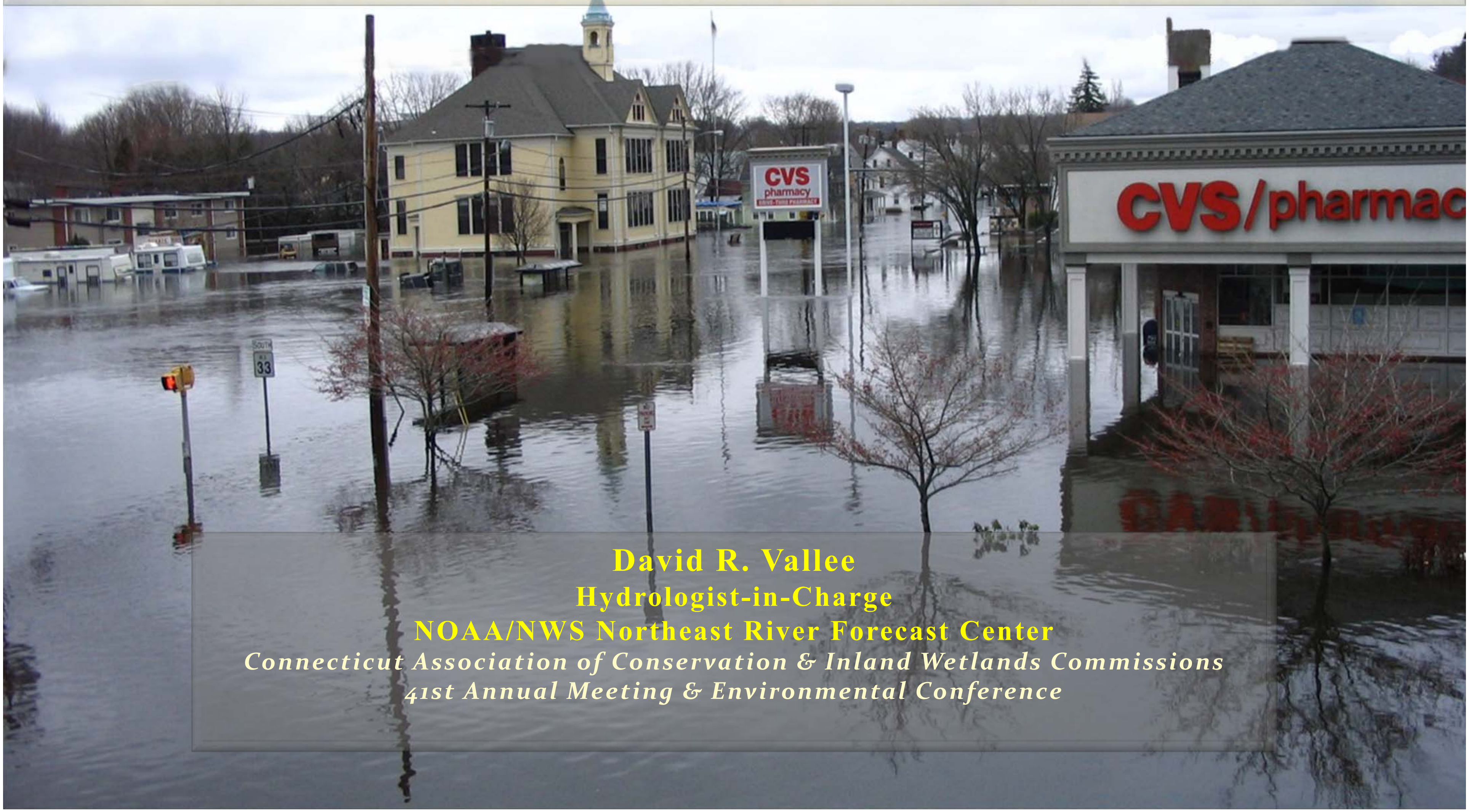
Climate Trends in Connecticut and Its Impact on Storm and Riverine Flood Behavior



David R. Vallee
Hydrologist-in-Charge
NOAA/NWS Northeast River Forecast Center

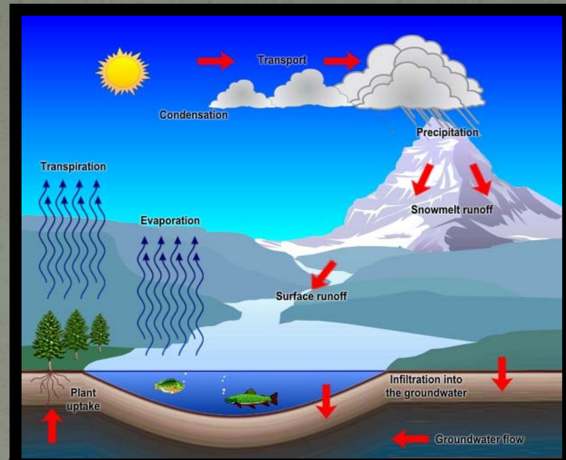
Connecticut Association of Conservation & Inland Wetlands Commissions
41st Annual Meeting & Environmental Conference

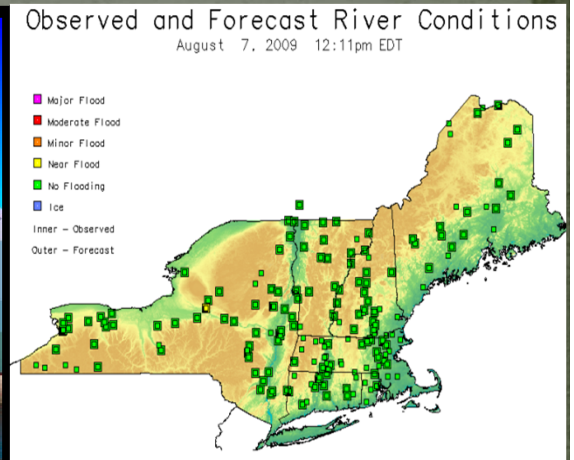
Outline

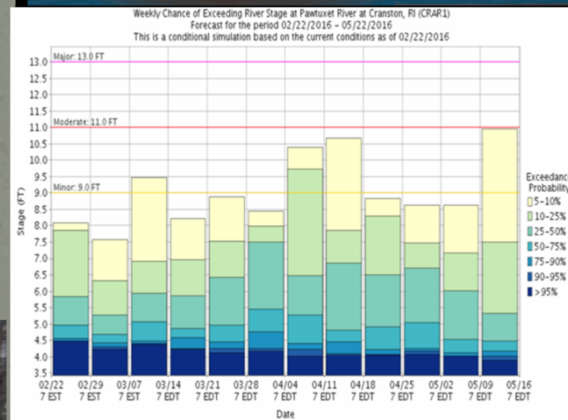
- From a "Practitioner's Perspective"
- Touch upon some of our major flood events of the past 10 years
  - Part I: Big Rainstorms & High Impact Floods
  - Part II: Coastal Storms & Sea Level Rise
- How may a changing climate be impacting flood behavior
  - "Accumulation of Ingredients" – not one single "source"
- The challenge ahead of us?

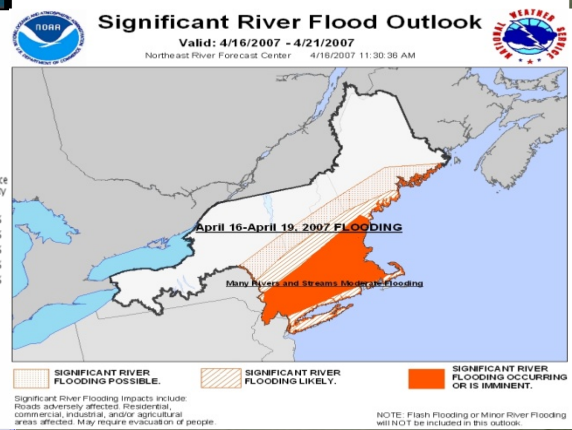
River Forecast Center Responsibilities

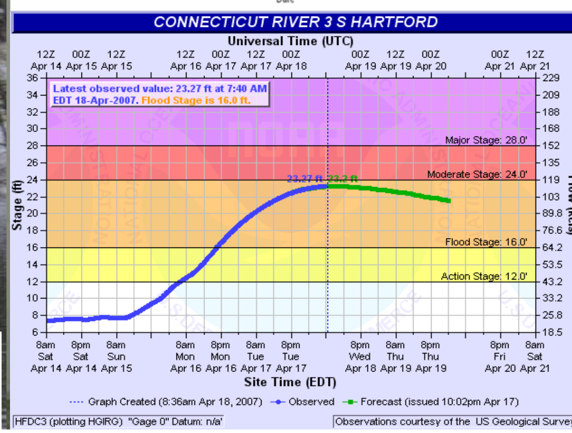
- Calibrate and implement a variety of hydrologic and hydraulic models to provide:
  - River flow and stage forecasts at 180 locations
  - Guidance on the rainfall needed to produce Flash Flooding
  - Ensemble streamflow predictions
  - Ice Jam and Dam Break support
  - Water Supply forecasts
  - Partner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

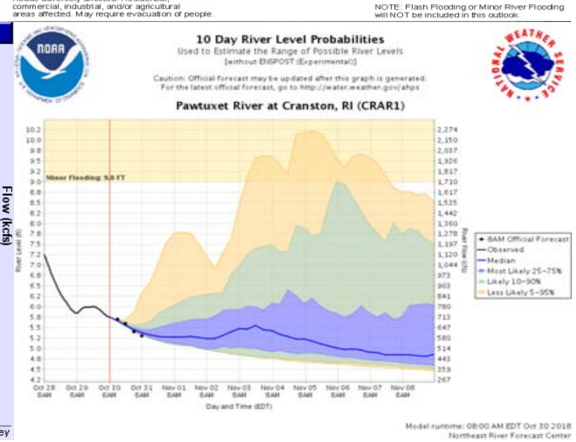








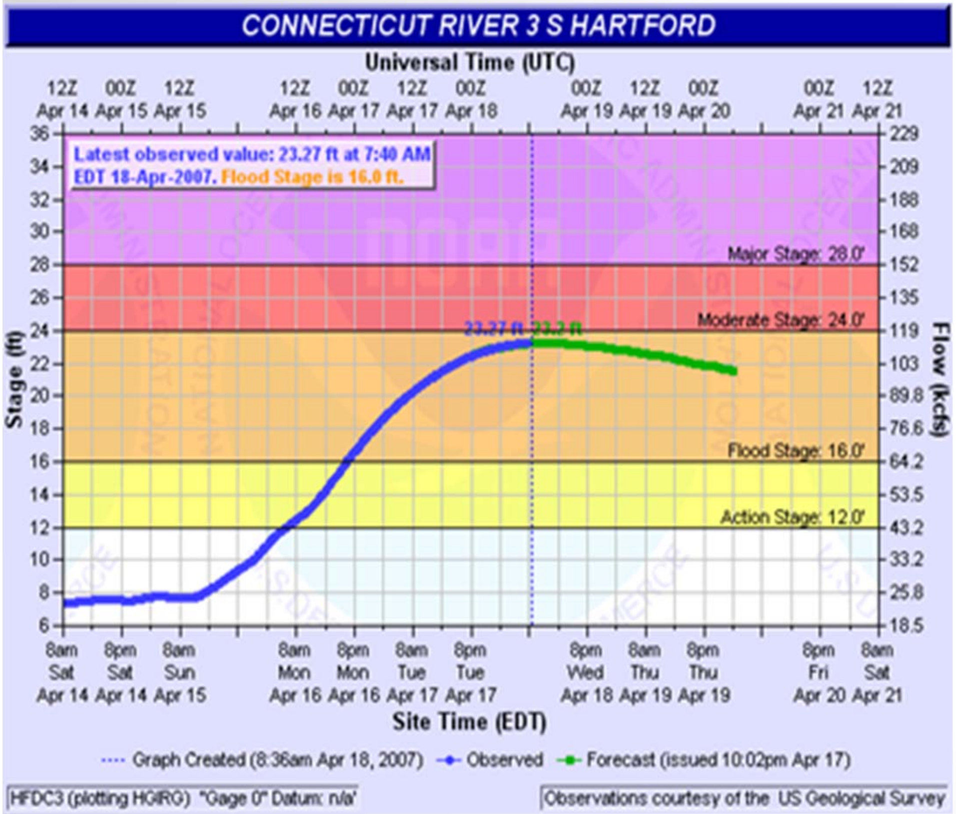


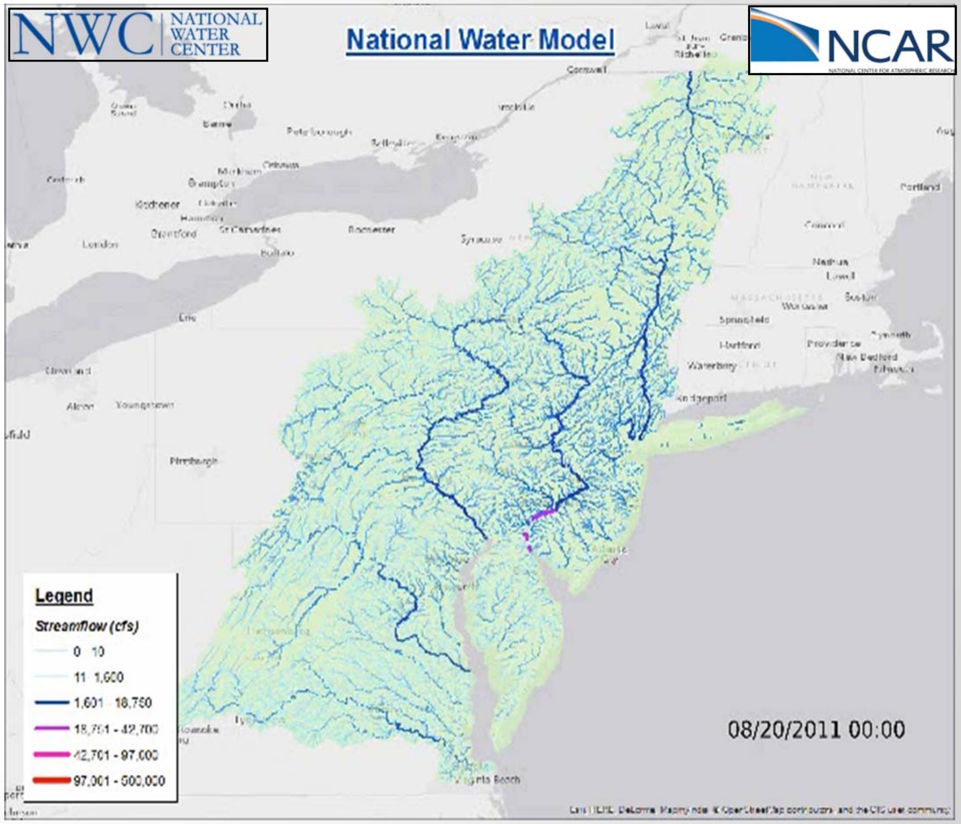



Moderate flooding - Connecticut River at Portland, CT.

A Look At Current & Future Water Prediction Services:

Moving from Point Specific to Street Level Hydrologic Forecasting



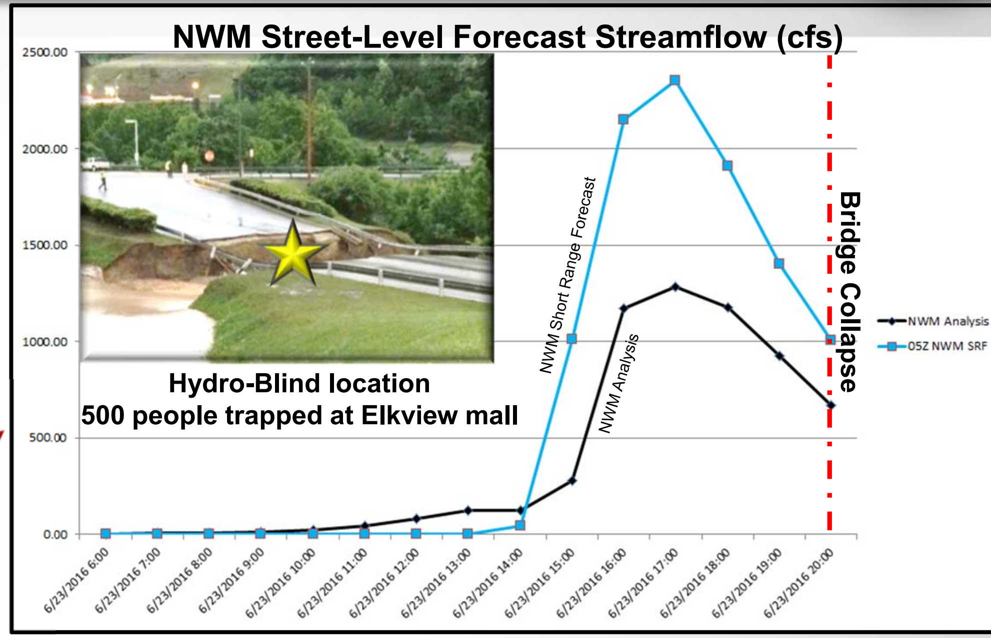


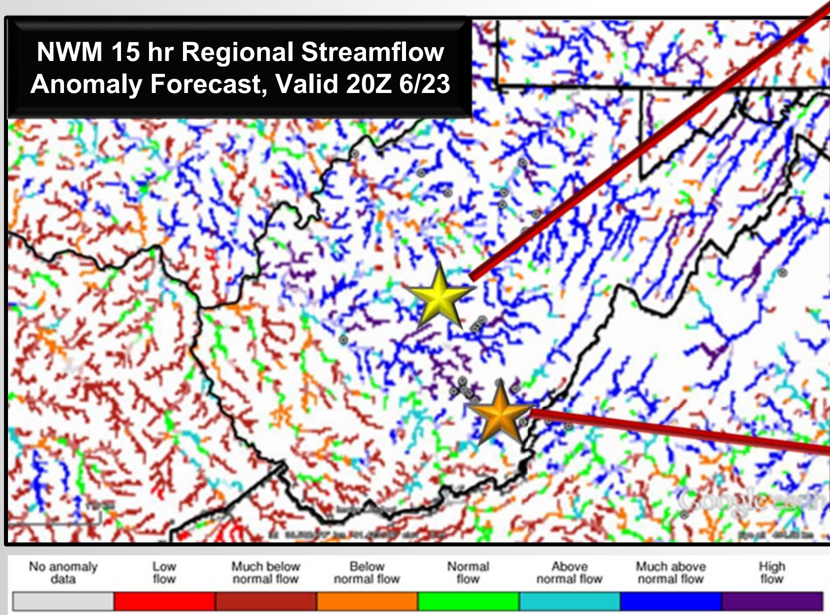
New services to include the Hydrologic Ensemble Prediction System & the new National Water Model

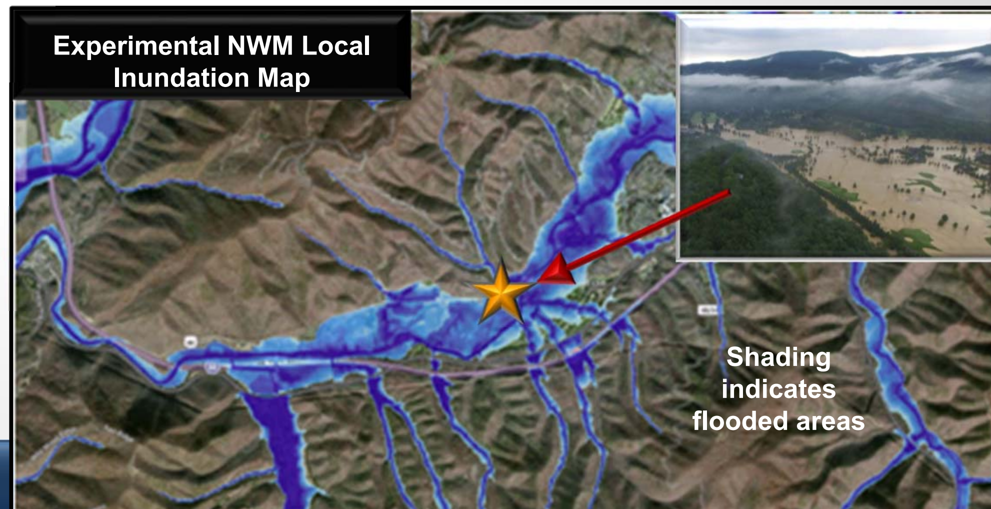
National Water Model

Based Street Level Hydrologic Prediction
Record Setting West Virginia Floods, 6/23/2016

- 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



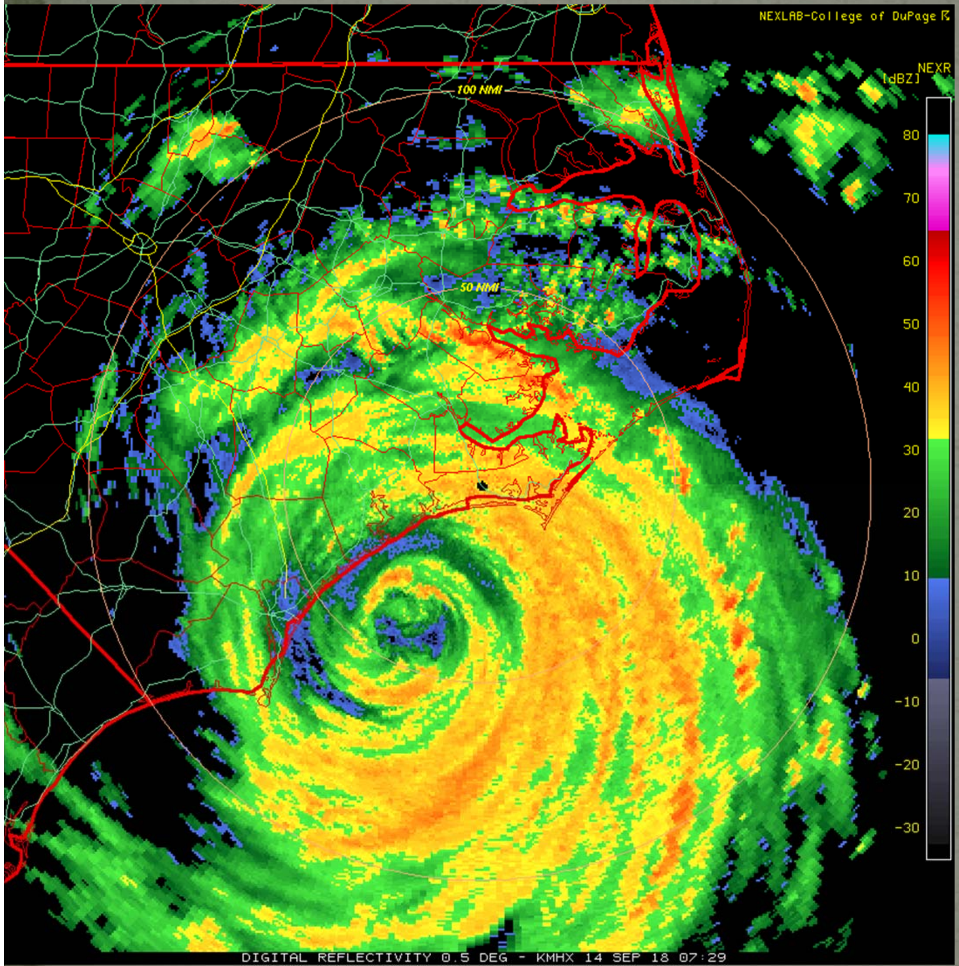


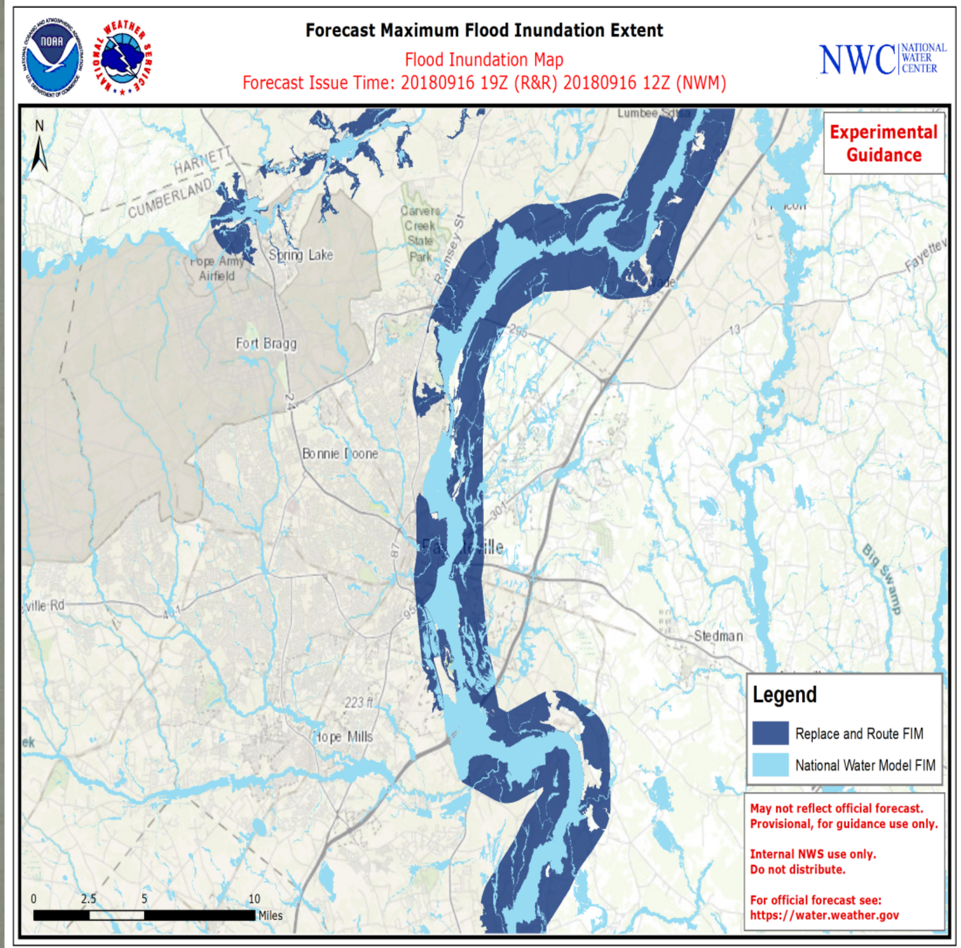


http://www.water.noaa.gov/map

Building a

A very recent example: Florence





Hurricane Florence's Assault on the Carolinas
Radar loop as she approached the coast

Areal extend of flood inundation experimental guidance mapping

We've been a little busy these past 10 years!
The face of changing flood behavior…

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

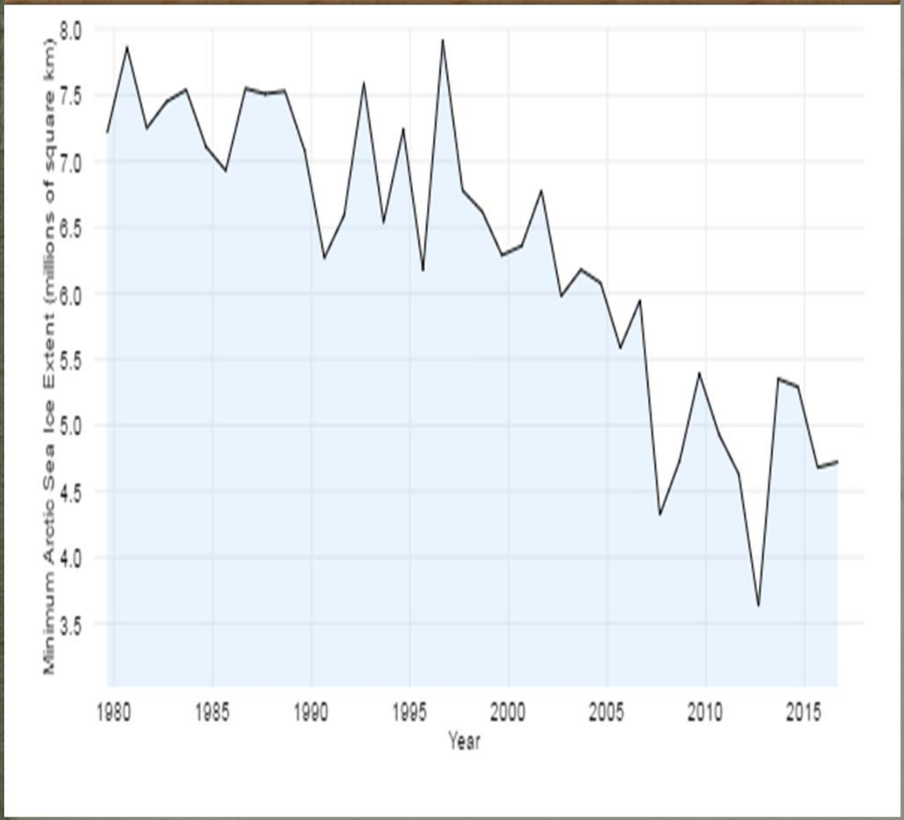
St-Jean-sur-Richelieu, Quebec, Canada, 5/6/11
Photo: AP//Canadian Press, R. Remoirz

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

Damage along Schoharie Creek, Prattsville, NY – T.S. Irene, Photo: J. Vielkind / Times Union

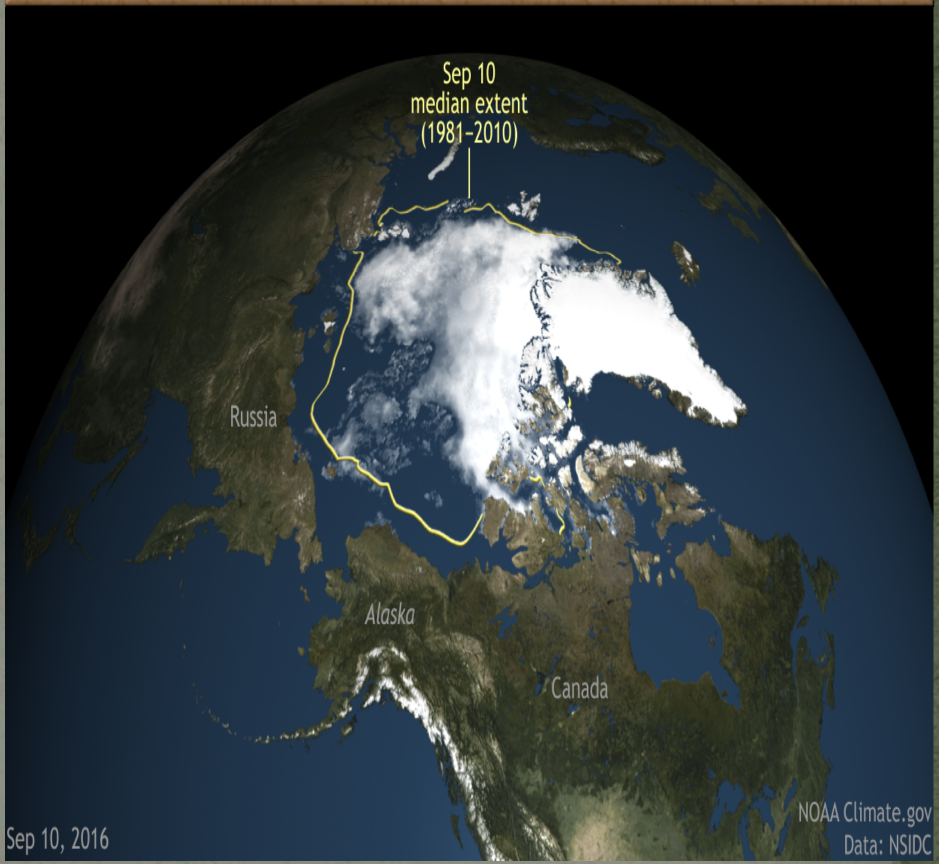
A warming planet and shrinking Arctic Sea ice

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.

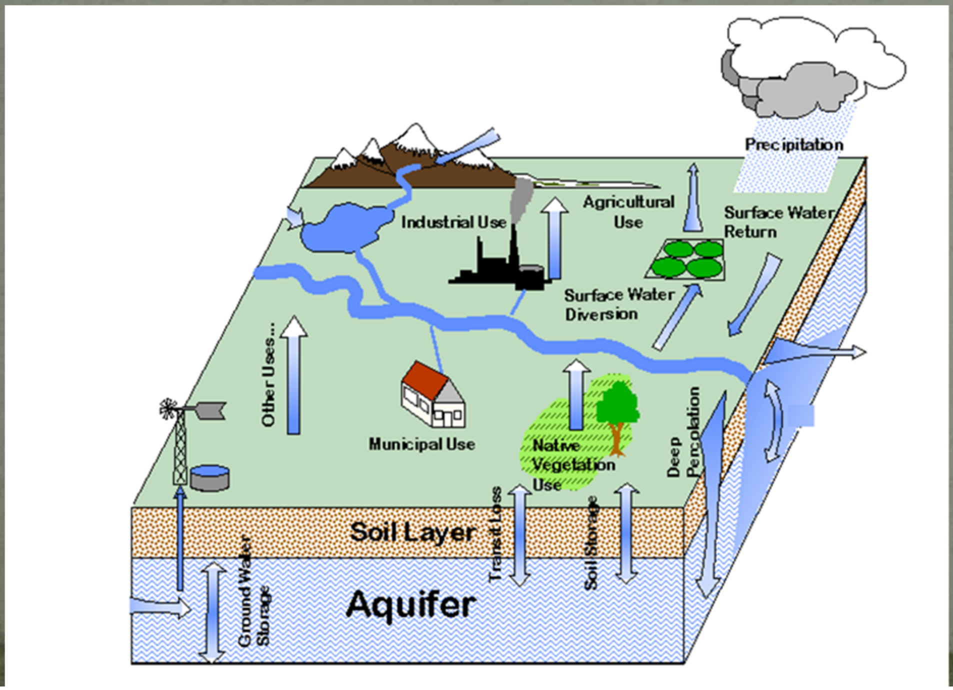
2016 Arctic Sea Ice Summer Minimum

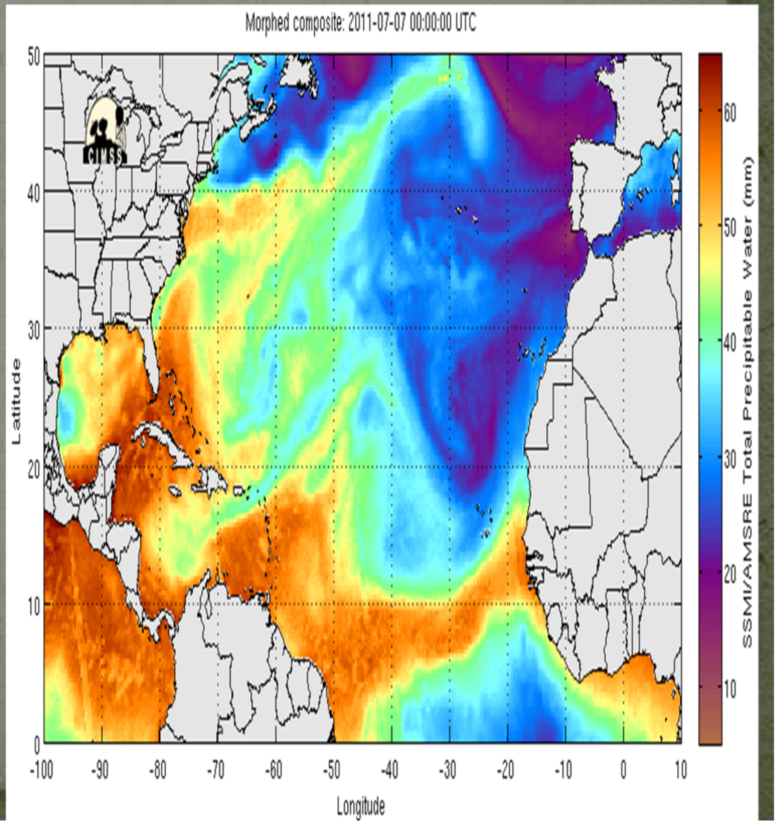


Arctic sea ice concentration on the date of the 2016 minimum extent, September 10, 2016. NOAA Climate.gov image based on NOAA and NASA satellite data from NSIDC.

Is there a common theme to recent floods?

- Several:
  - Slow moving weather systems – a blocked up atmosphere
    - Related to loss of artic ice cover
    - Multiple events in close succession or one big slow moving storm
  - Results in saturated antecedent conditions before "main event"
  - Each fed by a "tropical connection"
    - Plumes of deep moisture





The Changing Climate

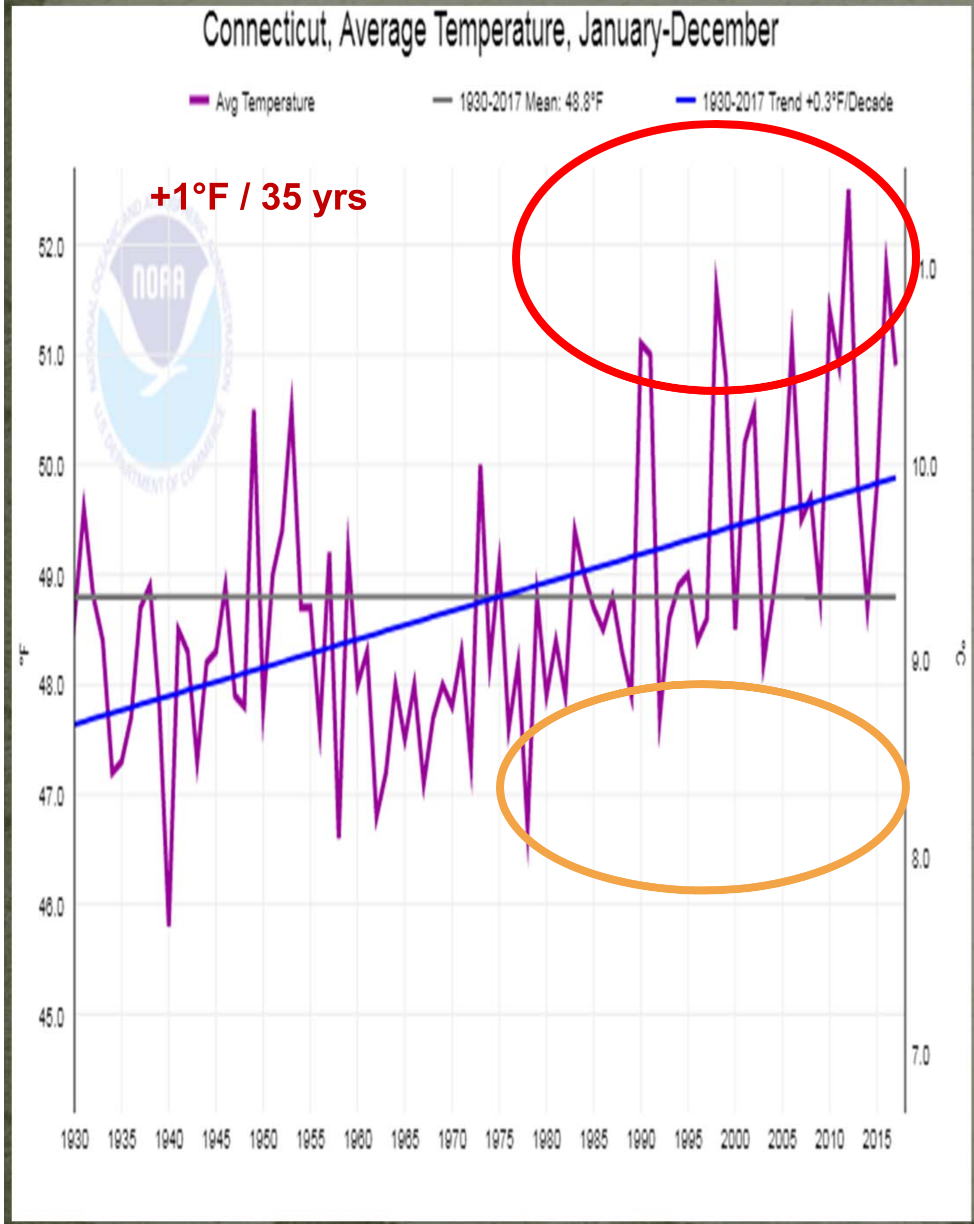
- Common themes in Connecticut:
  - Significant warming trend in annual temperatures
  - Increasing annual precipitation
  - Increasing frequency of heavy rains
  - Increased variability between dry and wet extremes
  - Shift in precipitation frequency
- Trend toward increased flood magnitude and/or frequency
  - Most pronounced where significant land use change and/or urbanization has occurred
  - More pronounced in smaller river basins and basins without flood control reservoirs

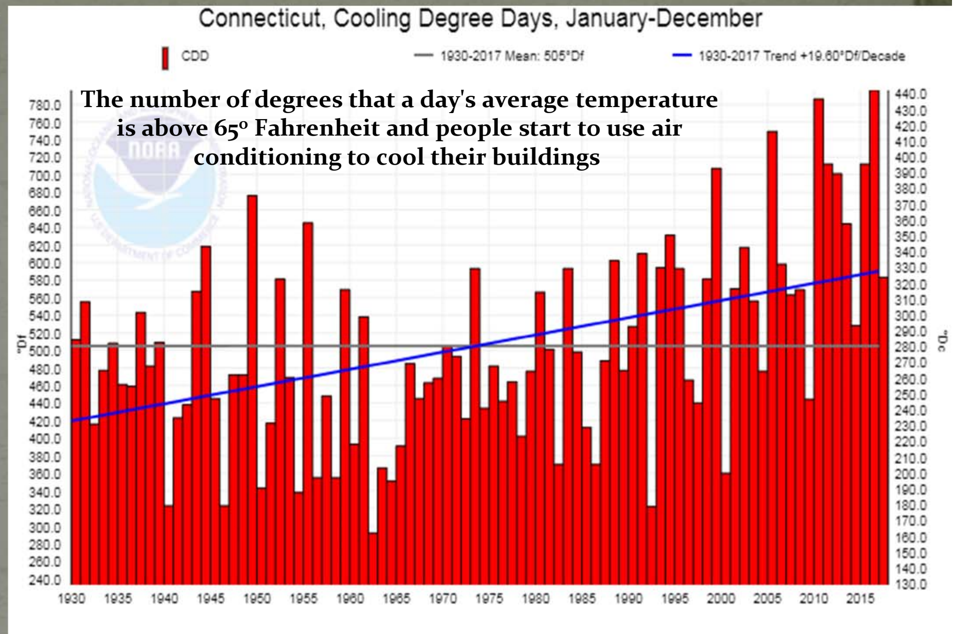
Residents are rescued from their homes by boat along flooded Pawcatuck River , Westerly RI, on March 30, 2010. Photo: www.theday.com

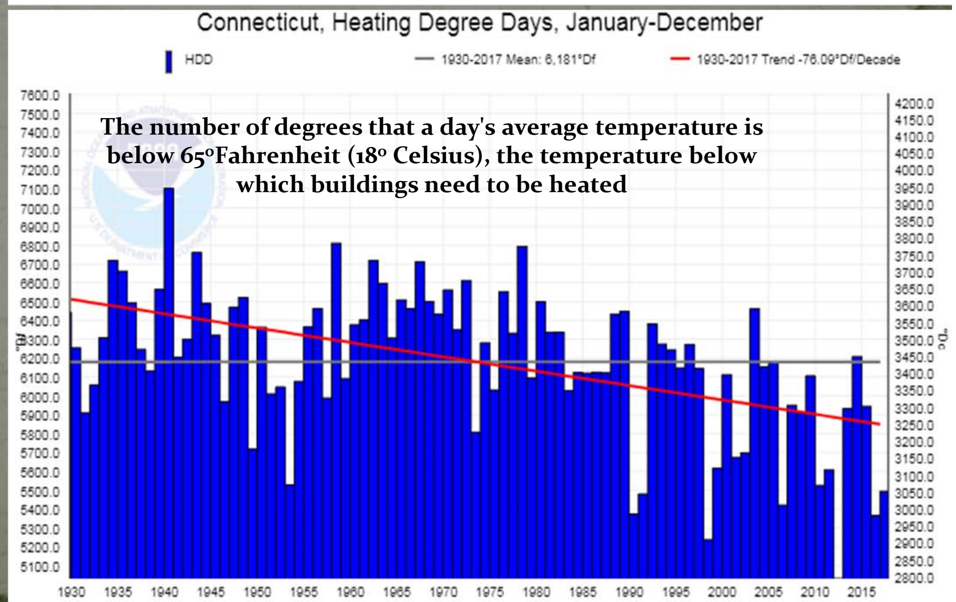
Major flooding along Route 7 from the Housatonic River in New Milford, CT on March 11, 2011. Source: Ctcameraeye.com

A Look at Temperature Trends

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

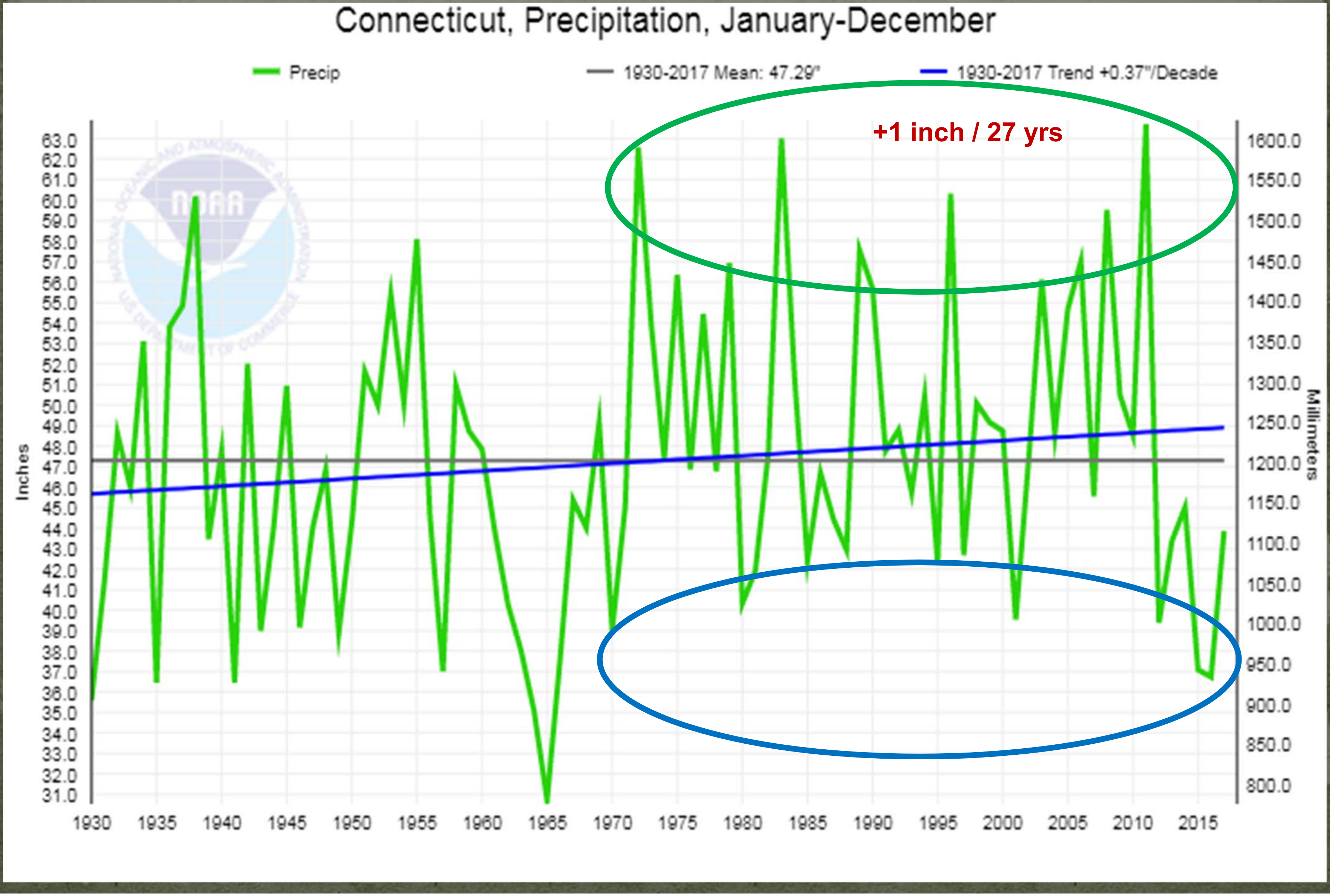






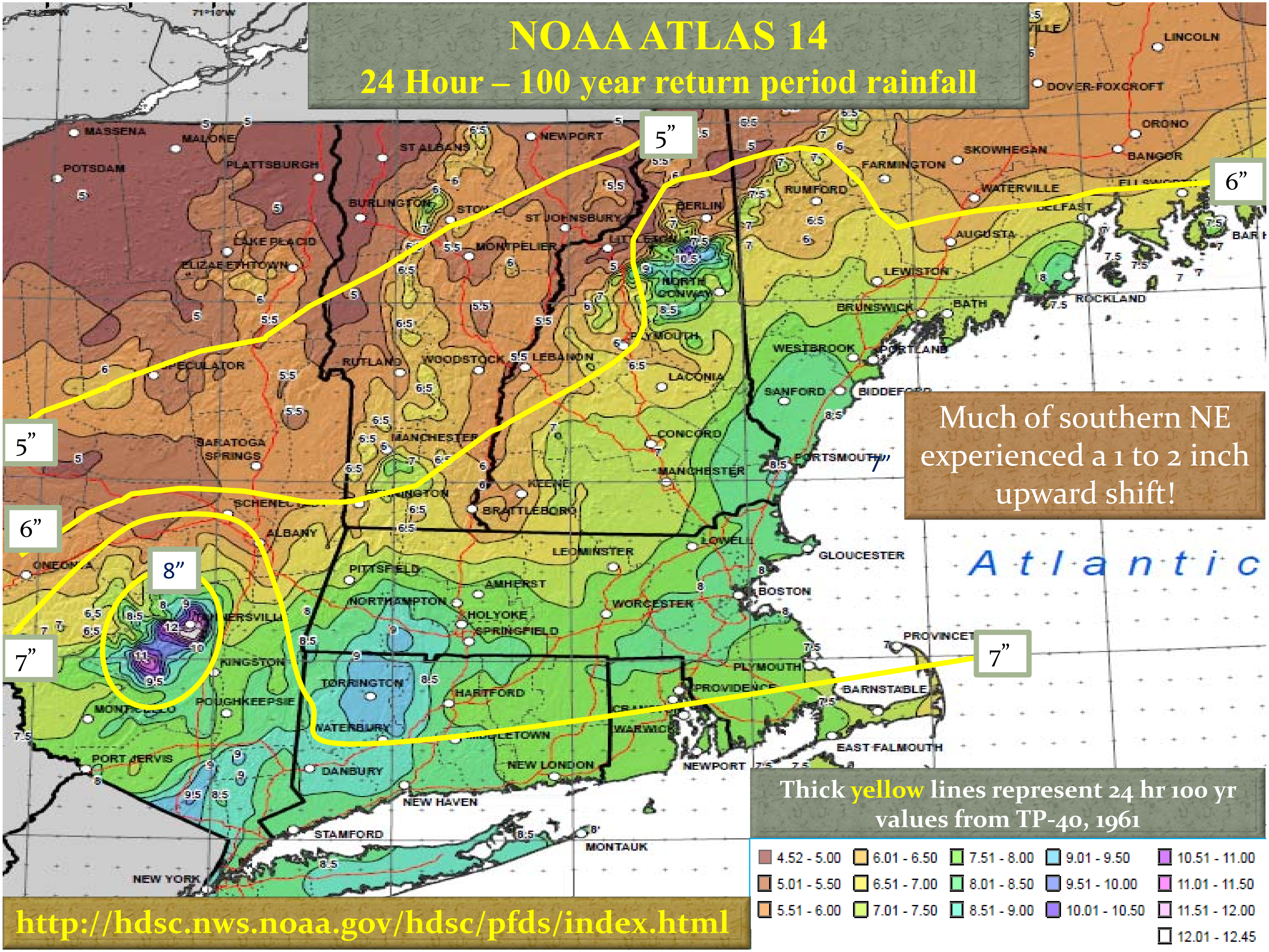
A Look at Precipitation Trends

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



NOAA ATLAS 14

24 Hour – 100 year return period rainfall



http://hdsc.nws.noaa.gov/hdsc/pfds/index.html

…But you cannot design for everything!

Example: August 13th, 2014 – Islip, NY – Rainfall 11 inches/3 hours

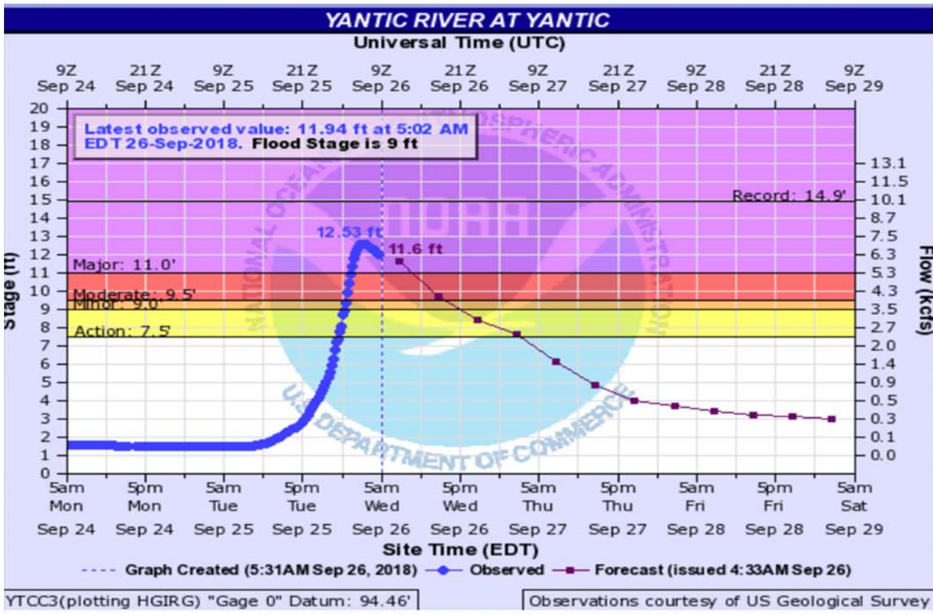
AMS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

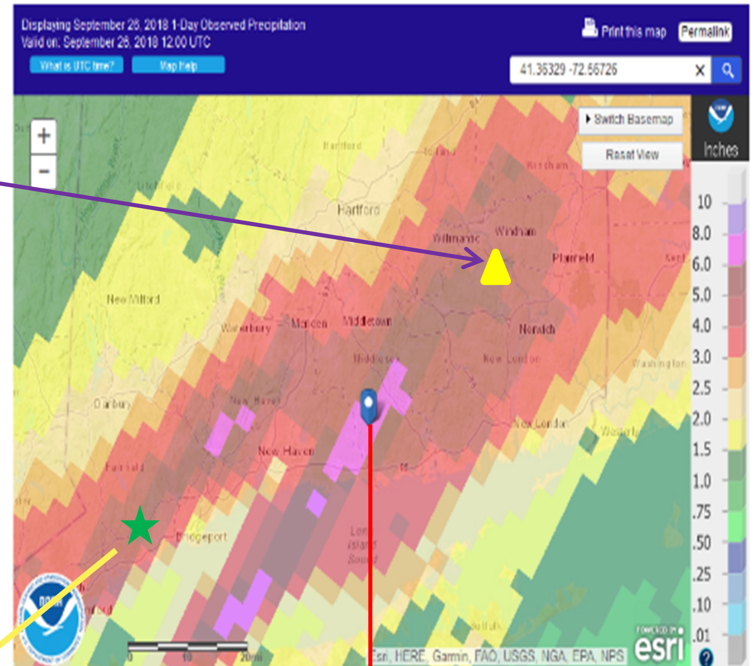
Duration	Annual exceedance probability (1/years)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
5-min	**0.400** (0.312-0.507)	**0.544** (0.423-0.693)	**0.654** (0.505-0.836)	**0.798** (0.597-1.06)	**0.907** (0.666-1.23)	**1.02** (0.727-1.42)	**1.16** (0.784-1.65)	**1.36** (0.880-1.98)	**1.51** (0.953-2.23)
10-min	**0.566** (0.442-0.719)	**0.771** (0.599-0.981)	**0.926** (0.715-1.18)	**1.13** (0.846-1.50)	**1.29** (0.944-1.74)	**1.44** (1.03-2.02)	**1.65** (1.11-2.33)	**1.92** (1.25-2.80)	**2.13** (1.35-3.15)
15-min	**0.666** (0.520-0.846)	**0.907** (0.705-1.15)	**1.09** (0.842-1.39)	**1.33** (0.995-1.77)	**1.51** (1.11-2.05)	**1.69** (1.21-2.37)	**1.94** (1.31-2.74)	**2.26** (1.47-3.29)	**2.51** (1.59-3.71)
30-min	**0.938** (0.731-1.19)	**1.28** (0.992-1.63)	**1.53** (1.19-1.96)	**1.87** (1.40-2.49)	**2.13** (1.56-2.88)	**2.39** (1.71-3.34)	**2.73** (1.84-3.86)	**3.18** (2.06-4.63)	**3.53** (2.23-5.22)
60-min	**1.21** (0.942-1.53)	**1.65** (1.28-2.10)	**1.98** (1.53-2.53)	**2.42** (1.81-3.21)	**2.75** (2.02-3.72)	**3.08** (2.20-4.31)	**3.52** (2.37-4.98)	**4.11** (2.66-5.97)	**4.55** (2.88-6.72)
2-hr	**1.60** (1.26-2.02)	**2.21** (1.73-2.79)	**2.67** (2.08-3.39)	**3.28** (2.47-4.32)	**3.74** (2.76-5.02)	**4.20** (3.01-5.83)	**4.80** (3.25-6.74)	**5.59** (3.63-8.08)	**6.19** (3.93-9.09)
3-hr	**1.86** (1.47-2.33)	**2.58** (2.02-3.24)	**3.12** (2.44-3.94)	**3.84** (2.90-5.03)	**4.38** (3.24-5.86)	**4.93** (3.54-6.80)	**5.63** (3.81-7.87)	**6.55** (4.27-9.43)	**7.25** (4.61-10.6)
6-hr	**2.35** (1.86-2.93)	**3.25** (2.57-4.06)	**3.93** (3.09-4.93)	**4.84** (3.67-6.29)	**5.52** (4.11-7.32)	**6.20** (4.48-8.50)	**7.08** (4.82-9.83)	**8.24** (5.39-11.8)	**9.12** (5.82-13.3)
12-hr	**2.87** (2.30-3.55)	**3.95** (3.15-4.90)	**4.76** (3.77-5.93)	**5.84** (4.46-7.55)	**6.65** (4.98-8.78)	**7.47**	**8.55**	**9.97**	**11.1**
24-hr	**3.34** (2.69-4.10)	**4.64** (3.72-5.71)	**5.62** (4.48-6.95)	**6.92** (5.32-8.90)	**7.90** (5.96-10.4)				
2-day	**3.72** (3.02-4.54)	**5.31** (4.29-6.48)	**6.50** (5.22-7.98)	**8.09** (6.28-10.4)	**9.28** (7.07-12.2)				
3-day	**4.01** (3.26-4.86)	**5.72** (4.64-6.96)	**7.02** (5.66-8.58)	**8.74** (6.81-11.2)	**10.0** (7.68-13.1)				
4-day	**4.27** (3.49-5.16)	**6.05** (4.92-7.34)	**7.40** (5.98-9.01)	**9.18** (7.18-11.7)	**10.5** (8.09-13.7)				
7-day	**4.98** (4.09-5.99)	**6.84** (5.60-8.24)	**8.24** (6.70-9.98)	**10.1** (7.95-12.8)	**11.5** (8.89-14.9)				
10-day	**5.67** (4.68-6.79)	**7.58** (6.23-9.10)	**9.02** (7.36-10.9)	**10.9** (8.61-13.8)	**12.4** (9.56-15.9)				
20-day	**7.79** (6.47-9.26)	**9.85** (8.15-11.7)	**11.4** (9.37-13.6)	**13.5** (10.6-16.7)	**15.0** (11.6-19.0)				
30-day	**9.57** (7.98-11.3)	**11.7** (9.76-13.9)	**13.4** (11.1-16.0)	**15.6** (12.3-19.1)	**17.2** (13.3-21.5)				
45-day	**11.8** (9.88-13.9)	**14.1** (11.8-16.6)	**15.8** (13.1-18.8)	**18.1** (14.4-22.1)	**19.9** (15.4-24.7)				
60-day	**13.7** (11.5-16.0)	**16.1** (13.4-18.9)	**17.9** (14.9-21.1)	**20.3** (16.1-24.6)	**22.1** (17.1-27.2)				

>11”

A very real local example:

Coastal Connecticut – September 25th, 2018





Westport firefighters rescued two adults and two children from vehicles that were swept off the road by floodwaters. Crews had to break a window to extricate one victim, but no injuries were reported.

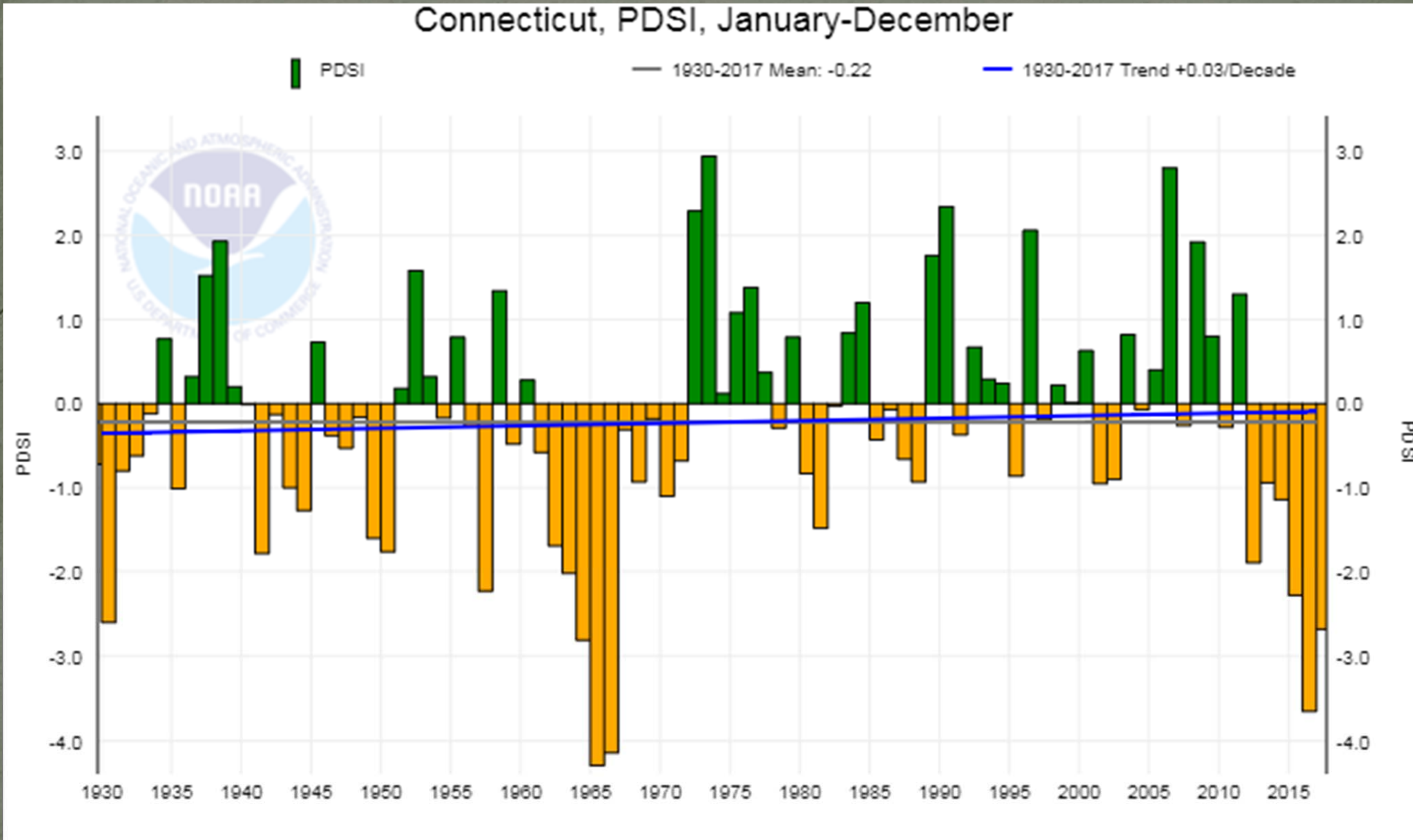
Photo credit: Town of Westport Fire Department

Killingsworth, CT experienced 6.78 inches in ~ 24 hours
3hr ~ 50 yr. event and the 6-12 hr. ~ 75 yr. event

Duration	Obs	Approx ARI	1	2	5	10	25	50	100
1h	1.56	~5-yr	0.993	1.2	1.53	1.81	2.19	2.49	2.78
2h	2.95	~25-yr	1.31	1.58	2.01	2.37	2.86	3.24	3.63
3h	3.74	~50-yr	1.53	1.83	2.34	2.75	3.32	3.76	4.21
6h	4.95	>50-yr	1.95	2.34	2.98	3.51	4.24	4.8	5.36
12h	6.21	>50-yr	2.42	2.91	3.71	4.38	5.29	6	6.7
24h	6.78	>25-yr	2.84	3.44	4.43	5.25	6.38	7.25	8.13

Changes in the Palmer Drought Index

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



Since the late 60s, signature of less frequent & shorter dry periods and longer, more frequent and intense wet periods

Trends in Flood Frequency:
Smaller watersheds feeling the effects first

- Changes in frequency/magnitude
- Part land use/urbanization
  - Compounded by encroachment in the floodplain
- Part changing climate
- Larger basins & those with flood control haven't seen as noticeable a shift
  - Greater capacity to handle more rain
  - Greater capacity to control releases
- Northern and western parts of the state are seeing the most dramatic increase in flooding
  - Same area where 100 year rainfall has shifted dramatically

Flooding along the Housatonic River following Lee, Sept 8, 2011. Photo: A. Driscoll, CT Post

Moderate flooding along Connecticut River , April 1st, 2010. Photo: NBC Connecticut

Instantaneous peak flows

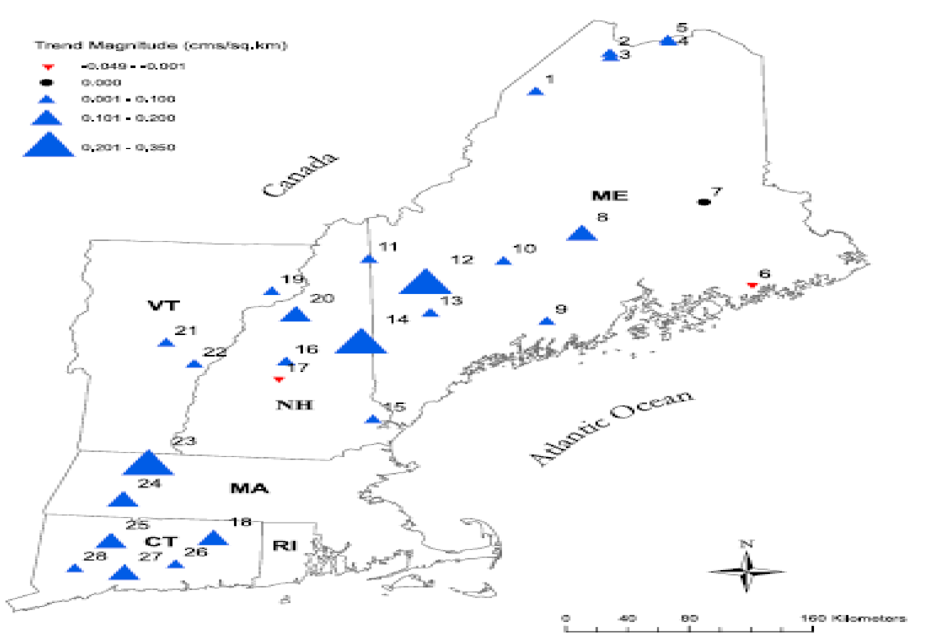
Mathias Collins – NOAA NFMS

2009 study of 28 watersheds with minimal human influences

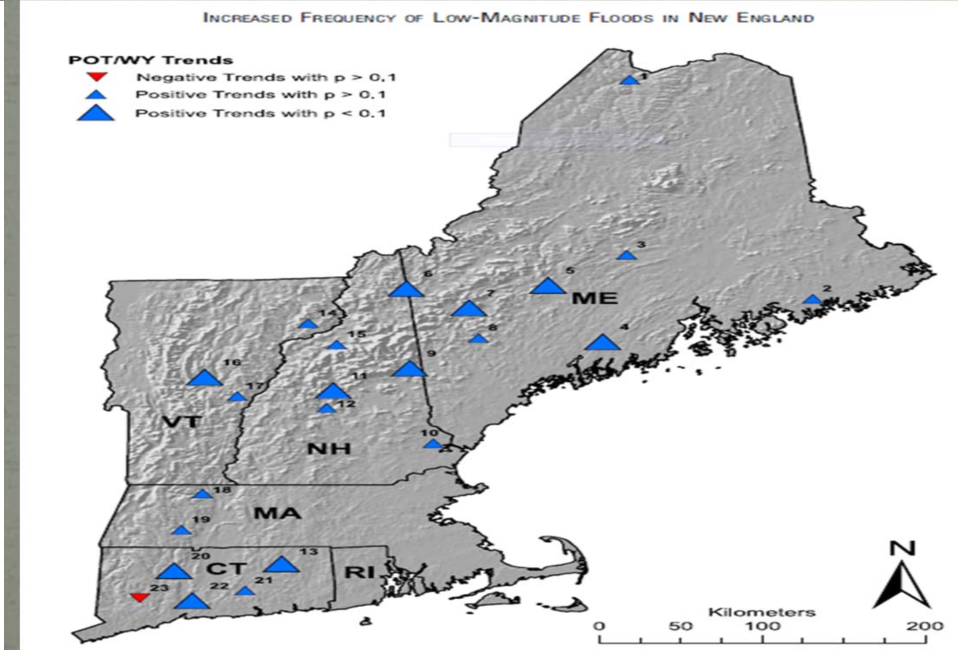
- Results indicate basins have experienced increased peak annual flows
  - Strongest statistical trends noted by the large blue triangles

2011 study of 23 watersheds with minimal human influences

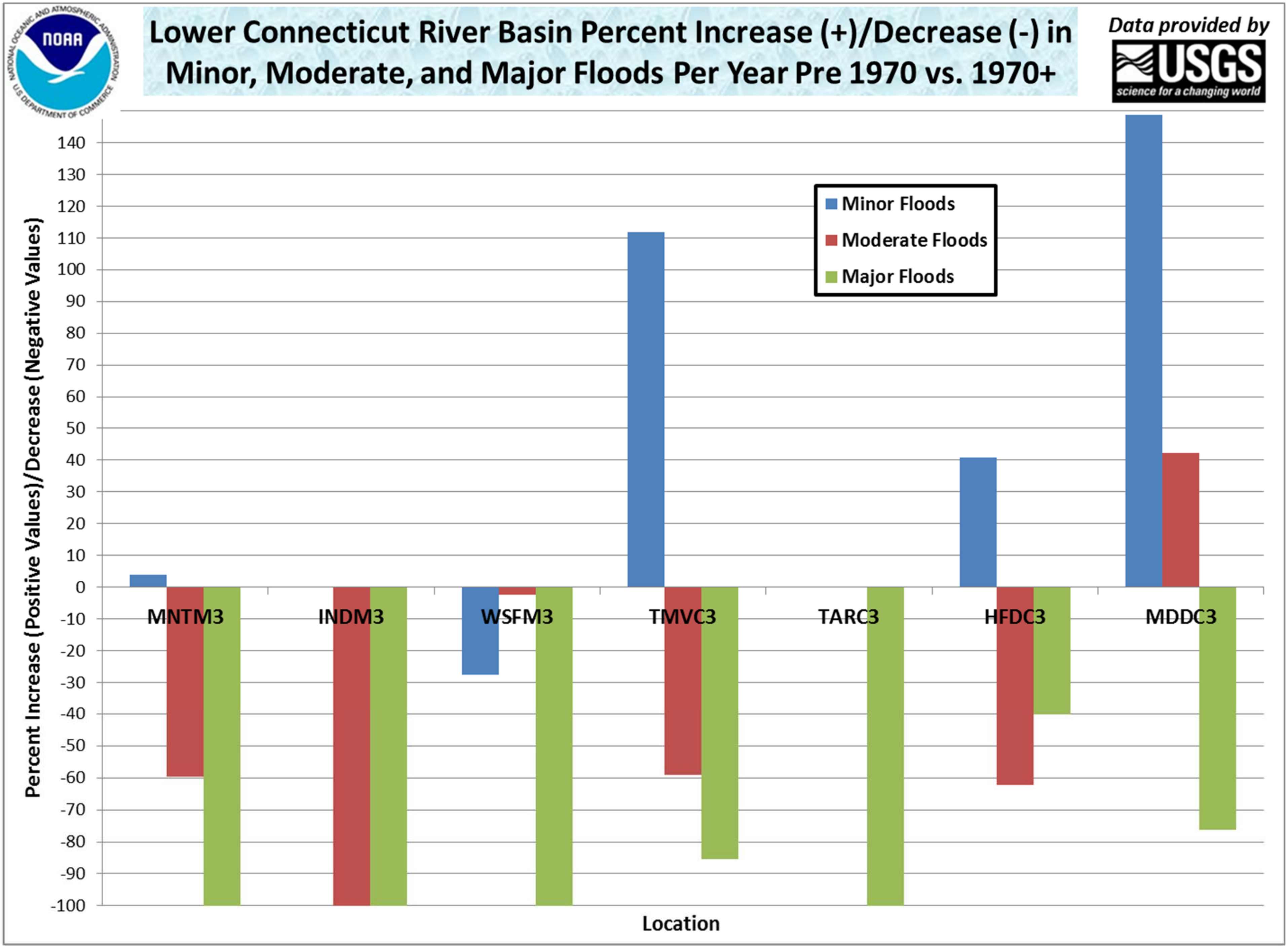
- Examined peaks over defined thresholds per water year
- More frequent flooding at 22 of 23 locations
- Increasing flood magnitude at 17 of 23 locations



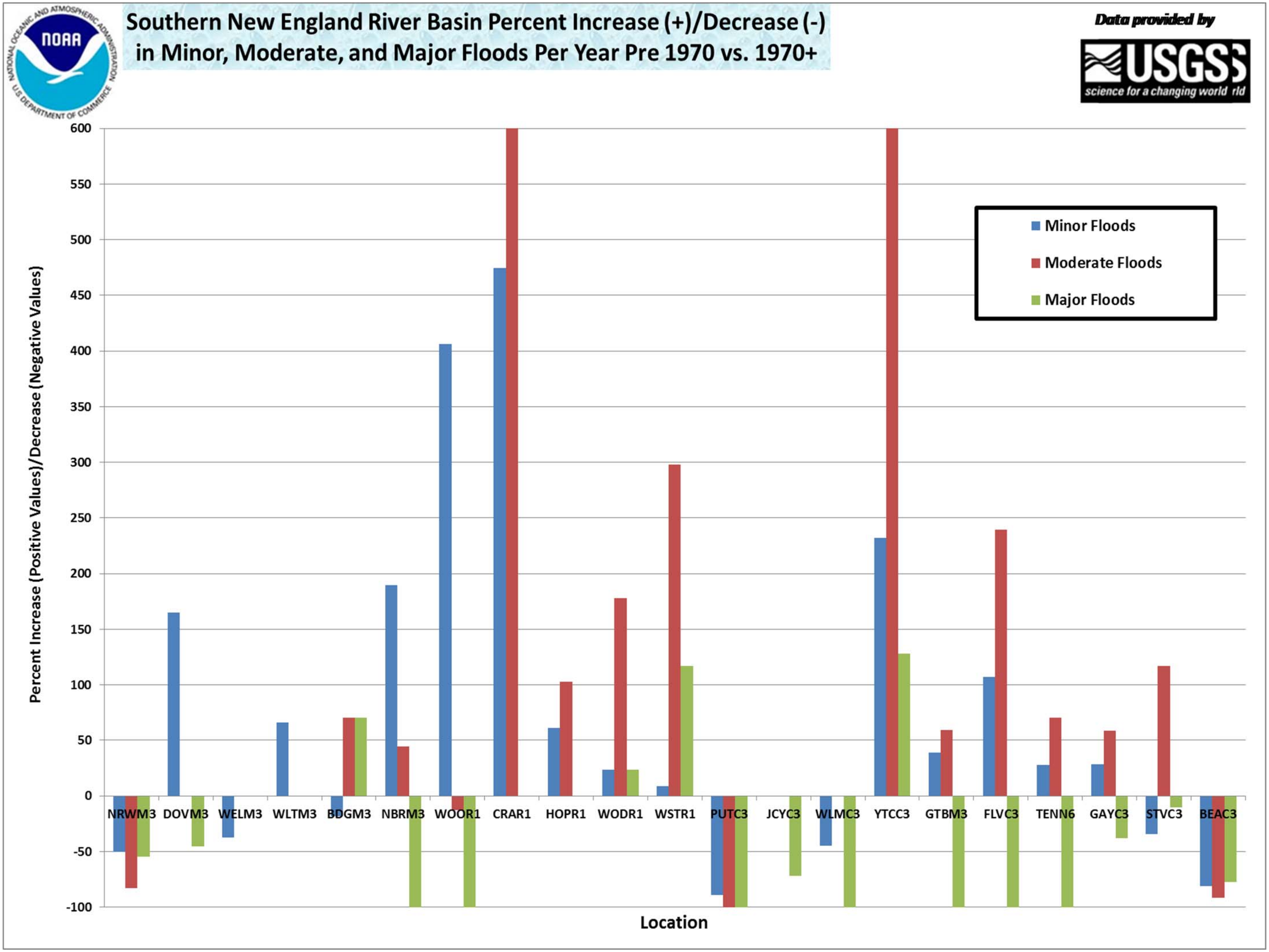
Spatial distribution of trend directions & magnitudes for based with minimal human influences.
Reference: *M. Collins, Journal of The American Water Resources Association (JAWRA) April 2009.*



Spatial Distribution of Flood Frequency – as measured by peaks over threshold per water year.
Reference: W. Armstrong, *M. Collins, and N. Snyder Journal of The American Water Resources Association (JAWRA) April 2011.*



Lower Connecticut River Basin Percent Increase (+)/Decrease (-) in Minor, Moderate, and Major Floods Per Year Pre 1970 vs. 1970+
Data provided by
USGS
science for a changing world
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
Minor Floods
Moderate Floods
Major Floods
Percent Increase (Positive Values)/Decrease (Negative Values)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
MNTM3
INDM3
WSFM3
TMVC3
TARC3
HFDC3
MDDC3
Location



Southern New England River Basin Percent Increase (+)/Decrease (-) in Minor, Moderate, and Major Floods Per Year Pre 1970 vs. 1970+
Data provided by
USGS
science for a changing world
Percent Increase (Positive Values)/Decrease (Negative Values)
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
-100
Minor Floods
Moderate Floods
Major Floods
NRWM3
DOVM3
WELM3
WLTM3
BDGM3
NBRM3
WOOR1
CRAR1
HOPR1
WODR1
WSTR1
PUTC3
JCYC3
WLMC3
YTCC3
GTBM3
FLVC3
TENN6
GAYC3
STVC3
BEAC3
Location

Part I: Summary

- Common themes across New England and Connecticut:
  - Warming annual temperatures
  - Increasing annual precipitation
    - Large swings in extremes (wet & dry)
  - Increasing frequency of heavy rains
  - Shift in precipitation frequency
- Trend toward increased flood magnitude and/or frequency
  - Most pronounced where significant land use change and/or urbanization has occurred
  - More pronounced in smaller river basins

Residents are rescued from their homes by boat along flooded Pawcatuck River , Westerly RI, on March 30, 2010. Photo: www.theday.com

Major flooding along Route 7 from the Housatonic River in New Milford, CT on March 11, 2011. Source: Ctcameraeye.com

Part II:
Coastal Impacts

Consider The 2011 and 2012 Seasons:

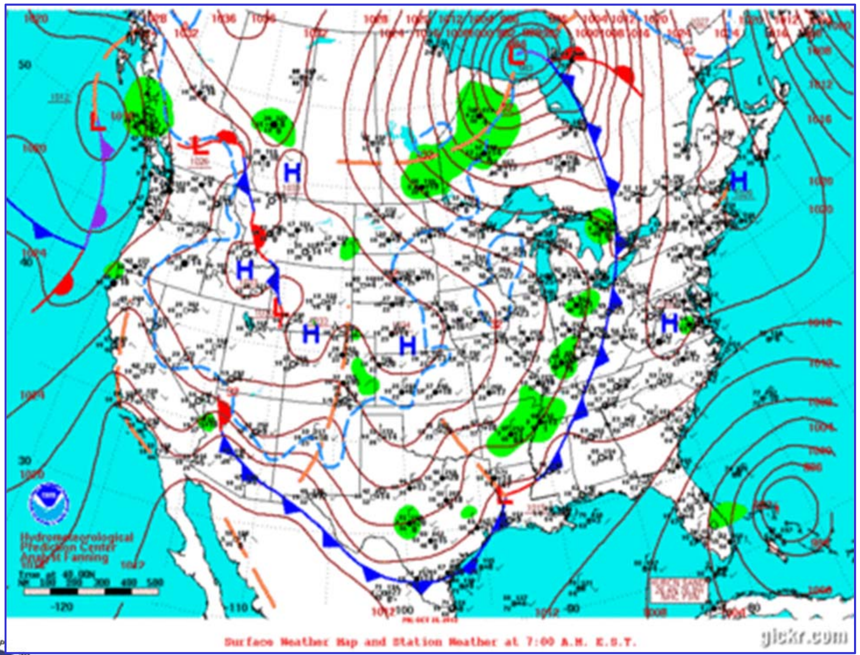
IRENE

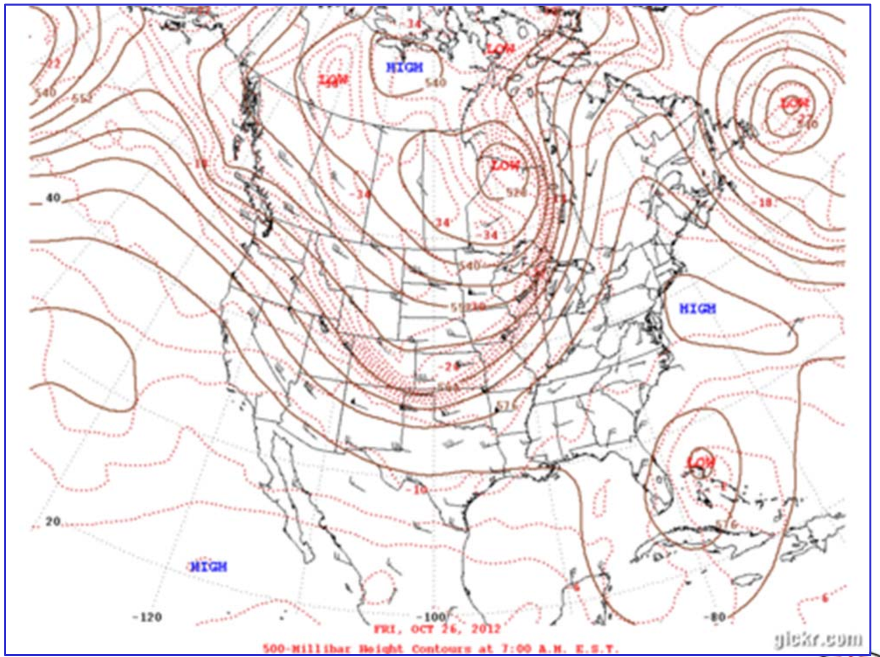
SANDY

- **Irene: Widespread wind damage & power disruption in the east & devastating flooding rains in the west**
  - "It's all about the wind and rain!"
- **Sandy: Significant coastal flooding but with less wind and little if any rain**
  - "It's all about the coastal flooding!"

Sandy: A Perfect Storm of Sorts

- **Formed in the western Caribbean**
  - Not at all unusual for late October
- **Encountered a very deep trough of Low Pressure in the eastern United States and very strong High Pressure moving southward from the Canadian Maritimes**
  - A winter-type dual jet stream set up (classic for a New England Hurricane)
  - Captured Sandy & blocked her attempt to race out to sea

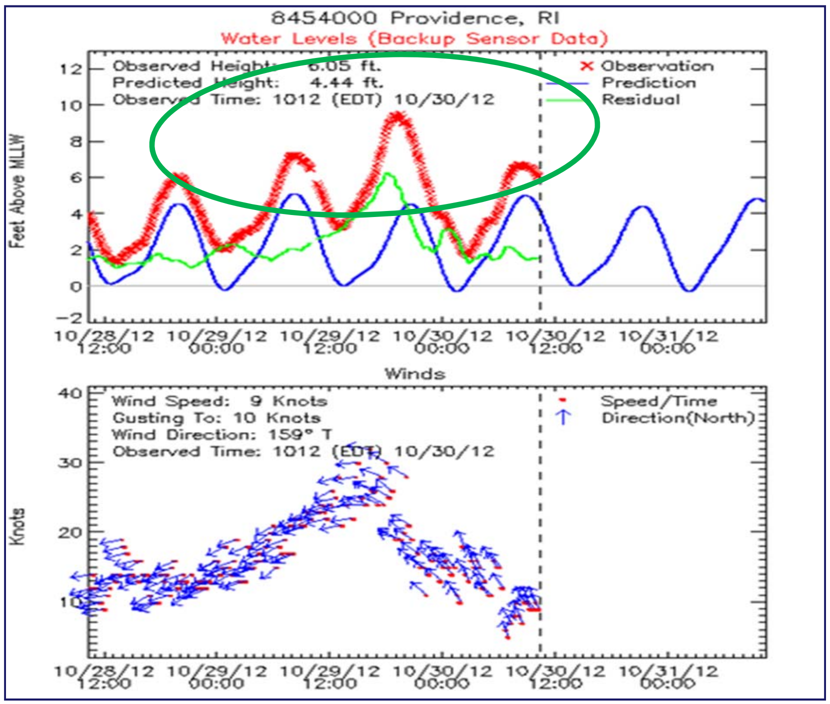


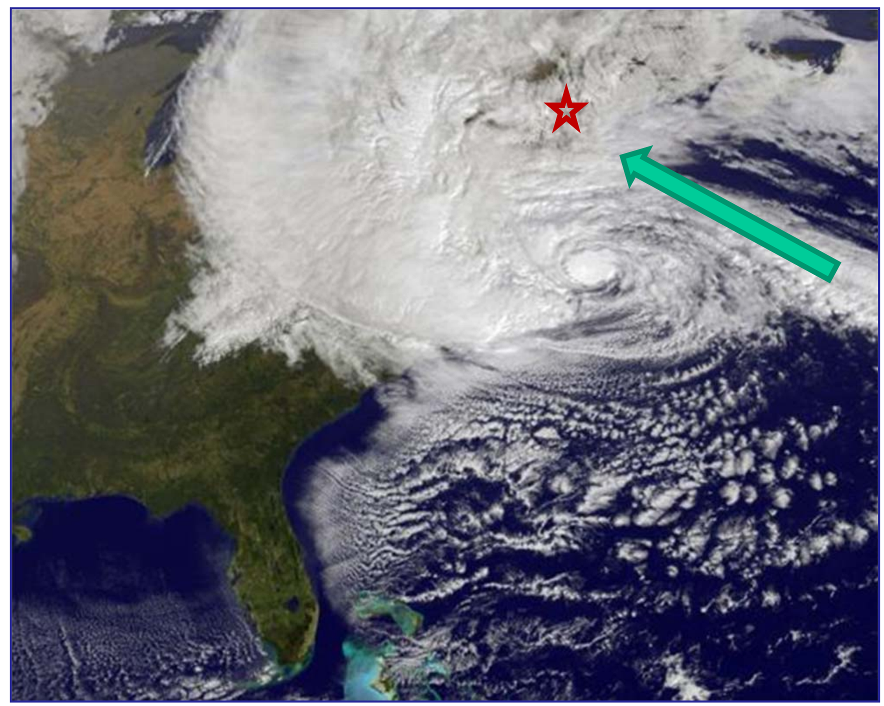


Long Duration Southeast Fetch

Damaging Waves, Multiple Tide Cycles & a 4-8 ft Storm Surge

- **Southeast swells built on 2 days of southeast winds were driven right into the south coast & Long Island Sound**
  - Impacted Multiple Tide Cycles – worst of which was Monday night
  - 15-30 foot seas resulted in relentless pounding surf which first weakened then obliterated the dunes along parts of the exposed coast
  - Storm surge of 4-8 feet atop a “middle-of-the-road” astronomical tide produced significant coastal flooding and inundation 4 to 7 feet above ground level
  - What she lacked in intensity she made up for in duration!



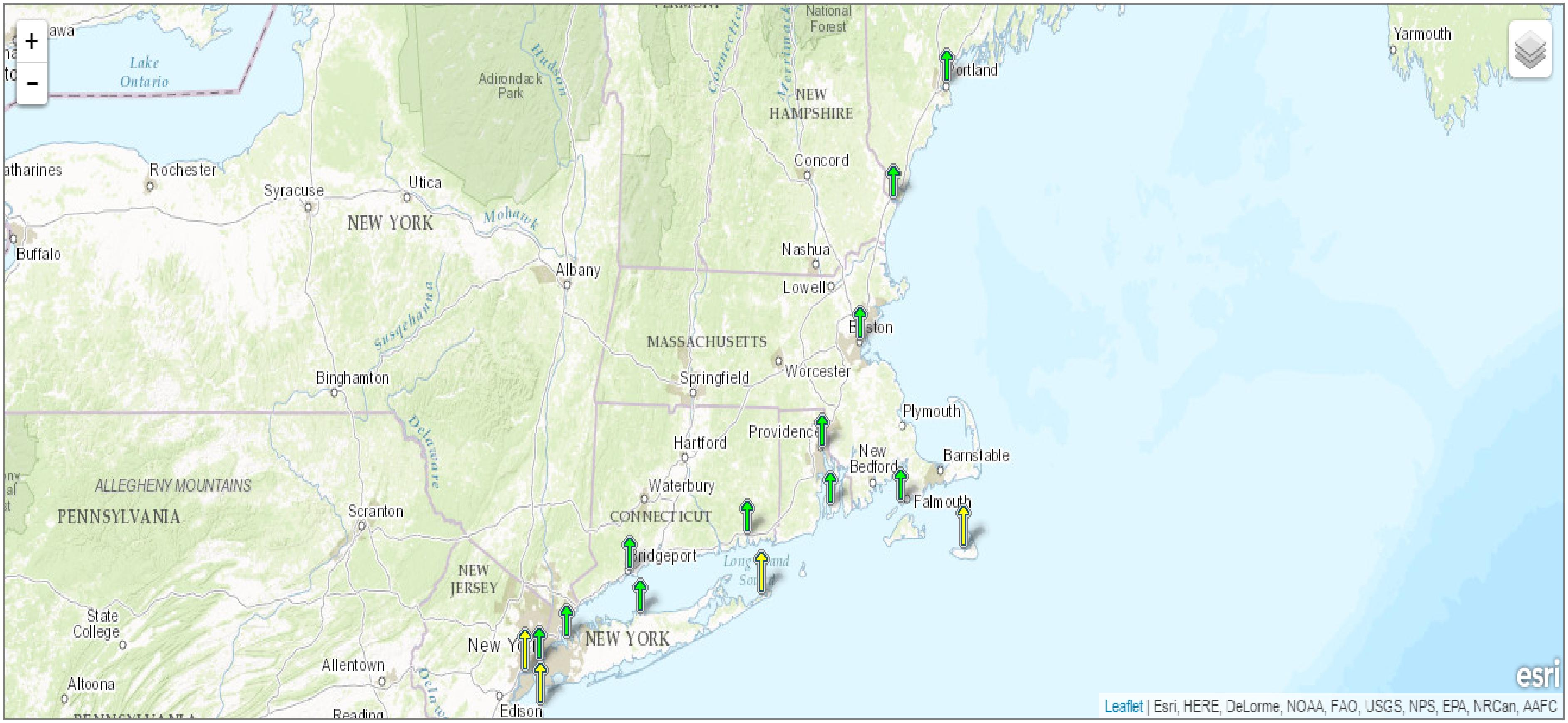


Sea Level Trends

http://tidesandcurrents.noaa.gov/sltrends/index.shtml

East Coast | West Coast | Gulf Coast | Alaska | Hawaii | Global

View in Google Earth

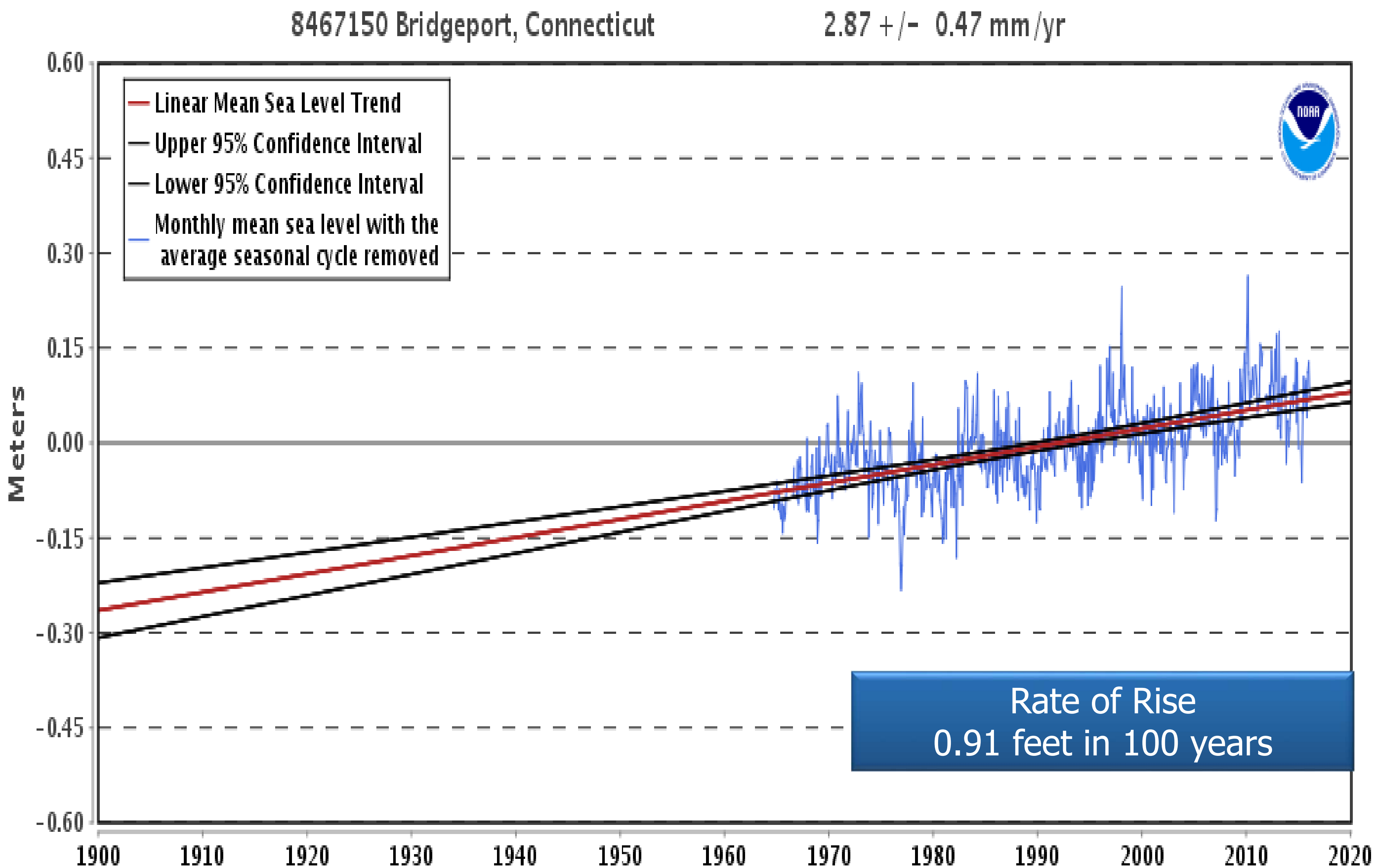


The map above illustrates regional trends in sea level, with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.

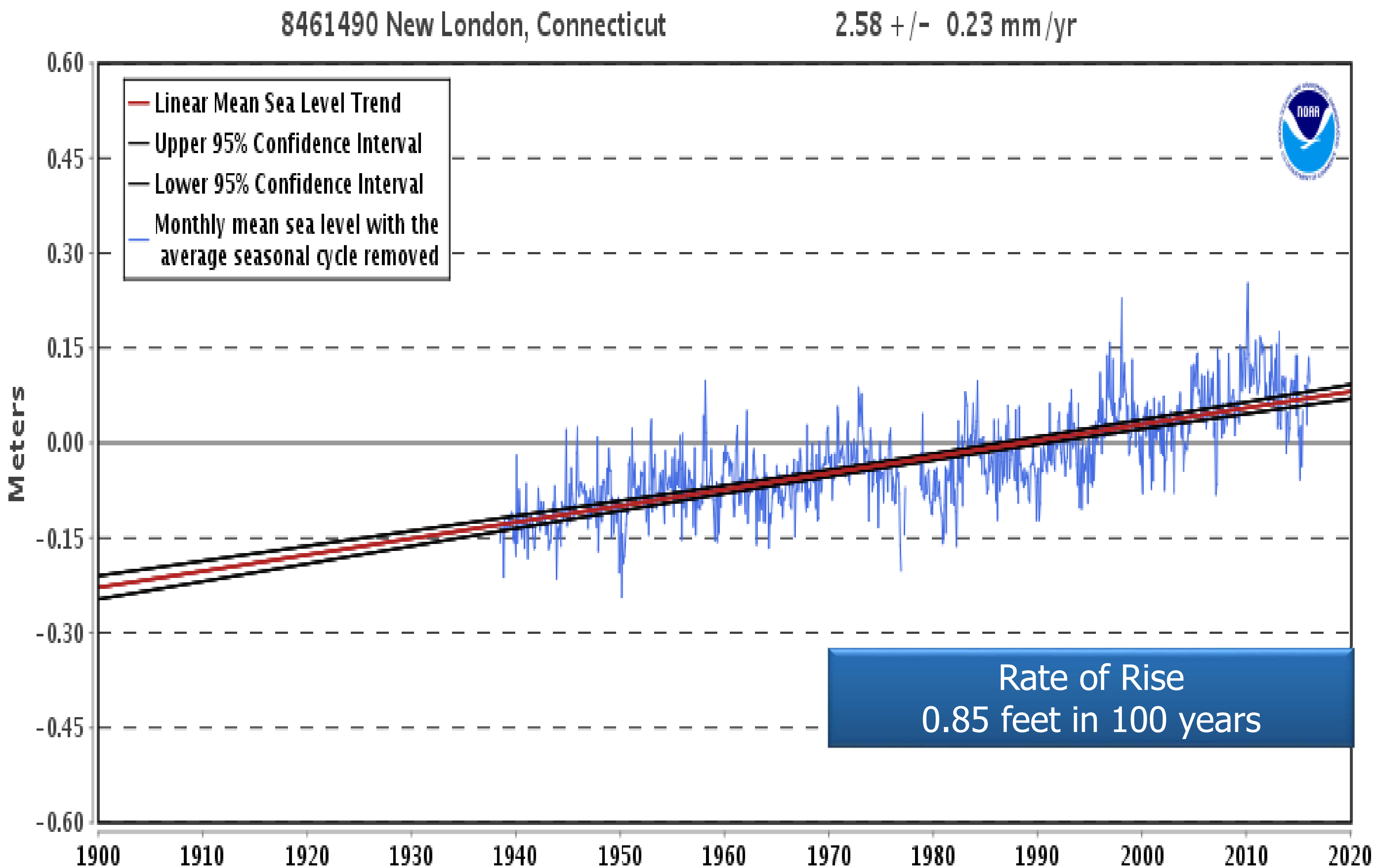
Sea Level Trends

mm/yr (feet/century)

15 to 21 (5 to 7)	6 to 9 (2 to 3)	-3 to 0 (-1 to 0)	-12 to -9 (-4 to -3)
12 to 15 (4 to 5)	3 to 6 (1 to 2)	-6 to -3 (-2 to -1)	-15 to -12 (-5 to -4)
9 to 12 (3 to 4)	0 to 3 (0 to 1)	-9 to -6 (-3 to -2)	-18 to -15 (-6 to -5)



The mean sea level trend is 2.87 millimeters/year with a 95% confidence interval of +/- 0.44 mm/yr based on monthly mean sea level data from 1964 to 2014 which is equivalent to a change of 0.91 feet in 100 years.



The mean sea level trend is 2.58 millimeters/year with a 95% confidence interval of +/- 0.23 mm/yr based on monthly mean sea level data from 1938 to 2014 which is equivalent to a change of 0.85 feet in 100 years.

Tropical Storm Irene's Coastal Damage

- Significant damage across western Connecticut coastline
  - Significant coastal flooding – from a 3 to 6 foot storm surge
  - Seventeen highway bridges destroyed by rampaging waters
  - Rockslides blocked dozens of other roadways
  - New Haven Rail Line reported 24 washouts, six landslides, one 5-car derailment

East Haven, Connecticut

Photos courtesy of C. Zuraw, CT Post

Cosey Beach, East Haven, Connecticut
Photo courtesy of TWC/Storify

Fairfield, Connecticut

Hurricane Sandy's Coastal Damage

- Large damaging waves over multiple tide cycles
- Highest tide coincides with highest onshore winds
- Sends storm surge of several feet up the coastal rivers

Milford, Connecticut
Photo: M. McLoughlin/Reuters

Plum Bank Road, Old Saybrook
Photo: Stephen Dunn/Hartford Courant

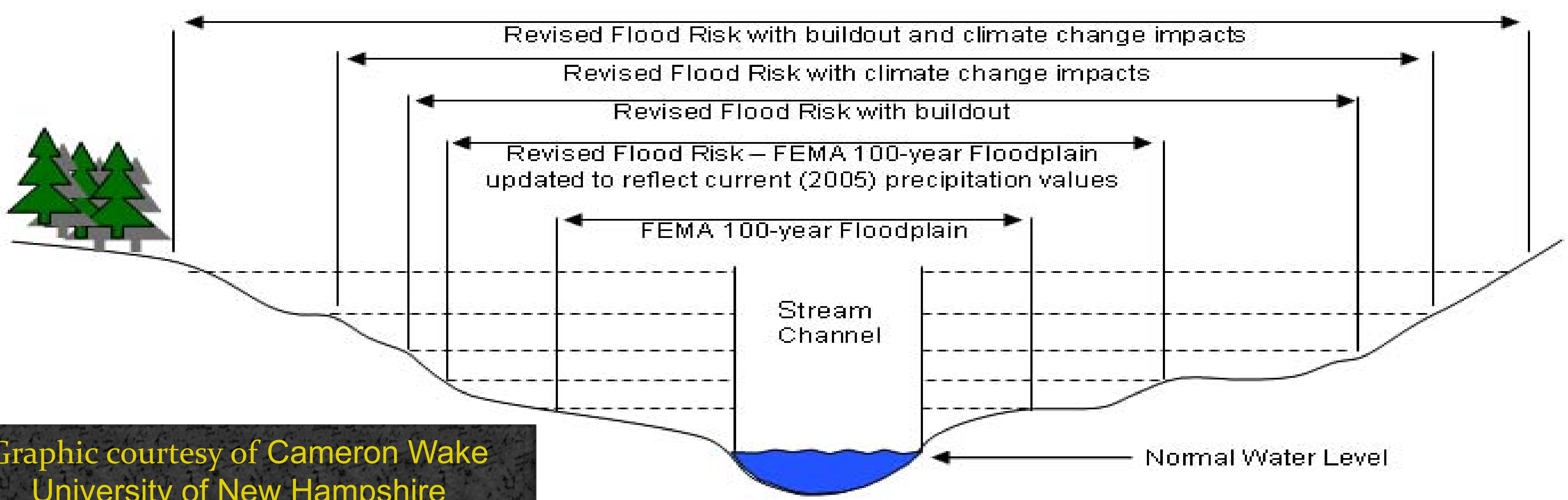
Milford, Connecticut
Photo: CNN

Summary

- The Northeast U.S. has become a “hot spot” for record floods & heavy rainfall in the past 20 years
  - Noticeable trends include increased yearly rainfall and increased annual temperatures
  - Smaller watersheds & those with significant urbanization and/or land use change are most vulnerable to increased river & stream flooding
- Continued sea level rise combined with intense coastal storms has renewed the coastal flood threat
  - A weaker category of storm is now capable of producing inundation once limited to the more intense hurricanes and coastal storms

Far reaching implications:
Protect, Adapt or Retreat???

- Floodplain, land use, infrastructure, dam spillway requirements, drainage requirements, storm water management, 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?

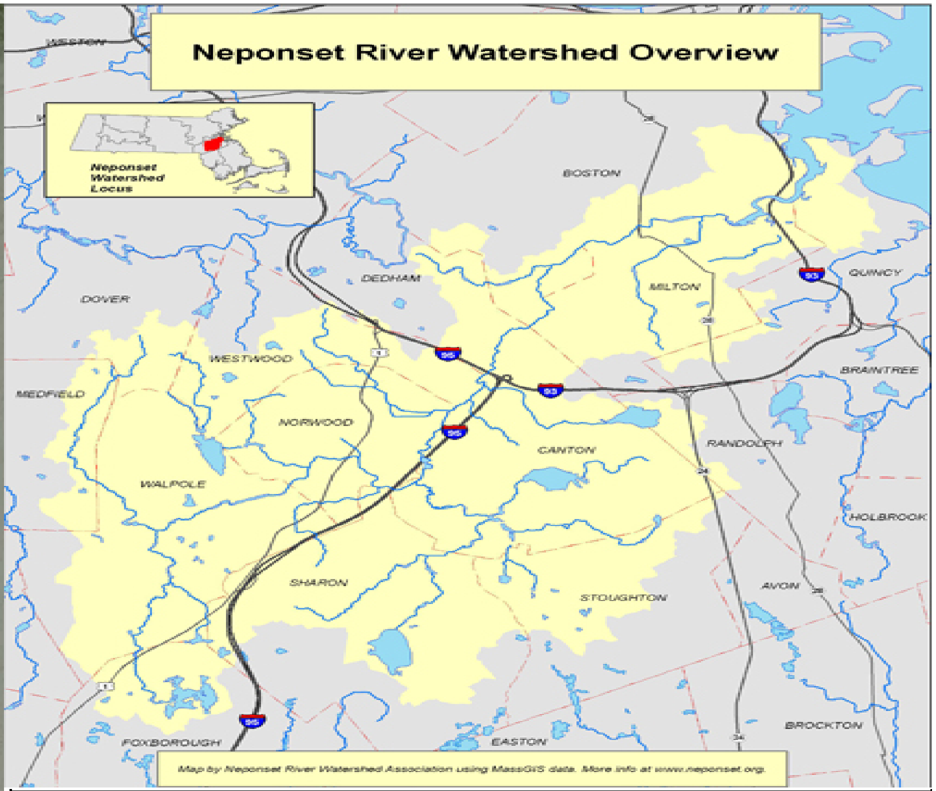


Graphic courtesy of Cameron Wake
University of New Hampshire

The Neponset Basin:
Natural Valley Storage & Wetlands Restoration

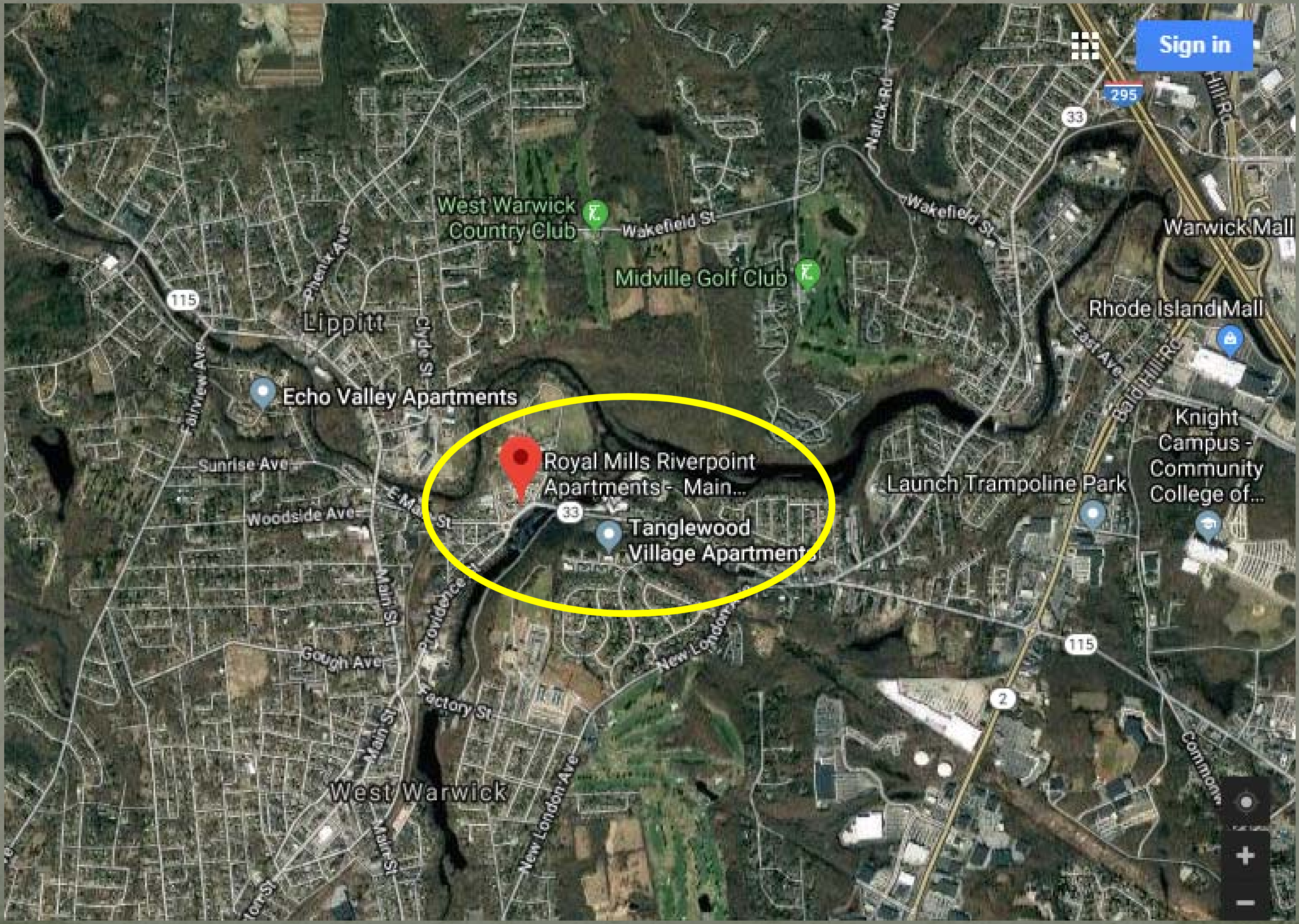
Land Trusts can help to:

- Preserve the land
- Retain and restore grounds to their natural state
- Increase rainfall/runoff storage capacity of a given parcel of land
- Improve water quality through restoration of lands and vegetation to a more natural state
- Reduce storm water runoff

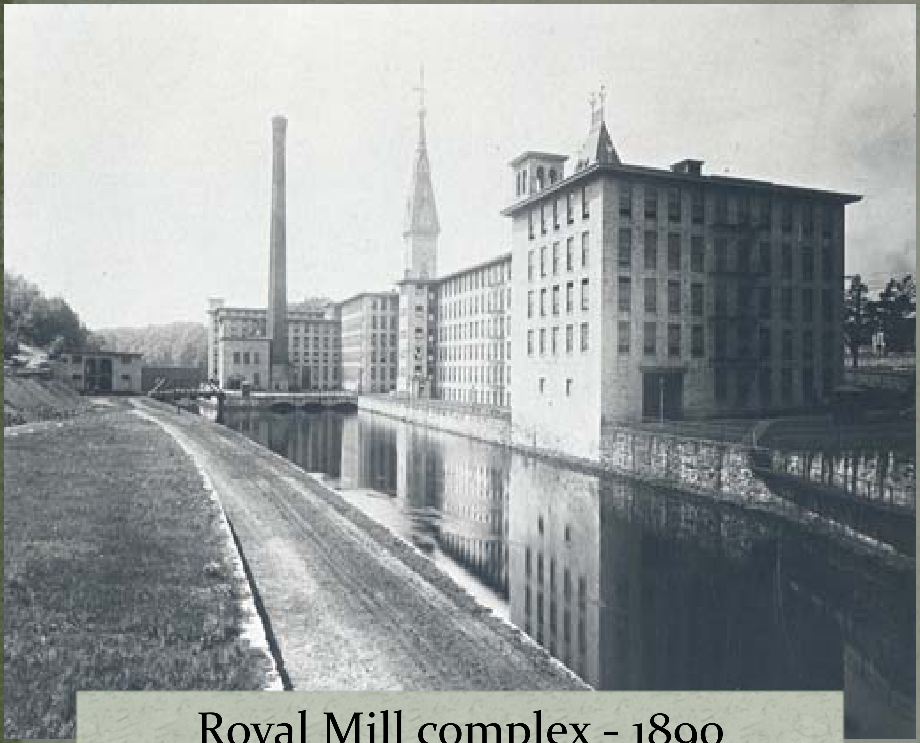


Neponset Basin Wetland Restoration.
Photo: MA Exec. Office Env. Affairs

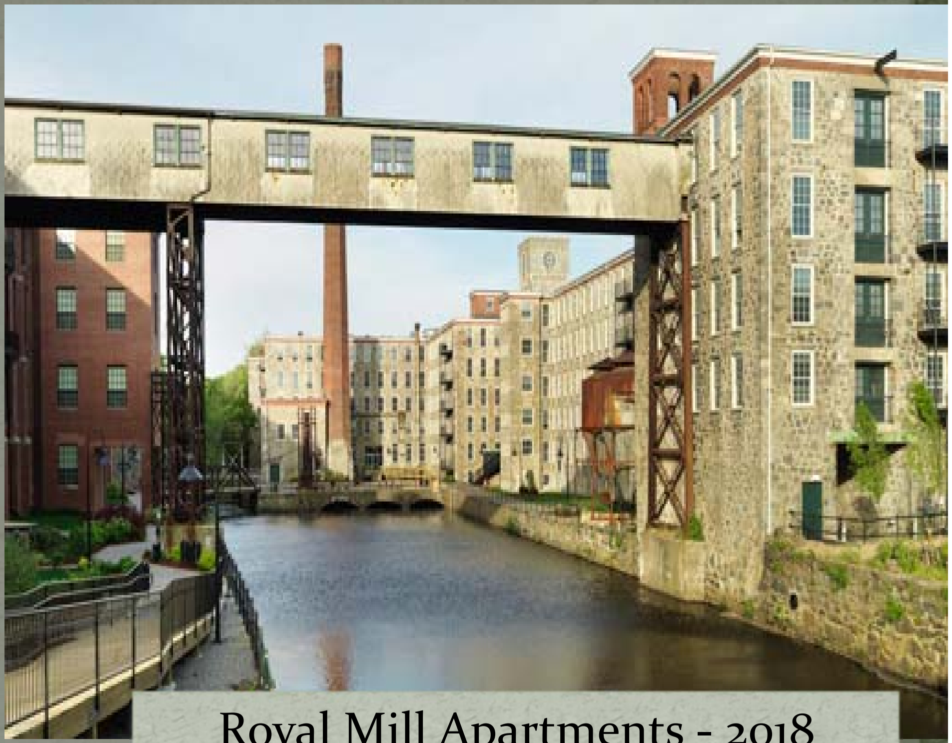
Smart Building Approaches



Smart Building Approaches



Royal Mill complex - 1890



Royal Mill Apartments - 2018

Concept: Refurbish old textile mill into apartments
Challenge: Flood-prone area on the Pawtuxet River
Plan: Critical infrastructure located on floors 2 and above
Lowest levels used for parking so can be cleared out during a flood…which happened in March 2010!

Chelsea Screen house

Assessing Vulnerability and Taking Mitigating Actions
Elevating Critical Infrastructure

Chelsea Creek Screen House
Southwest Facility View

Chelsea Creek Screen House
Backup Generator

Slide courtesy of Lise Marx, Senior Program Manager, Master Planning
Massachusetts Water Resources Agency (MWRA)

Using Green Technology: Bioswales

- Stormwater runoff best management practice
- Receives and slows runoff generated during small to medium sized storms
- Provides modest local flood storage
- Filters, traps and removes contaminants in stormwater runoff that would otherwise be carried downstream.

Porous pavement

- Another best practice
- Reduces risk for ice formation on parking lots and walkways
- Slows arrival of stormwater into near by catchments
- Depending upon design, can also act as a filter mechanism

Climate Trends in Connecticut and Its Impact on Storm and Riverine Flood Behavior

David R. Vallee
Hydrologist-in-Charge
NOAA/NWS Northeast River Forecast Center
Connecticut Association of Conservation & Inland Wetlands Commissions
41st Annual Meeting & Environmental Conference

Flooding along the Housatonic River following Lee, Sept 8, 2011.