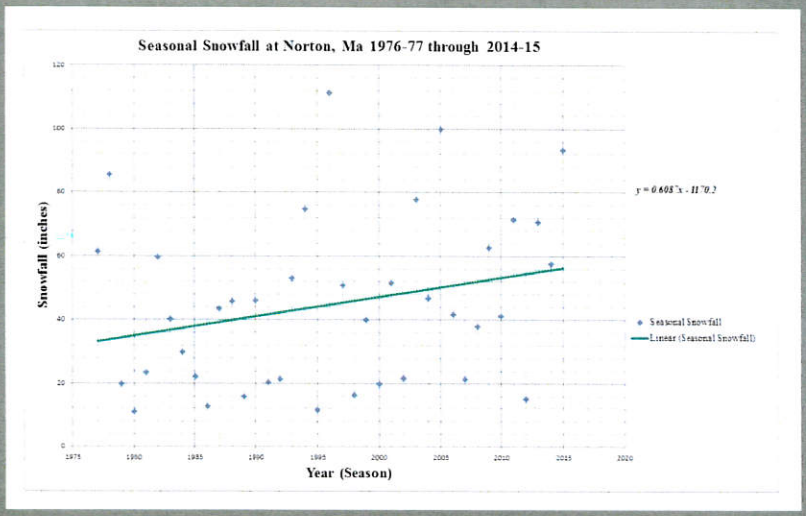
CT Valley to Merrimack Valley

Eastern/Coastal Massachusetts

Norton Perspective on Precipitation

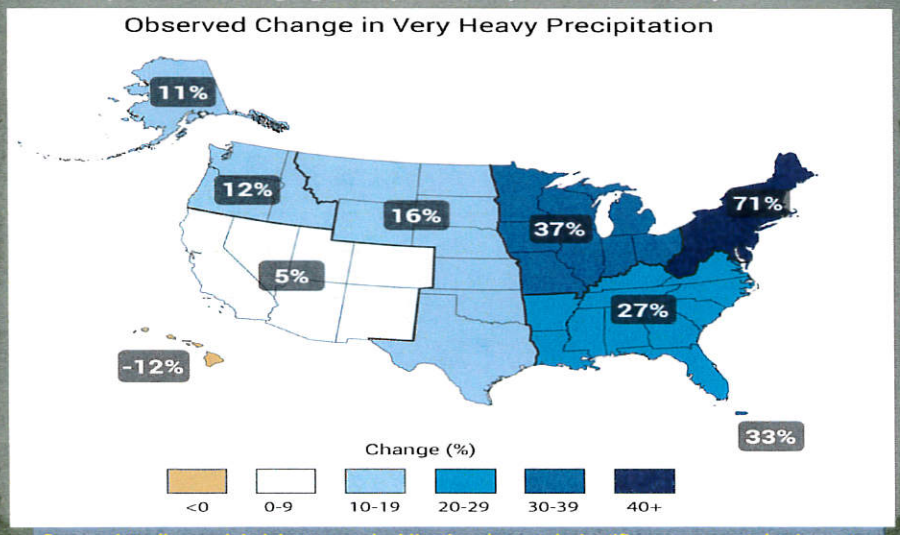


Norton Perspective on Snowfall

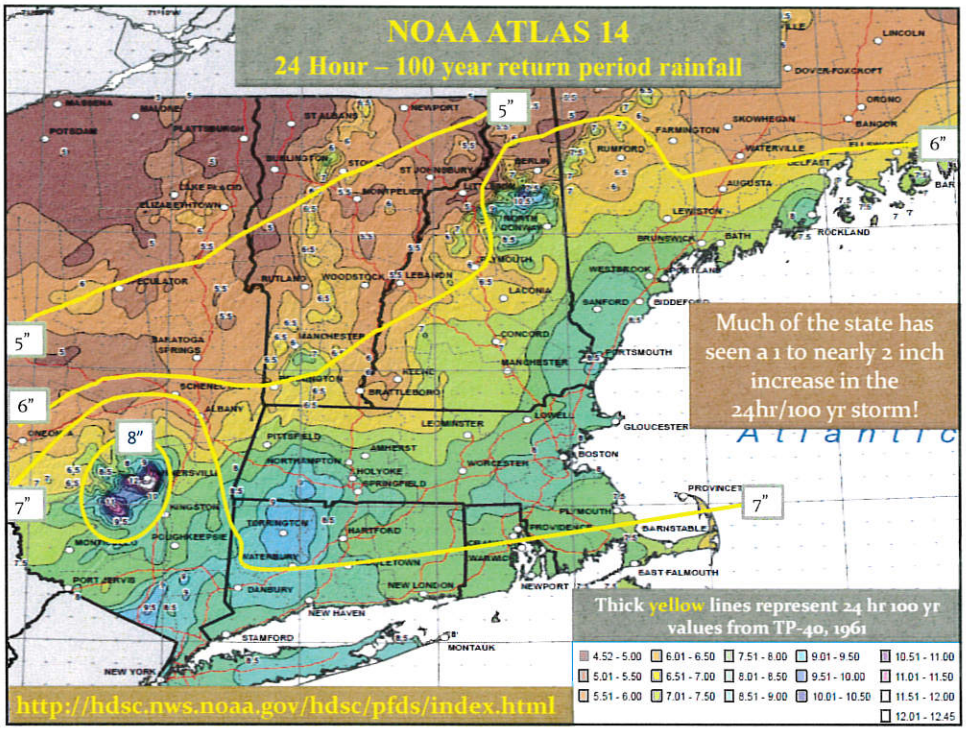


Change in frequency of Heavy Precipitation

- Intense precipitation events (the heaviest 1%)
- Used to average 6-8 days a year of >1" of rain or more
- Today we are averaging nearly 12-15 days! (Norton 14 days)



Source: http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts



Norton Perspective on Heavy Rain events

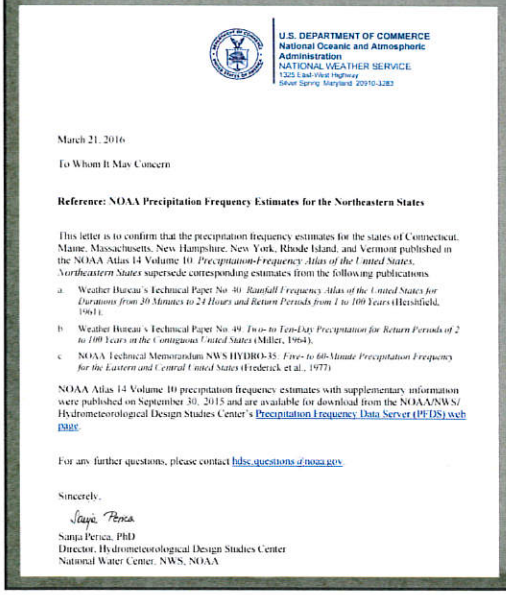
PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)								
	1	2	5	10	25	50	100	200	500	1000
5-min	0.307 (0.247-0.375)	0.380 (0.305-0.464)	0.498 (0.399-0.612)	0.597 (0.475-0.737)	0.732 (0.563-0.950)	0.837 (0.629-1.11)	0.941 (0.686-1.30)	1.09 (0.740-1.53)	1.29 (0.837-1.87)	1.44 (0.909-2.13)
10-min	0.435 (0.350-0.531)	0.538 (0.433-0.658)	0.706 (0.566-0.866)	0.845 (0.673-1.04)	1.04 (0.797-1.35)	1.19 (0.891-1.57)	1.33 (0.972-1.85)	1.54 (1.05-2.17)	1.82 (1.19-2.65)	2.04 (1.29-3.01)
15-min	0.511 (0.412-0.625)	0.633 (0.509-0.774)	0.830 (0.666-1.02)	0.995 (0.792-1.23)	1.22 (0.938-1.58)	1.40 (1.05-1.85)	1.57 (1.14-2.17)	1.82 (1.23-2.55)	2.15 (1.39-3.11)	2.39 (1.51-3.54)
30-min	0.715 (0.576-0.873)	0.887 (0.714-1.08)	1.17 (0.937-1.44)	1.40 (1.12-1.73)	1.72 (1.32-2.24)	1.97 (1.48-2.62)	2.22 (1.62-3.07)	2.57 (1.75-3.60)	3.04 (1.97-4.41)	3.39 (2.09-5.01)
60-min	0.918 (0.740-1.12)	1.14 (0.919-1.40)	1.51 (1.21-1.85)	1.81 (1.44-2.23)	2.23 (1.71-2.89)	2.55 (1.92-3.38)	2.87 (2.09-3.97)	3.33 (2.26-4.66)	3.93 (2.55-5.70)	4.38 (2.77-6.48)
2-hr	1.17 (0.946-1.41)	1.47 (1.20-1.79)	1.98 (1.60-2.41)	2.40 (1.92-2.94)	2.97 (2.30-3.83)	3.42 (2.59-4.51)	3.86 (2.84-5.31)	4.51 (3.08-6.26)	5.37 (3.51-7.71)	6.02 (3.83-8.81)
3-hr	1.35 (1.10-1.64)	1.71 (1.39-2.07)	2.30 (1.86-2.79)	2.79 (2.24-3.40)	3.46 (2.69-4.43)	3.97 (3.02-5.22)	4.49 (3.32-6.15)	5.25 (3.60-7.25)	6.26 (4.10-8.93)	7.02 (4.49-10.2)
6-hr	1.78 (1.46-2.14)	2.22 (1.82-2.67)	2.94 (2.40-3.54)	3.53 (2.86-4.27)	4.34 (3.40-5.52)	4.97 (3.80-6.48)	5.60 (4.15-7.58)	6.50 (4.49-8.88)	7.69 (5.08-10.9)	8.59 (5.52-12.3)
12-hr	2.35 (1.94-2.80)	2.85 (2.35-3.40)	3.67 (3.02-4.39)	4.35 (3.55-5.23)	5.29 (4.16-6.64)	6.01 (4.62-7.71)	6.73 (5.00-8.96)	7.69 (5.35-10.4)	8.97 (5.97-12.5)	9.94 (6.43-14.1)
24-hr	2.88 (2.40-3.41)	3.47 (2.88-4.11)	4.44 (3.67-5.27)	5.24 (4.31-6.25)	6.34 (5.02-7.90)	7.19 (5.56-9.14)	8.04 (6.01-10.6)	9.17 (6.42-12.3)	10.7 (7.14-14.7)	11.8 (7.68-16.6)
2-day	3.27 (2.74-3.84)	3.99 (3.34-4.69)	5.17 (4.31-6.10)	6.15 (5.09-7.29)	7.50 (5.98-9.28)	8.54 (6.66-10.8)	9.58 (7.24-12.6)	11.0 (7.77-14.6)	13.0 (8.73-17.7)	14.4 (9.46-20.1)

4.7"

NRNM3 - Norton Coop Station 2016

NOAA Atlas-14 Replaces TP-40



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
1325 East-West Highway
Silver Spring, Maryland 20910-3283

March 21, 2016

To Whom It May Concern

Reference: NOAA Precipitation Frequency Estimates for the Northeastern States

This letter is to confirm that the precipitation frequency estimates for the states of Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont published in the NOAA Atlas 14 Volume 10 *Precipitation-Frequency Atlas of the United States, Northeastern States* supersede corresponding estimates from the following publications

a. Weather Bureau's Technical Paper No 40 *Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years* (Hershfield, 1961).

b. Weather Bureau's Technical Paper No 49 *Two- to Ten-Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States* (Miller, 1964).

c. NOAA Technical Memorandum NWS HYDRO-35 *Five- to 60-Minute Precipitation Frequency for the Eastern and Central United States* (Frederick et al., 1977)

NOAA Atlas 14 Volume 10 precipitation frequency estimates with supplementary information were published on September 30, 2015 and are available for download from the NOAA/NWS/ Hydrometeorological Design Studies Center's Precipitation Frequency Data Server (PFDS) web page.

For any further questions, please contact hdsc.questions@noaa.gov

Sincerely,

Sanja Perica

Sanja Perica, PhD
Director, Hydrometeorological Design Studies Center
National Water Center, NWS, NOAA

NOAA Atlas-14 Northeast

http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ma

Norton Historic Rainfall Information (1913-2016)

https://www.ncdc.noaa.gov/IPS/coop/coop.html?_page=2&state=MA&foreign=false&selectedCoopId=195984&_target3=Next+%3E

Norton Rainfall Data using NOAA Atlas-14

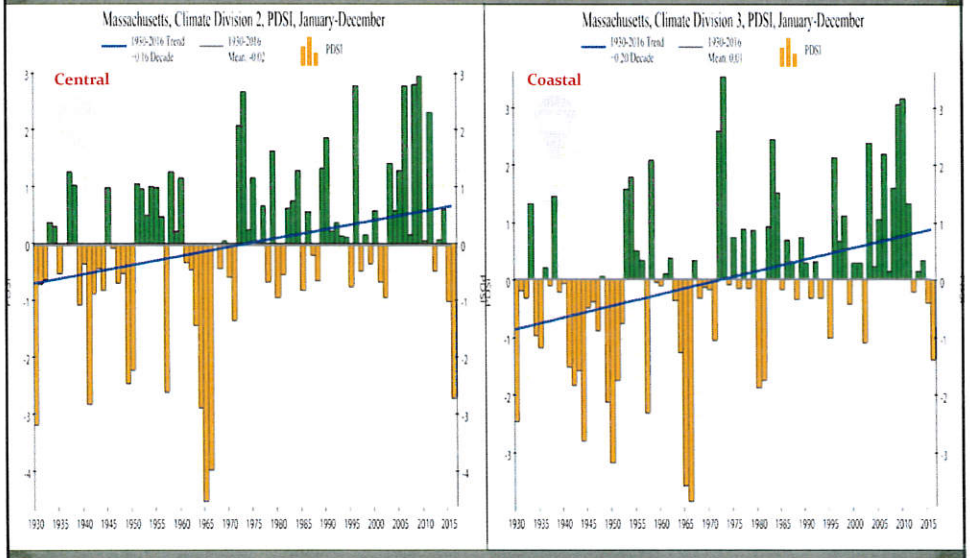
http://hydromet.weebly.com/1hr-rainfall.html

Norton Current Weather Information

http://hydromet.weebly.com/

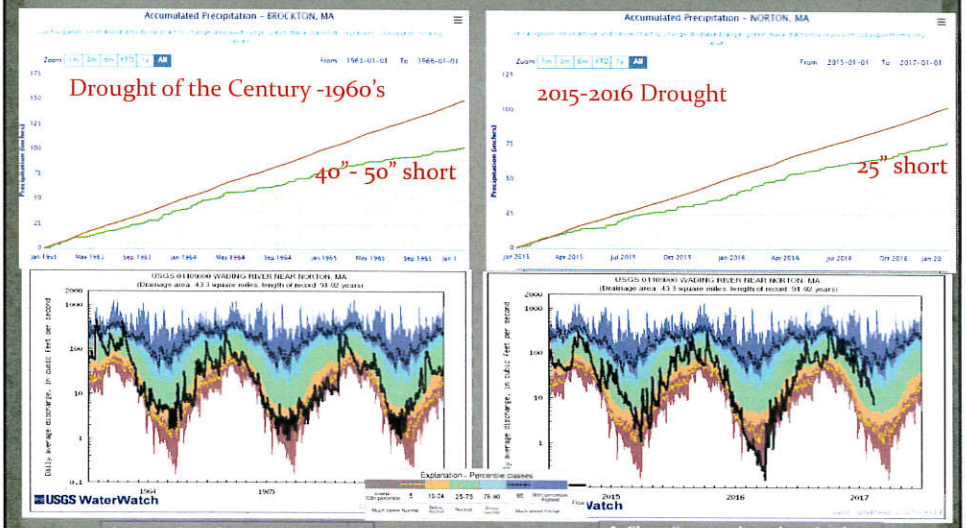
Changes in the Palmer Drought Index

http://www.ncdc.noaa.gov/cag



Since the late 60s, similar signature of much shorter, mostly less intense dry periods and longer higher amplitude wet periods

Drought/Rainfall characteristics

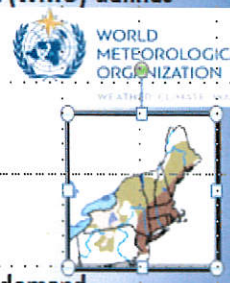


- Droughts of yesteryear:
  - 1964-66
- Prolonged record lows
  - Infrequent periods of recharge
  - But far longer in duration with little significant recharge

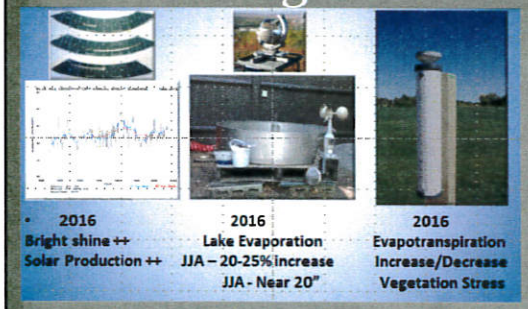
- Short/intense drought episodes:
  - 2014 and 2015
- Record daily flows
  - Minimums similar to the 1960s drought!
  - But…very short duration with frequent episodes of significant recharge if not flood volumes

Drought – many ways to define it!

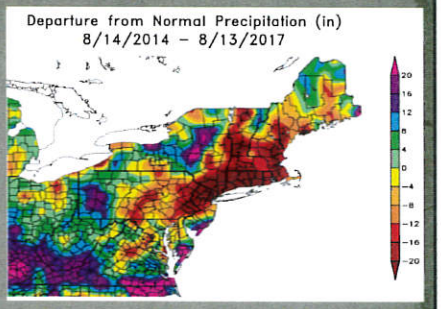
- **The World Meteorological Organization (WMO) defines different types of drought:**
  - **Meteorological**
  - **Climatological**
  - **Atmospheric**
  - **Agricultural**
  - **Hydrologic**
  - **Socioeconomic – i.e. Water supply and demand**
- ***"Drought is a normal, recurrent feature of climate, although it is erroneously considered as a rare and random event"***



Water Budget Concerns

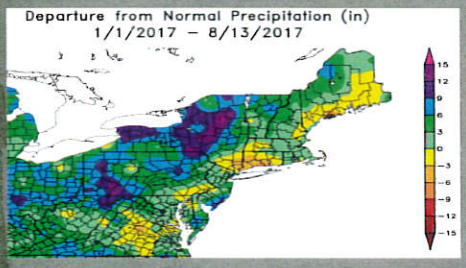


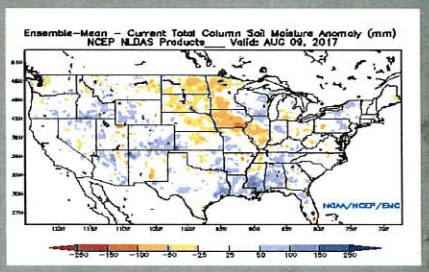
- 2016 Bright shine ++ Solar Production ++
- 2016 Lake Evaporation JJA – 20-25% increase JJA - Near 20"
- 2016 Evapotranspiration Increase/Decrease Vegetation Stress

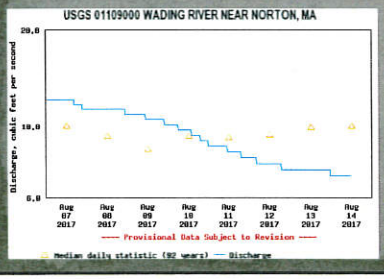


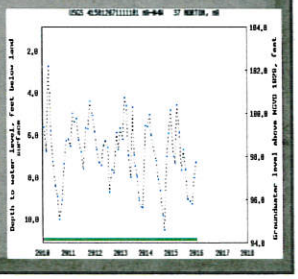
- But.....with Normal Precip of +50"/yr.....
- -25" goes to streamflow to the Atlantic
- -25" goes to ET/+Evaporation/GW/Sub (usage/diversion)
- Almost all got short-changed in 2016
- Now drought indices are "Normal" or above
- Weather pattern and water usage "key" during "AG" YR

Current conditions -- Norton

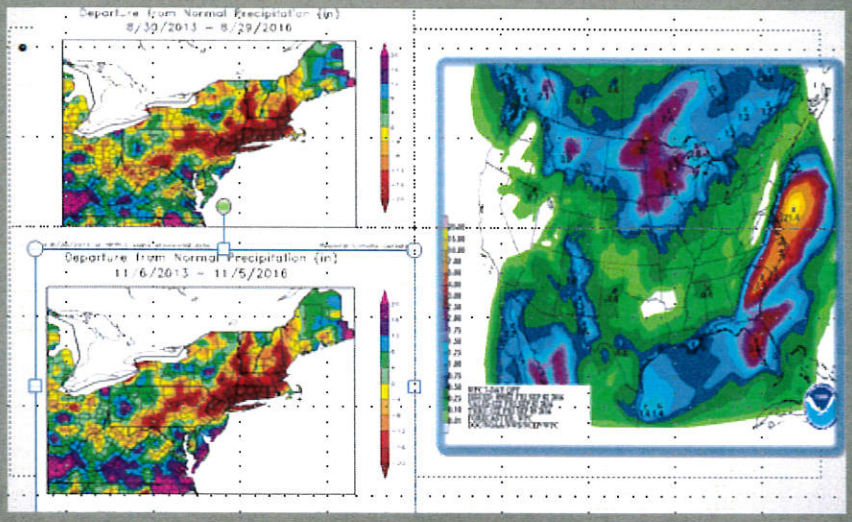




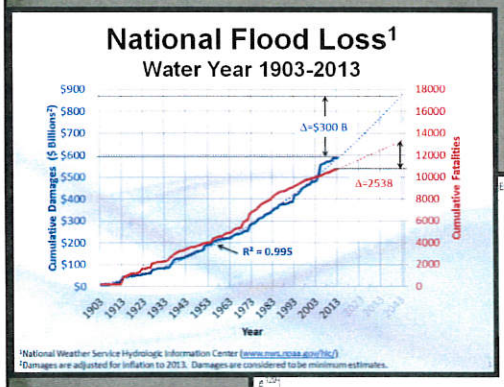


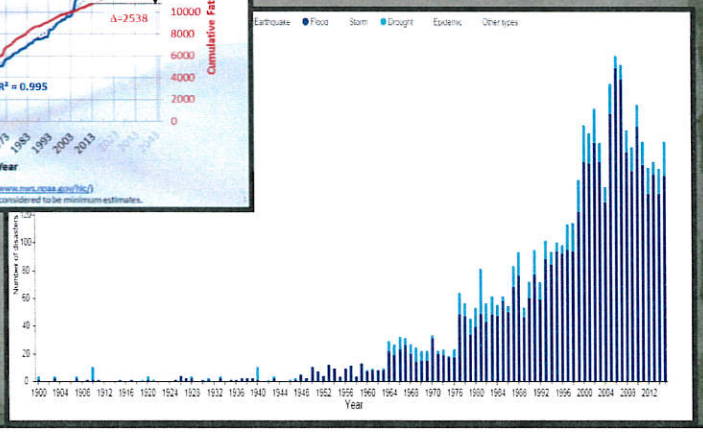


Do all Droughts end with a Flood? Fact or Folklore



Nationally – increased flood events/losses





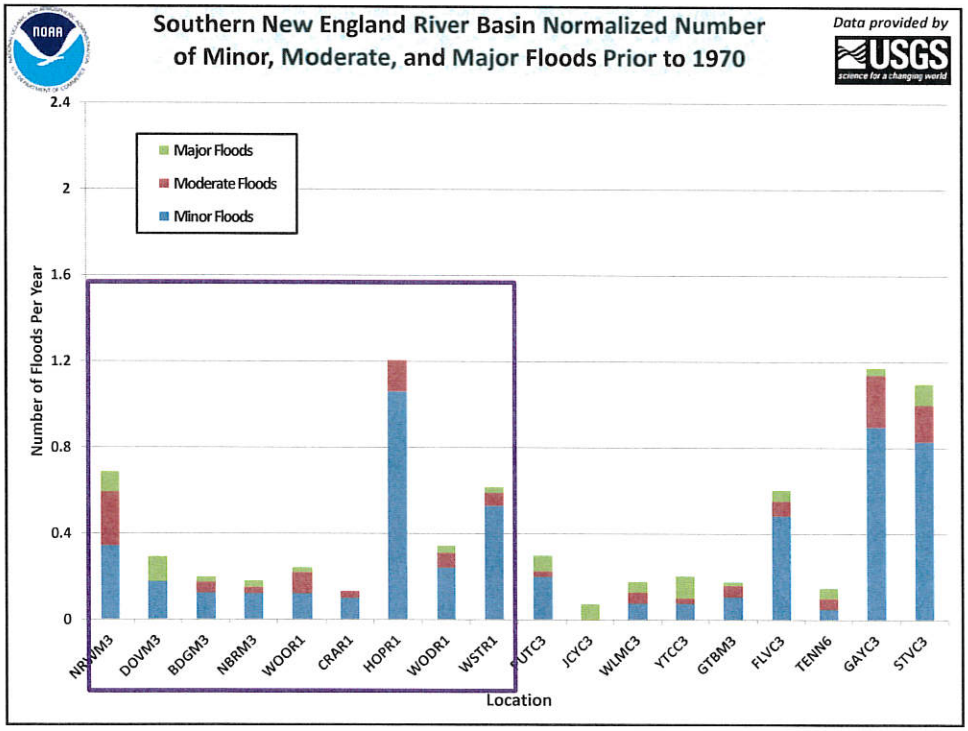
Trends in Flood Frequency:

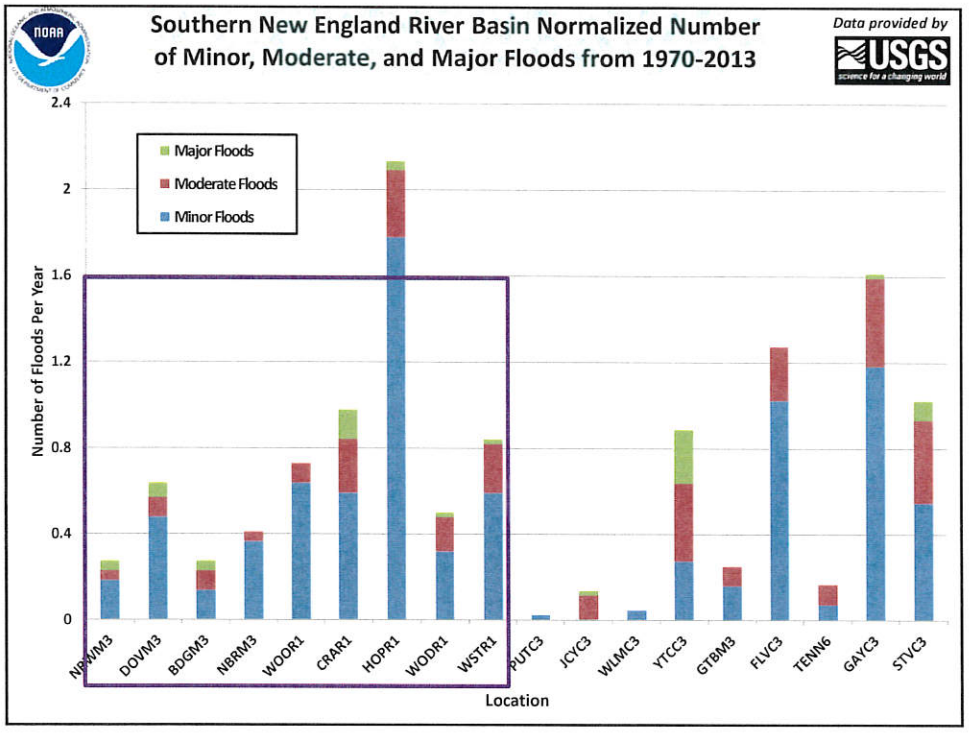
From the Practitioner's perspective

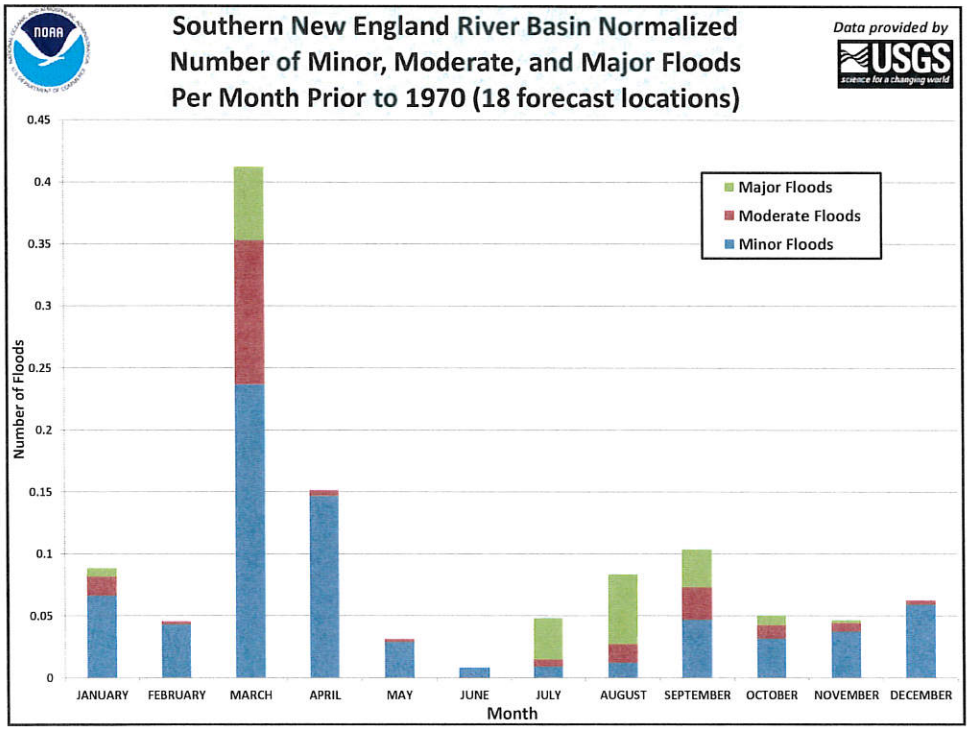
- Small watersheds feeling the effects
  - Changes in frequency/magnitude
  - Part land use/urbanization
    - Compounded by encroachment in the floodplain
  - Part changing climate
- Larger basins with flood control haven't seen as noticeable a shift
  - Most USACE reservoirs are built for 6-8 inch runoff events
  - Greater capacity to handle more rain
- Urban "flash floods" increasing
  - Storm water systems cannot handle the volume of intense rainfall

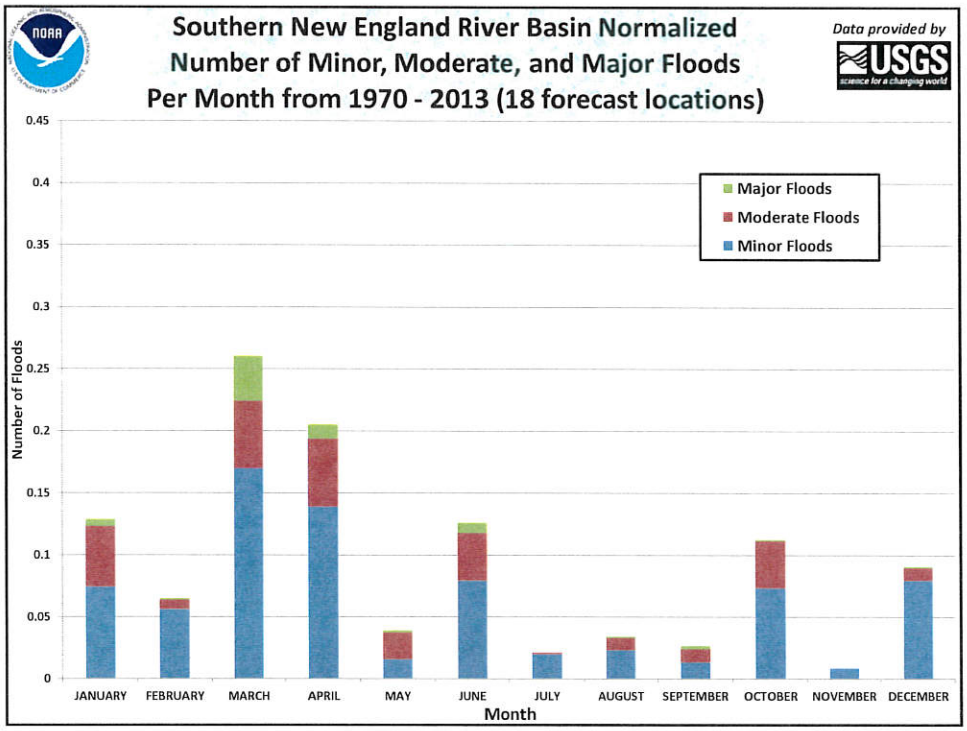
Record flooding during Mother's Day Floods; 5/16/06. Photo: Boston Globe

Flooding from the Concord River along Elsie Ave., in Billerica, MA. April 2nd, 2014. Photo: Billerica DPW




Southern New England River Basin Normalized Number of Minor, Moderate, and Major Floods from 1970-2013
Data provided by USGS
science for a changing world
Major Floods
Moderate Floods
Minor Floods
Number of Floods Per Year
2.4
2
1.6
1.2
0.8
0.4
0
NPWM3
DOVM3
BDGM3
NBRM3
WOOR1
CRAR1
HOPR1
WODR1
WSTR1
PUTC3
JCYC3
WLMC3
YTCC3
GTBM3
FLVC3
TENN6
GAYC3
STVC3
Location


Southern New England River Basin Normalized Number of Minor, Moderate, and Major Floods Per Month Prior to 1970 (18 forecast locations)
Data provided by USGS
science for a changing world
Major Floods
Moderate Floods
Minor Floods
Number of Floods
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
Month


Southern New England River Basin Normalized
Number of Minor, Moderate, and Major Floods
Per Month from 1970 - 2013 (18 forecast locations)
Data provided by
USGS
Major Floods
Moderate Floods
Minor Floods
Number of Floods
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
JANUARY
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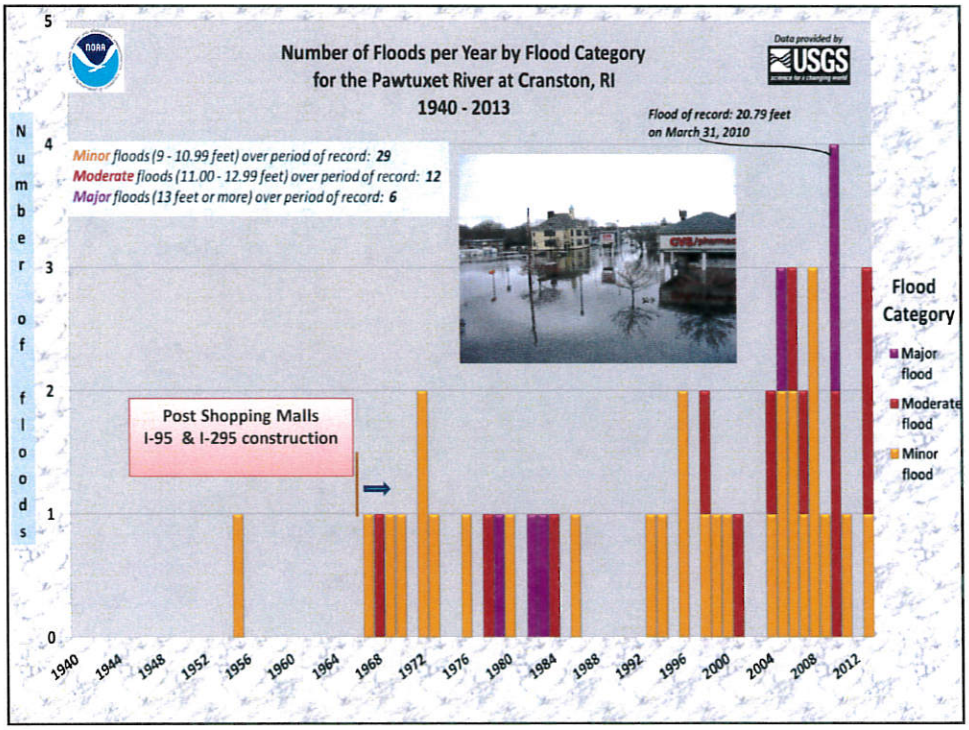
Month


Number of Floods per Year by Flood Category
for the Pawtuxet River at Cranston, RI
1940 - 2013
Data provided by
USGS
Flood of record: 20.79 feet
on March 31, 2010
Minor floods (9 - 10.99 feet) over period of record: 29
Moderate floods (11.00 - 12.99 feet) over period of record: 12
Major floods (13 feet or more) over period of record: 6
Post Shopping Malls
I-95 & I-295 construction
Flood Category
Major flood
Moderate flood
Minor flood
Number of floods
5
4
3
2
1
0
1940
1944
1948
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012

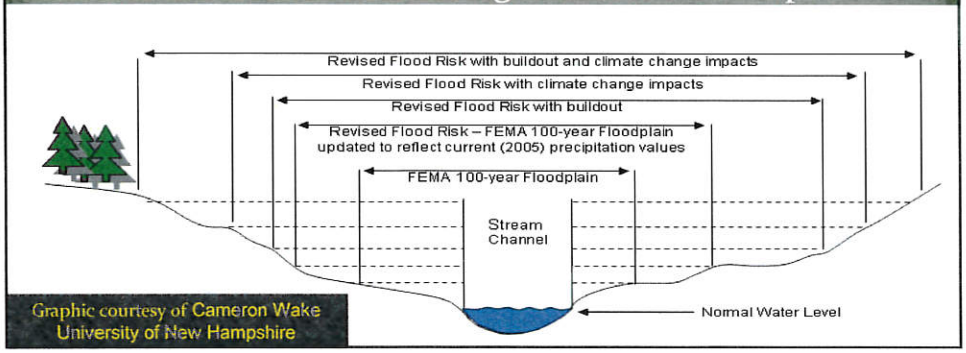
Summary:

- The Northeast has become a "hot spot" for record floods & heavy rainfall in the past 10 years
- Noticeable trends include increased yearly rainfall and increased annual temperatures
  - Portions of Massachusetts have experienced a 1 to 2 inch shift upwards in the 100 yr – 24 hour rainfall
- Smaller watersheds & those with significant urbanization are most vulnerable to increased river & stream flooding
- Drought episodes have become shorter in duration and of a "Flash/Rapid Onset" variety

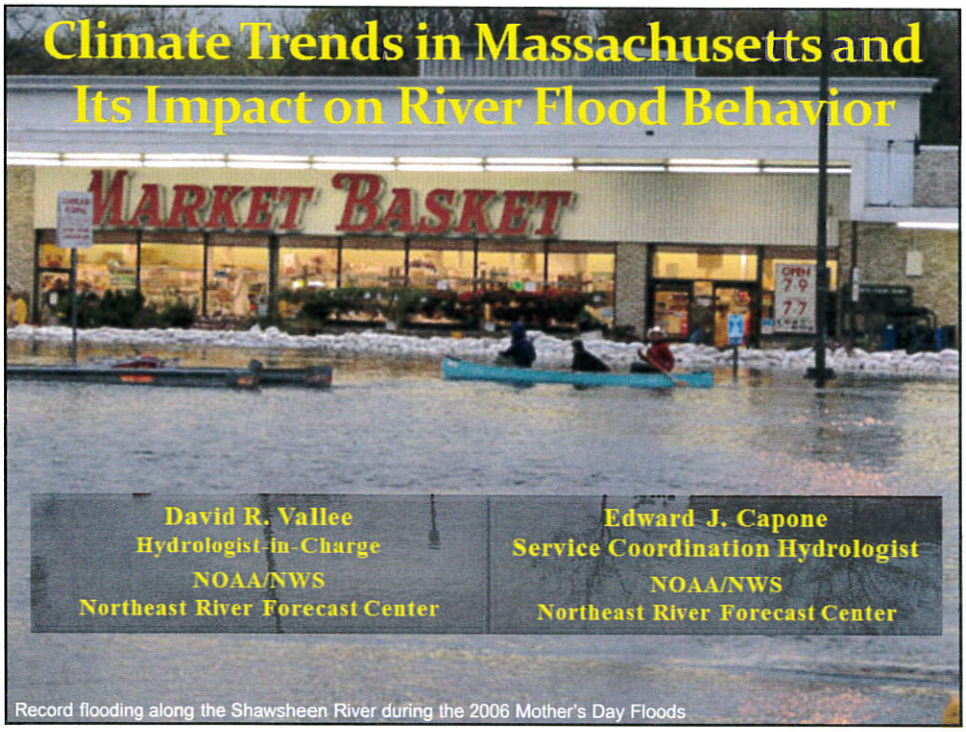
Far reaching implications:

Protect, Adapt or Retreat???

- Floodplain, land use, infrastructure, dam spillway requirements, drainage requirements, non-point source runoff, bridge clearances, "hardening" of critical facilities in the floodplain, property values etc...
- Flood Insurance – work to increase participation
- How much risk are we willing to insure and accept?



Graphic courtesy of Cameron Wake University of New Hampshire


Climate Trends in Massachusetts and Its Impact on River Flood Behavior
MARKET BASKET
David R. Vallee
Hydrologist-in-Charge
NOAA/NWS
Northeast River Forecast Center
Edward J. Capone
Service Coordination Hydrologist
NOAA/NWS
Northeast River Forecast Center
Record flooding along the Shawsheen River during the 2006 Mother's Day Floods