

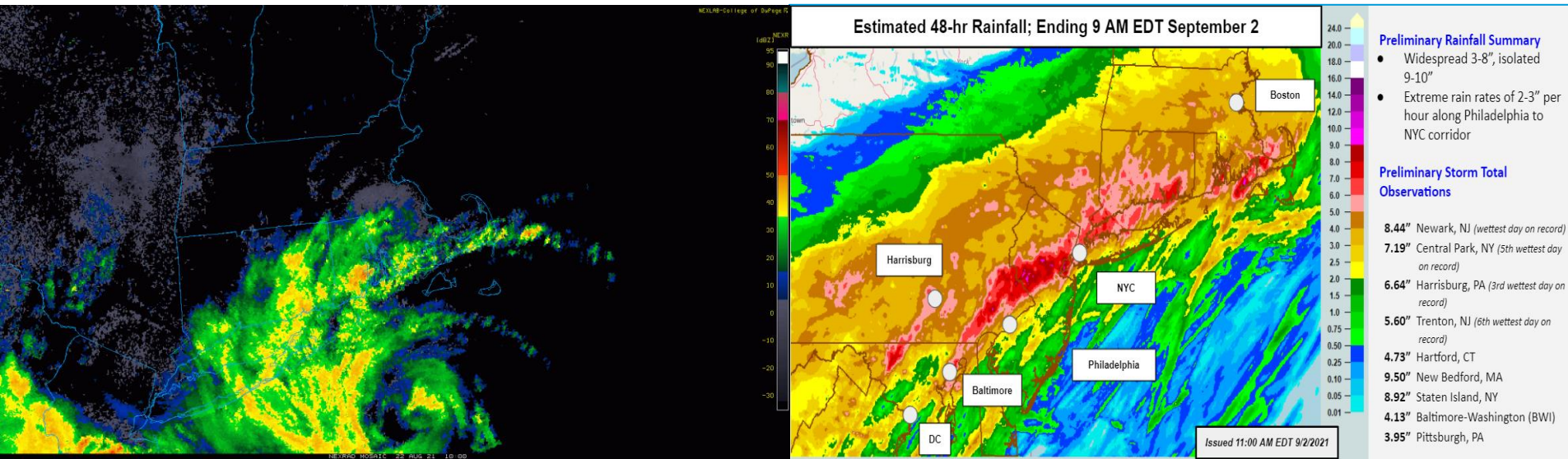


# NATIONAL WEATHER SERVICE

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## *Torrential Rains from Slow Moving Tropical Systems; Is This the New Normal?*



Henri making landfall – August 22<sup>nd</sup>, 2021

Ida's devastating rainfall – Sept 1-2, 2021

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

# This presentation will cover:

- A bit about the Northeast River Forecast Center and our operations and services
- An review of our changing climate
  - Rainfall/Temperature trends & the impacts on river flooding
- Tropical cyclones and their changing behavior
  - Henri & Ida aren't the only recent examples!
- A peak into the future of NWS flood forecast services



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**Building a Weather-Ready Nation // 2**





## 13 River Forecast Centers

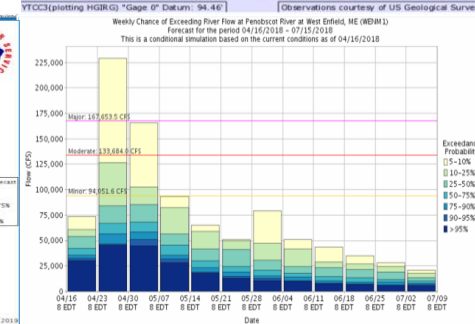
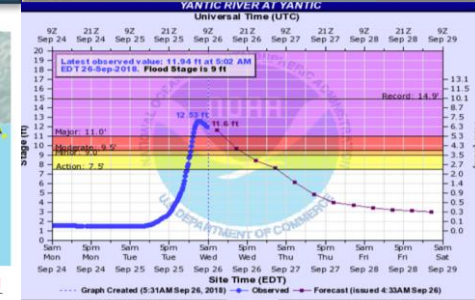
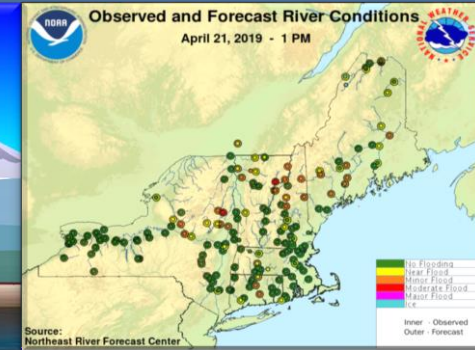
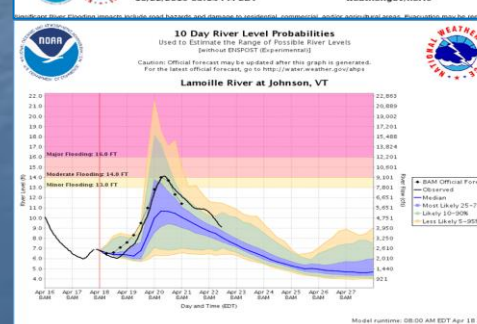
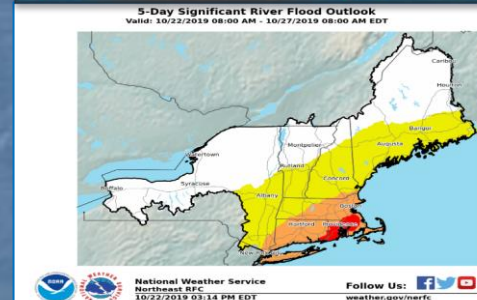
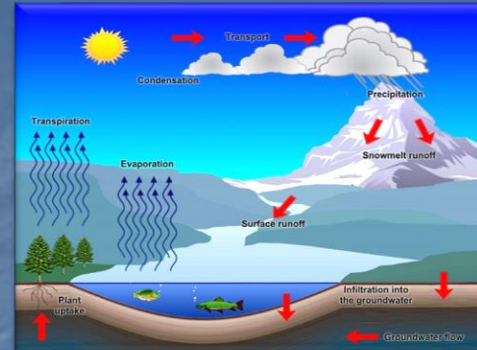


### Our Mission:

To provide our nation with river, flood and water resource forecasts for the protection of life and property and the enhancement of the national economy.

# Northeast River Forecast Center Responsibilities

- <https://www.weather.gov/nerfc>
- Calibrate and implement a variety of hydrologic and hydraulic models to provide:
  - River flow and stage forecasts at 200 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
  - Decision Support Services to regional partners

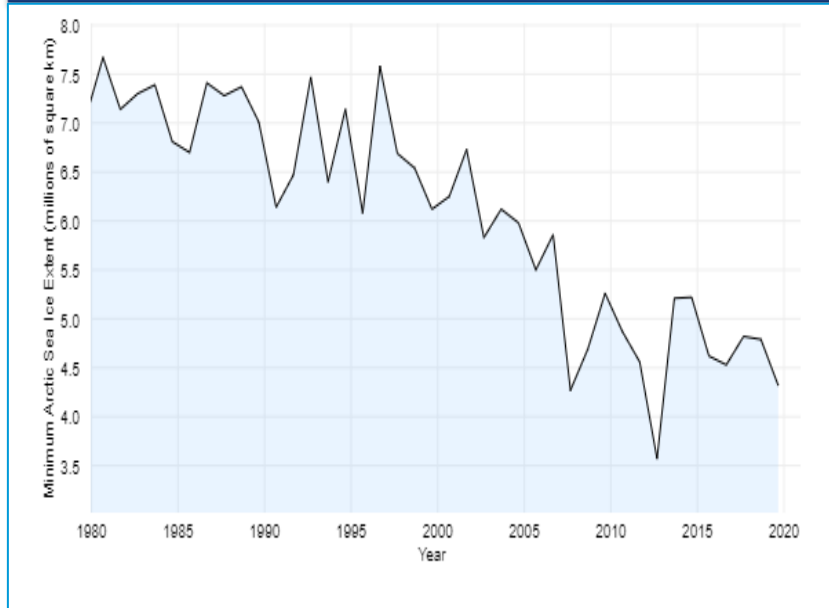




# The latest Science:

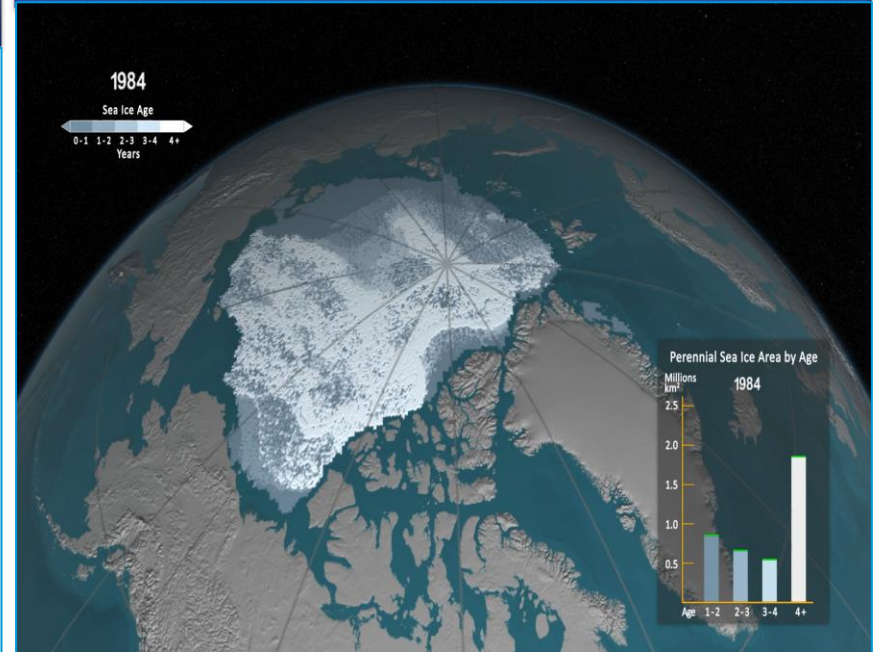
## A warming planet and shrinking Arctic Sea ice

September Minimum Sea Ice Cover  
1979-2019



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. Reference: Fourth National Climate Assessment <https://nca2018.globalchange.gov/chapter/1/#fig-1-2>

Arctic Sea Ice Summer Minimum



Loop of September Summer Minimum Ice Extent from 1984 through 2016. Note the steady decrease in coverage. Reference: Fourth National Climate Assessment. <https://nca2018.globalchange.gov/chapter/2/#key-message-7>



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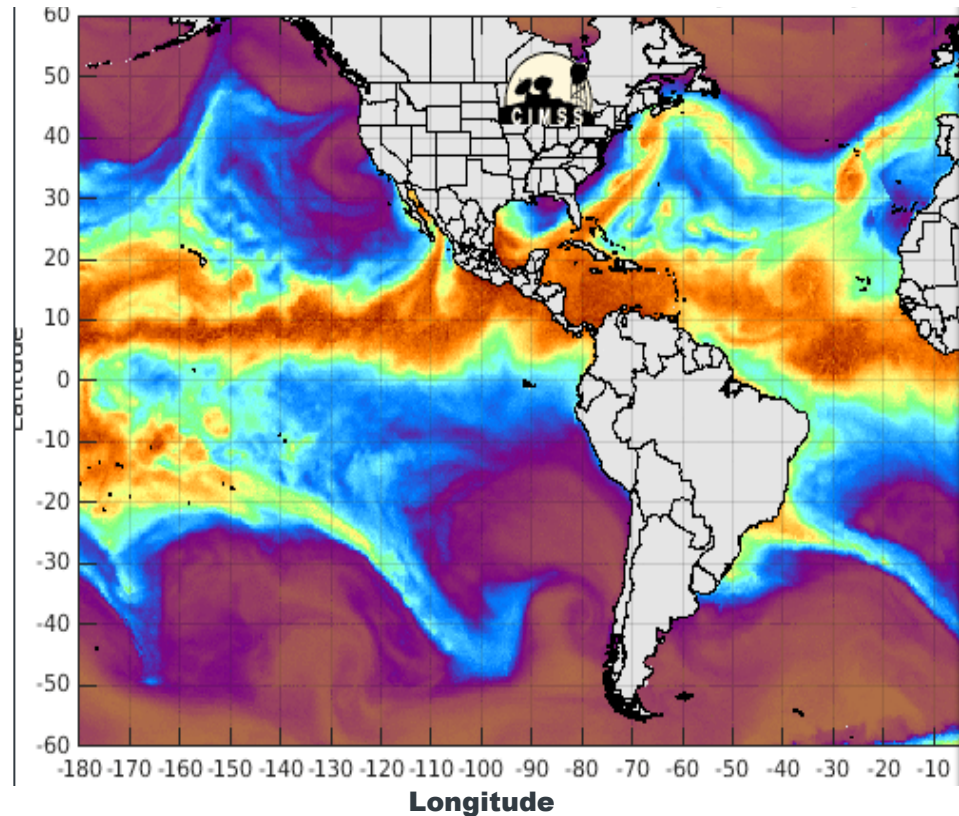
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# Is there a common theme to recent floods?

Composite loop of Atmospheric Water Vapor – 10/12/2018



## Several:

- Slow moving weather systems – a blocked up atmosphere
  - Multiple events in close succession
  - One big slow moving storm
- Results in saturated antecedent conditions before the “main event”
- Each fed by a “tropical connection”
  - Plumes of deep moisture
  - High moisture values are reaching our latitude more frequently
  - Storm tracks that impact the Northeast are interacting with these plumes more frequently



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# 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



Road and sidewalk damage on Ambassador Dr., Manchester, CT.  
Photo: Chris Dehnel/Patch



Pawlak Park in Seymour – flooded from Ida's torrential rainfall.  
Photo: Donald Eng / Hearst Connecticut Media



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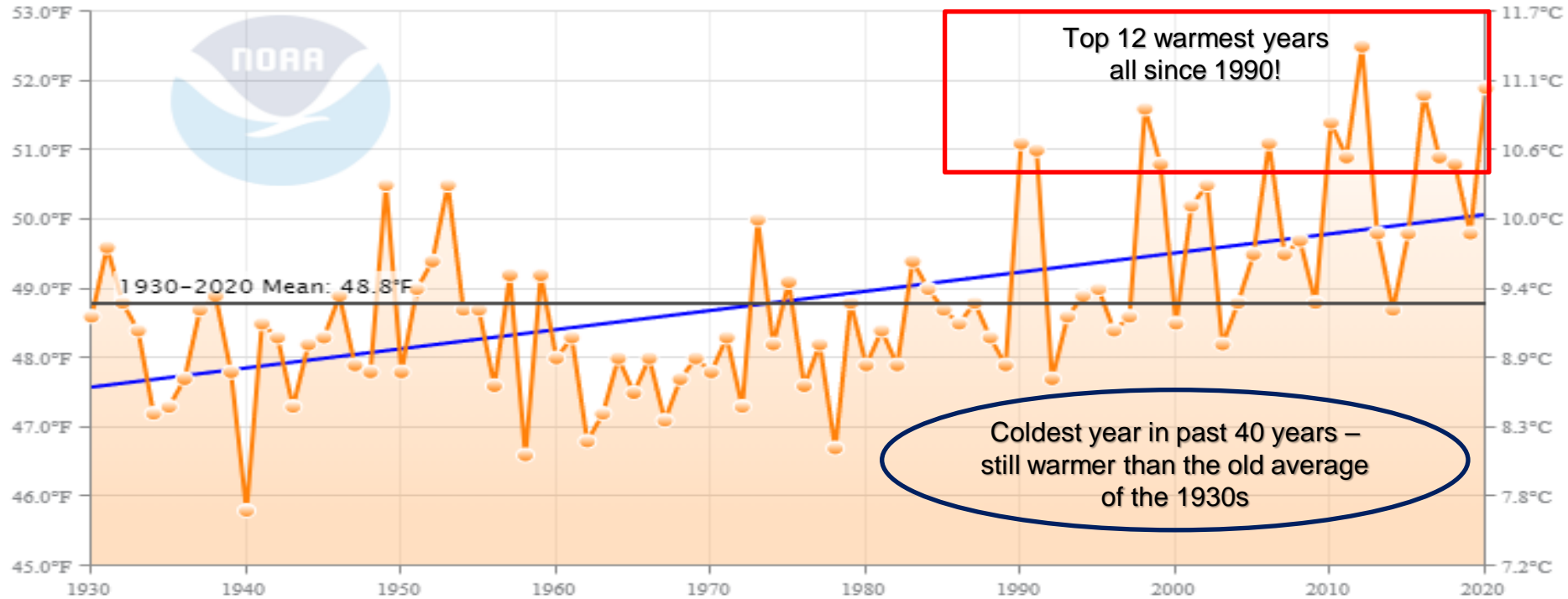
<http://www.weather.gov/nerfc>

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# A Look at Connecticut Annual Temperature Trends

## Connecticut Average Temperature January–December



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



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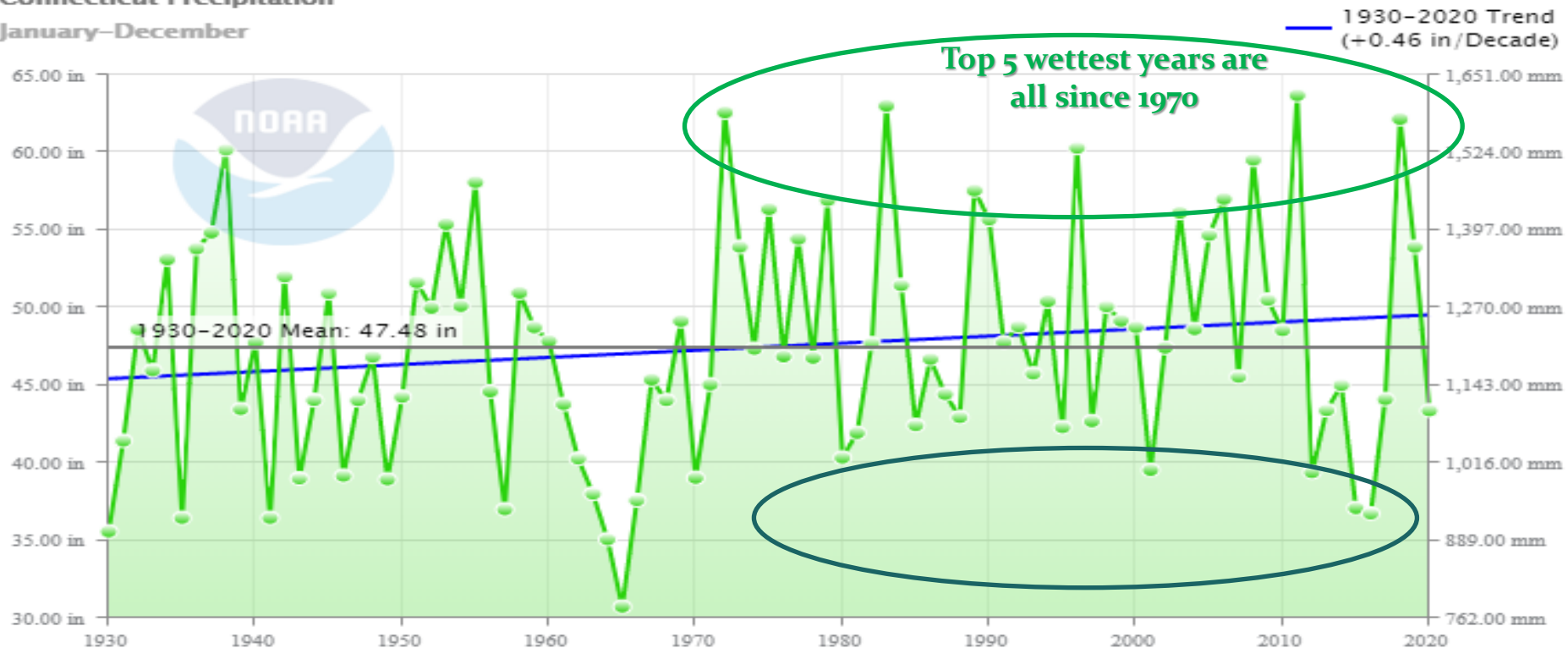
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# A Look at Connecticut Annual Precipitation Trends

Connecticut Precipitation  
January–December



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



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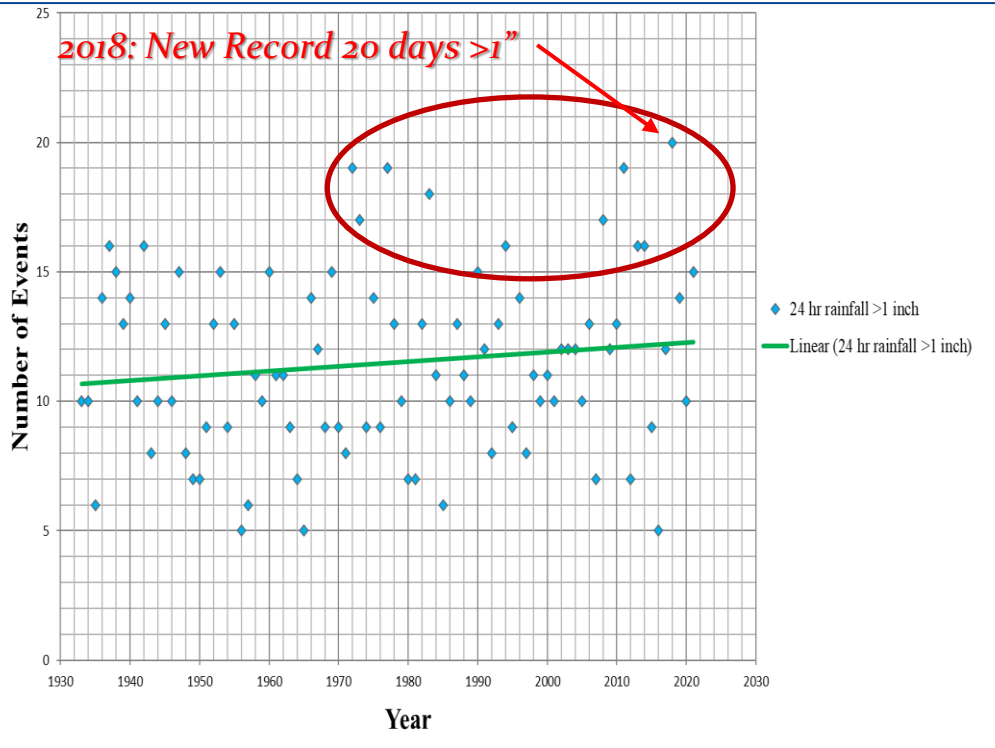
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# Intense Precipitation Trends

Frequency of  $\geq 1$  inch rainfall events Hartford, CT  
1930 through 2020



## Flash flood inducing rainfall

- August 13<sup>th</sup>, 2014 Long Island, NY:  
1.08 inches / 8 minutes  
11 inches / 3 hours  
13.57 inches / 24 hours
- September 25<sup>th</sup>, 2018 Westport, CT:  
5-7 inches / 3 hours
- August 22<sup>nd</sup>, 2021 Manchester, CT:  
4-6 inches in 2-3 hours ~ Henri
- September 1<sup>st</sup>, 2021 New York City:  
3.15 inches in 1 hour ~ Ida

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



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<http://www.weather.gov/nerfc>  
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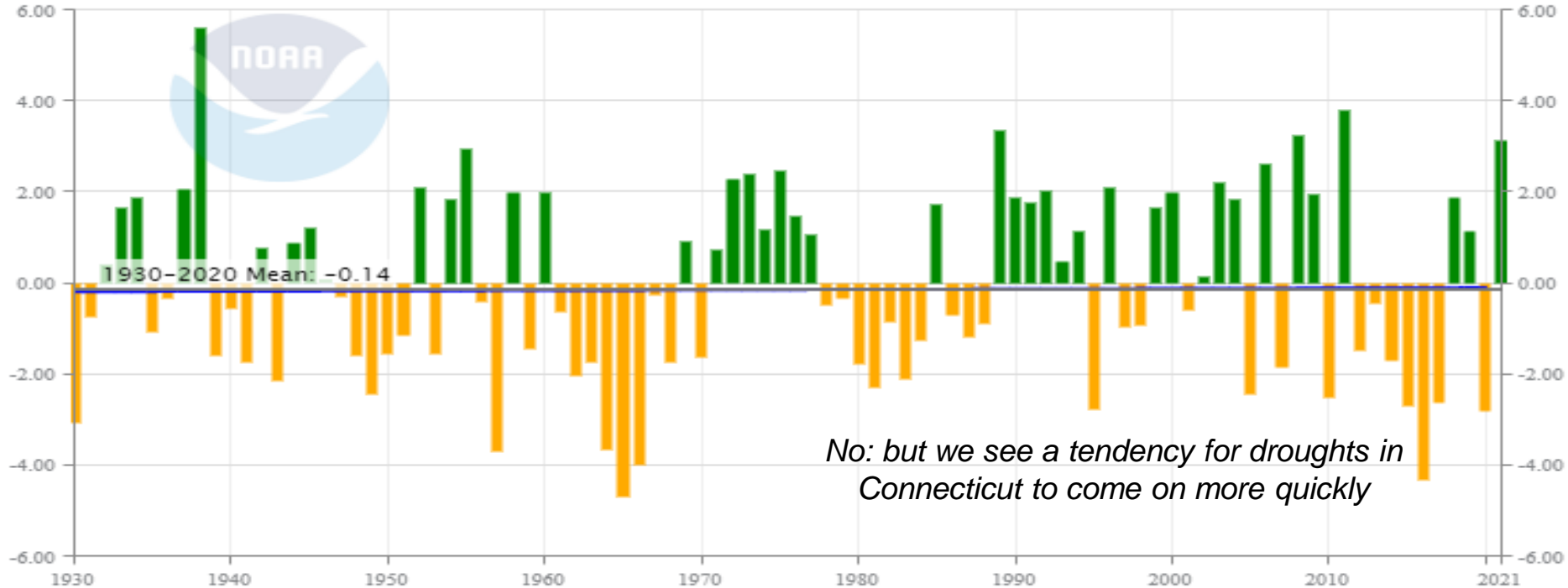


# So Do Droughts Become A Thing of the Past?

Connecticut Palmer Drought Severity Index (PDSI)

September

1930-2020 Trend  
(+0.01 / Decade)



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



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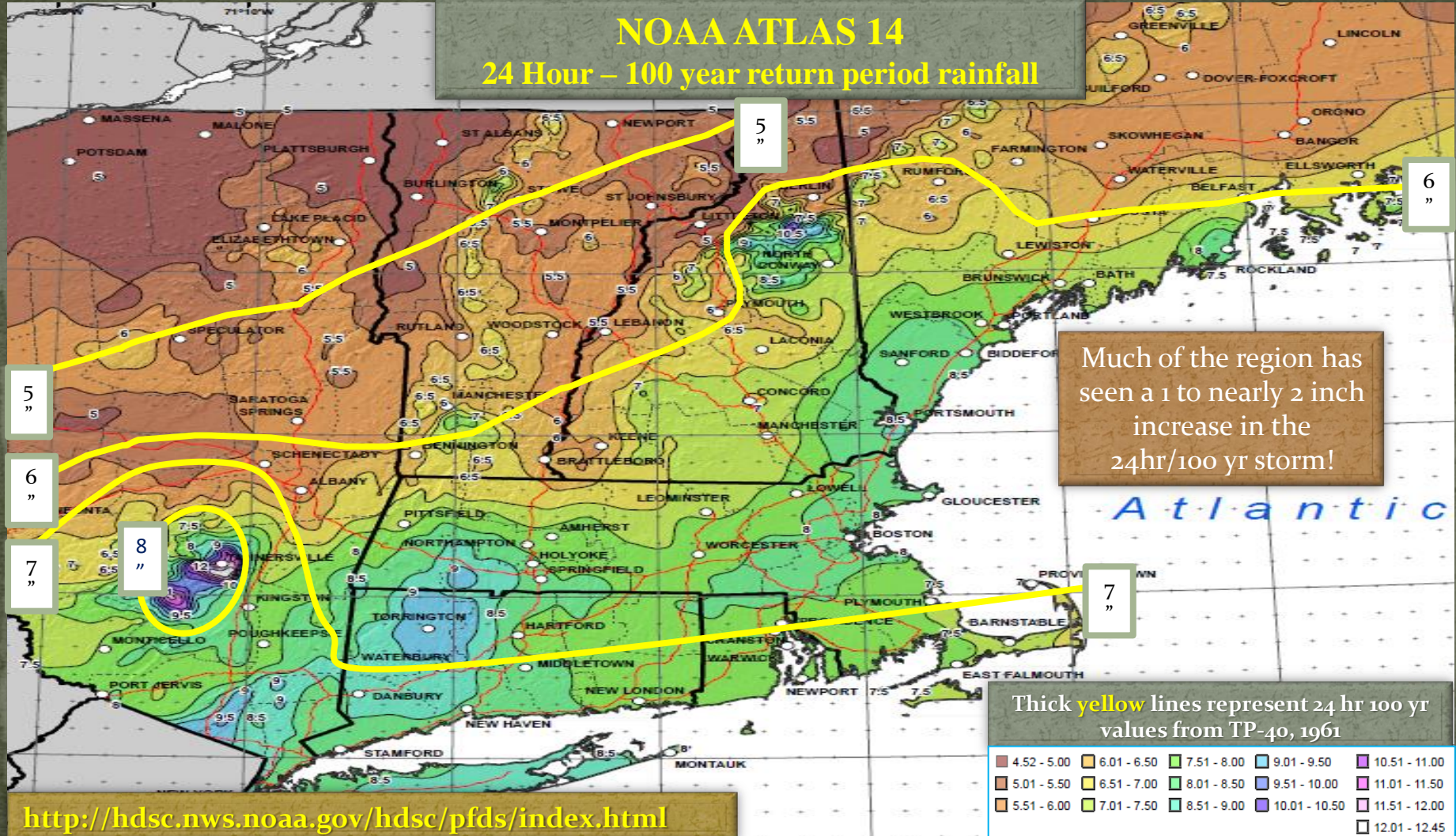
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# NOAA ATLAS 14

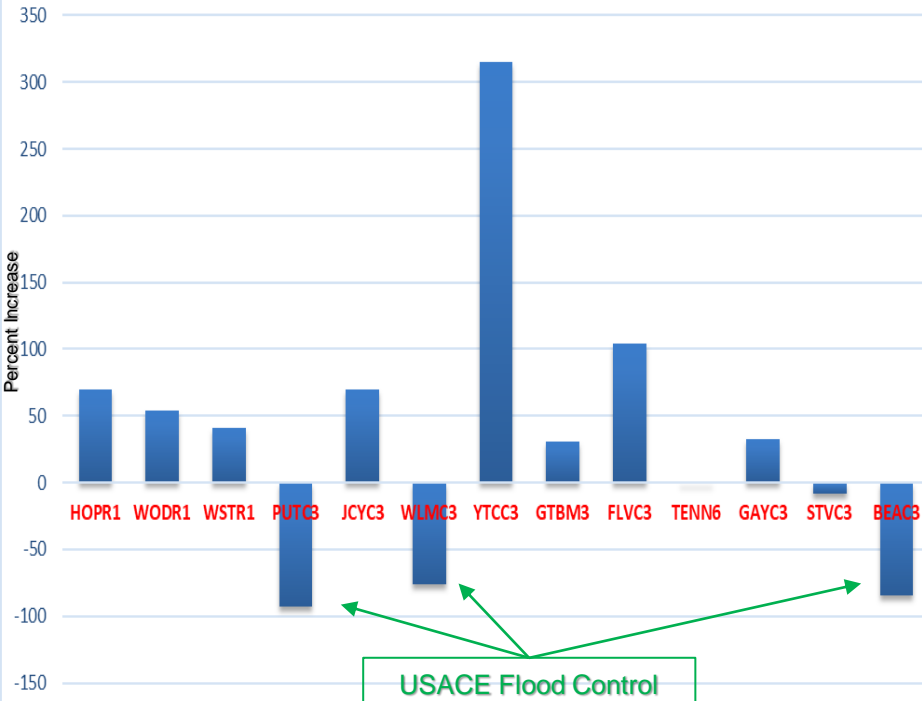
## 24 Hour – 100 year return period rainfall



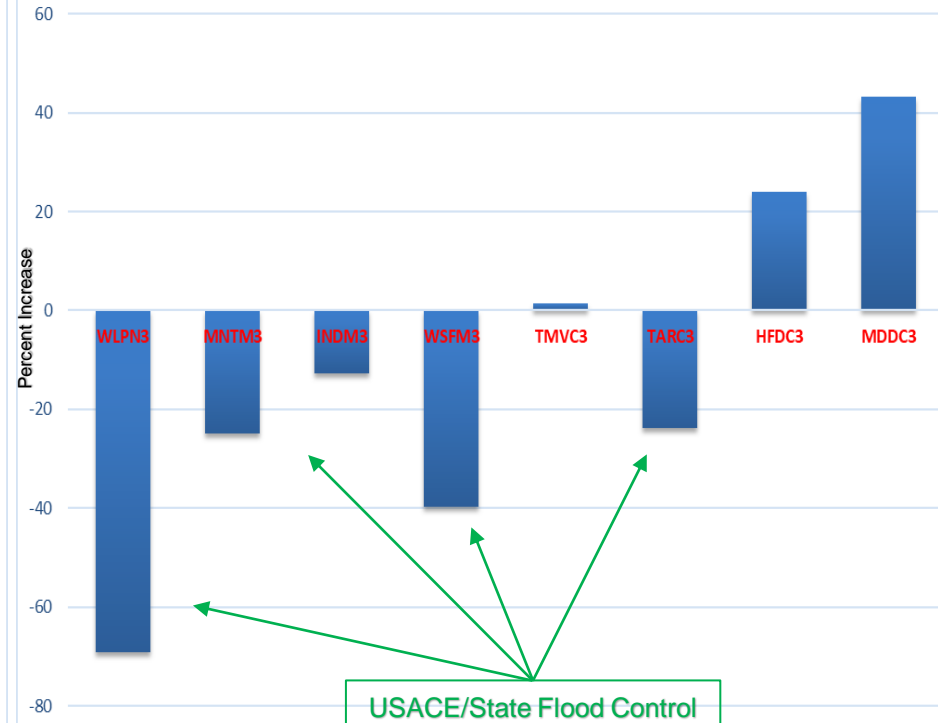


# The Riverine Response: Increased Flooding

Southern New England River Basin Flooding  
Percent Increase Pre 1970 vs. Post 1970



Lower Connecticut River Basin Flooding  
Percent Increase Pre 1970 vs. Post 1970





Record Flash Flooding from 5-7 inches of rain. Westport, CT  
September 25<sup>th</sup>, 2018. Photo: Westport Fire Department



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



Warwick Mall overtaken by the Pawtuxet River - Warwick, RI at  
1030 am Wednesday 3/31/10. Photo: RI ANG



Record flooding in Dolgeville, NY on West Canada Creek, November  
1<sup>st</sup>, 2019. Source: D. McGee, Office of the Governor



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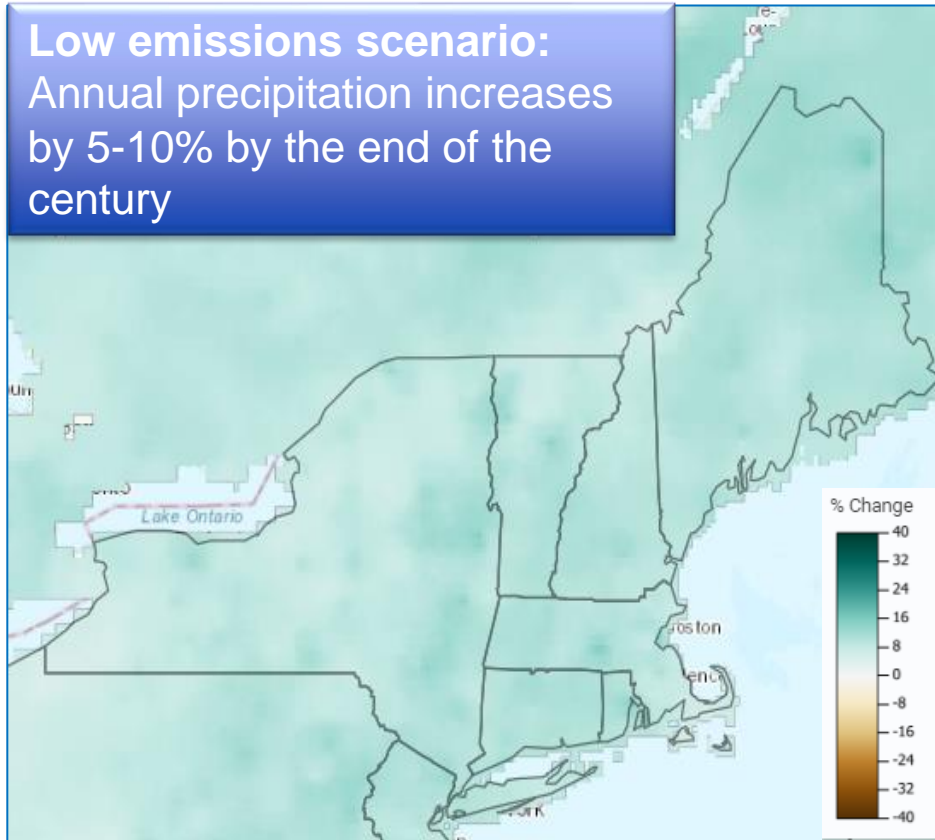


# Precipitation Projections

<https://crt-climate-explorer.nemac.org/>

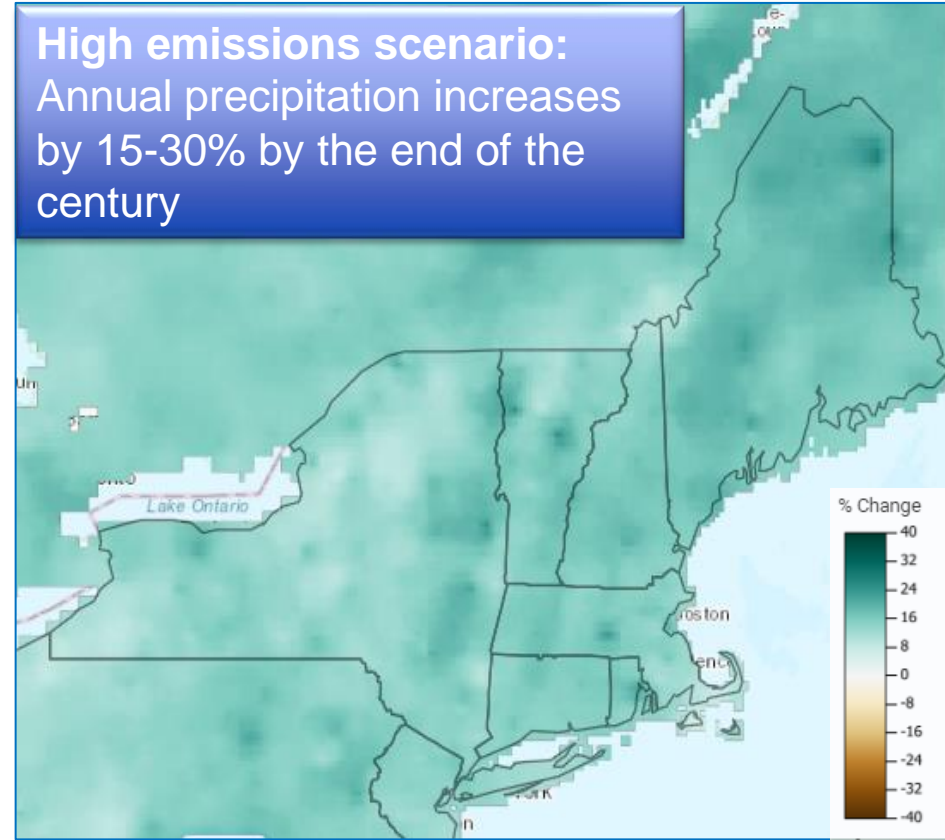
## Low emissions scenario:

Annual precipitation increases by 5-10% by the end of the century



## High emissions scenario:

Annual precipitation increases by 15-30% by the end of the century



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# Fitting our recent Tropical Cyclones into the pattern

- What's changed:
  - Rapidly accelerating storms seem a bit less frequent
  - Slower moving systems at our latitude always pose a significant flood risk
  - Increased frequency of very high moisture content (plumes)
- The Net Result:
  - Increased risk for significant/catastrophic events!



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# Rapid Acceleration Northward – well they used to accelerate

- Average forward motion for storms impacting New England: **33 mph**
- The Great New England Hurricane of 1938 made the trip from Cape Hatteras, NC to Providence, RI in 8 hours!
  - Forward speed at landfall was at least 51 mph and estimated as high as 60 mph
- Watch out for those slower movers
  - These tend to be prolific rainfall producers!

Storm	Forward Motion
New England Hurricane of 1938	>50 mph
Atlantic Hurricane of 1944	29 mph
Carol – August 1954	35 mph
Edna – September 1954	46 mph
Diane – August 1955	15 mph
Donna – September 1960	24 mph
Gloria – September 1985	45 mph
Bob – August 1991	32 mph
Floyd – September 1999	30 mph
Irene – August 2011	20 mph



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# A different behavior over the past 10 years

- Only three systems were “rapid accelerating” system
  - Average forward motion: 24 mph
- Seven produced heavy rains and flooding
  - Six of these were considered slower movers which passed over or south/east of the region resulting in torrential rainfall and flash flooding
- Most of the rainfall occurred in less than 24 hours
  - Several in less than 12 hours!

Storm	Forward Motion
Irene – August 2011 (10-16 inches eastern NY and western NE)	20 mph
Andrea – June 2013 (3-5 inches)	35 mph
Arthur – July 2014 (5-8 inches – southeast MA)	24 mph
Florence – 2018 (4-8 inches in CT)	15 mph
Isaias – 2020 (2-4 inches in NY)	40 mph
Elsa – 2021 (5-7 inches in CT)	31 mph
Fred – 2021 (4-8 inches in central NY)	14 mph
Henri – 2021 (5-9 inches southeast NY and CT)	10 mph
Ida – 2021 (5-9 inches southeast NY, CT, RI, and southeast MA)	25 mph



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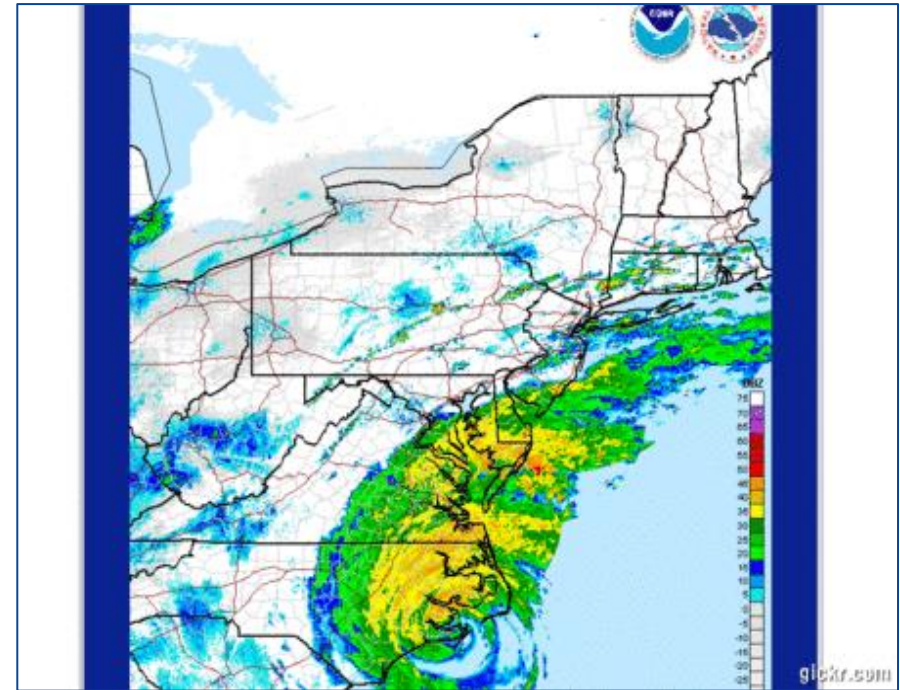
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# Heavy Rainfall Characteristics

- *Heaviest rainfall is almost always along or left of track*
  - A subset of storms produced the heaviest rains right along track (Carol 1954)
- Some systems “changed phase” as they turned and accelerated northeastward
- Nearly ½ of all our storms produced small stream/river flooding in the region!
- Average rainfall 6-8 inches
  - Blockbuster rains with some slower movers
    - Diane ‘1955 (15-20 inches)
    - Irene 2011 (10-16 inches)



Radar loop of Tropical Storm Irene's arrival  
in New England



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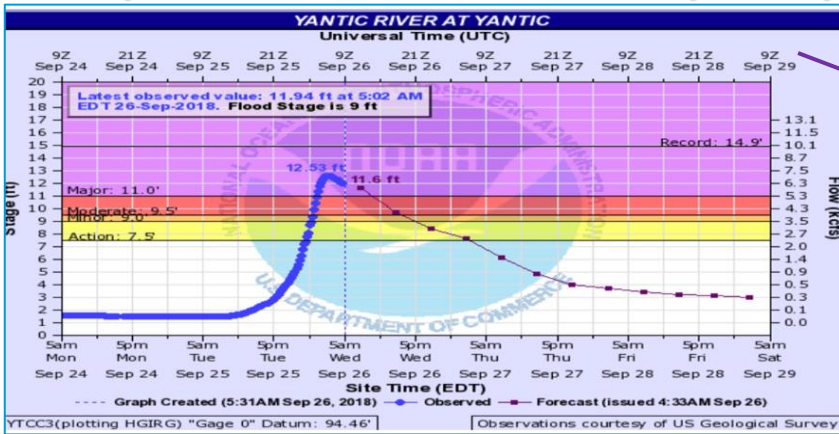
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<http://www.weather.gov/nerfc>

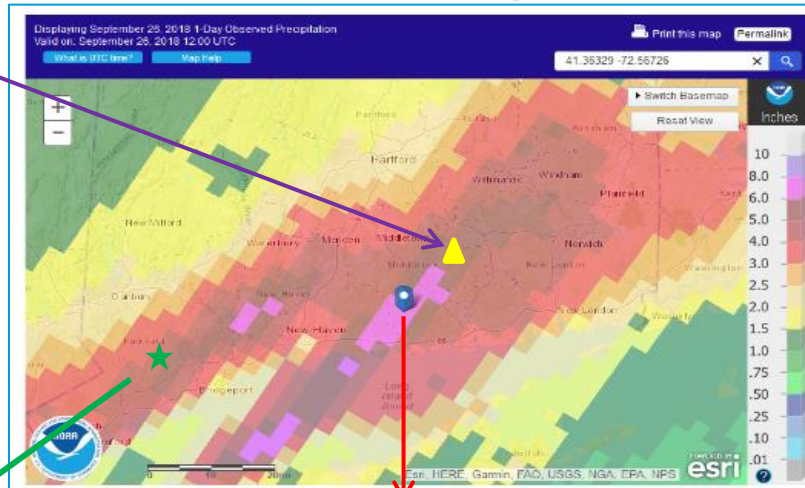
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# Remnants of Hurricane Florence – September 25<sup>th</sup>, 2018

100 yr events are more like 60 yr; 50 yr events more like 25-30 yr



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



Killingworth, CT experienced 6.78 inches in ~ 12 hours 100 yr return period or 1% Annual Exceedance Probability

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



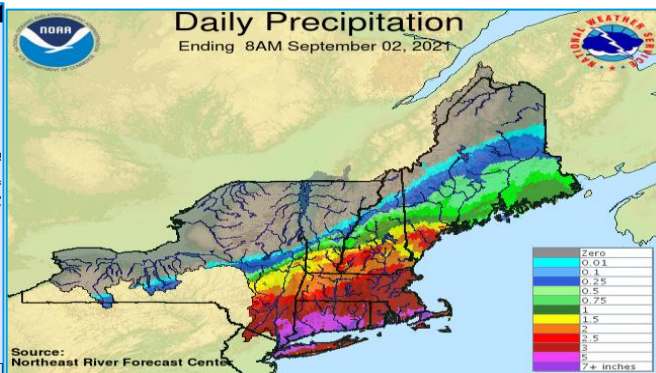
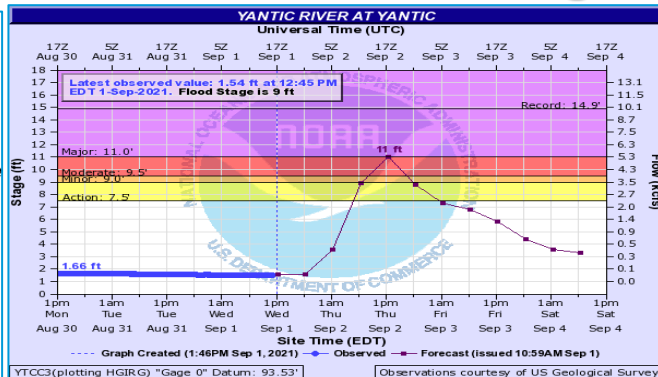
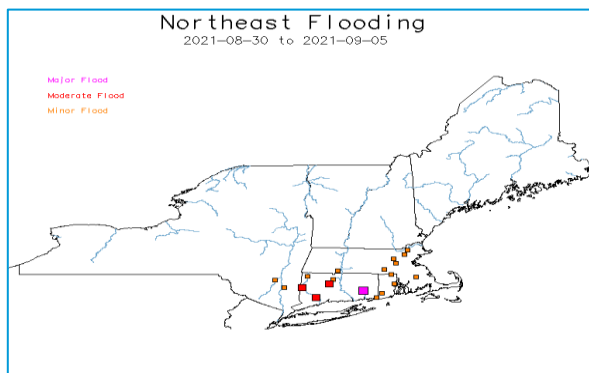
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# Remnants of Hurricane Ida

## Repeat performance in and around Yantic...again



Flooding at West Town Street, Norwich, CT, Sept 2, 2021.  
Image: NBCConnecticut



The swollen Yantic River at Yantic Falls Heritage Park following Ida's torrential rains. Photo: S. Elliot/The Day



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# Practices that are working to mitigate losses due to heavy rains, flooding, and storm surge



Natural valley storage



Building for the new normal



Setbacks & Elevating critical systems



Bioswales & Porous Pavement



Elevate & Evacuate!



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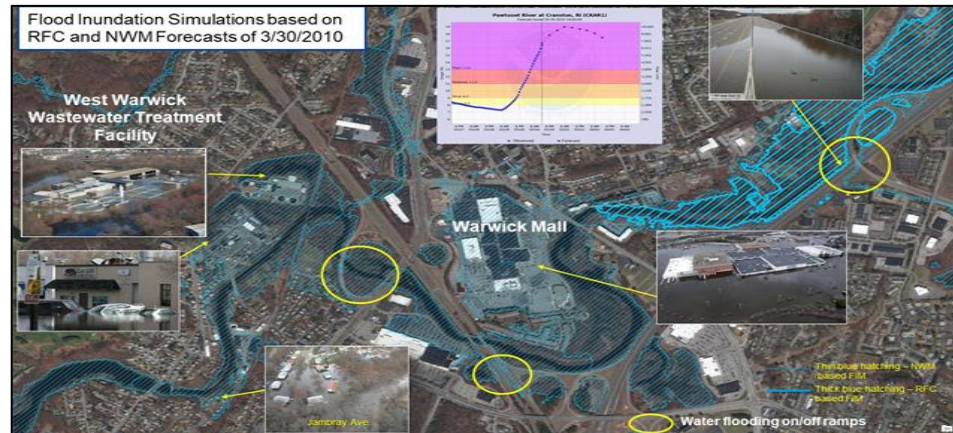
## Toward The Implementation of Near Real-Time Forecast Flood Inundation Mapping Services in the Northeast United States

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

Jason C. Elliott  
Service Coordination Hydrologist  
NOAA/NWS Northeast River Forecast Center



Example of our new experimental flood inundation forecast service, based on NERFC and National Water Model streamflow forecasts for August 27<sup>th</sup>, 2011



Example of our new experimental flood inundation forecast service, based on NERFC and National Water Model streamflow forecasts for March 30<sup>th</sup>, 2010





# Mitigate Flood Impacts by Demonstrating Improved Decision Support Services to Emergency Managers

**Achievement Statement:** By September 30, 2021, NOAA National Weather Service will improve its flood related decision support services by expanding the demonstration of a new flood inundation mapping capability to at least an additional 10% of the U.S. continental population residing in flood-vulnerable freshwater basins.

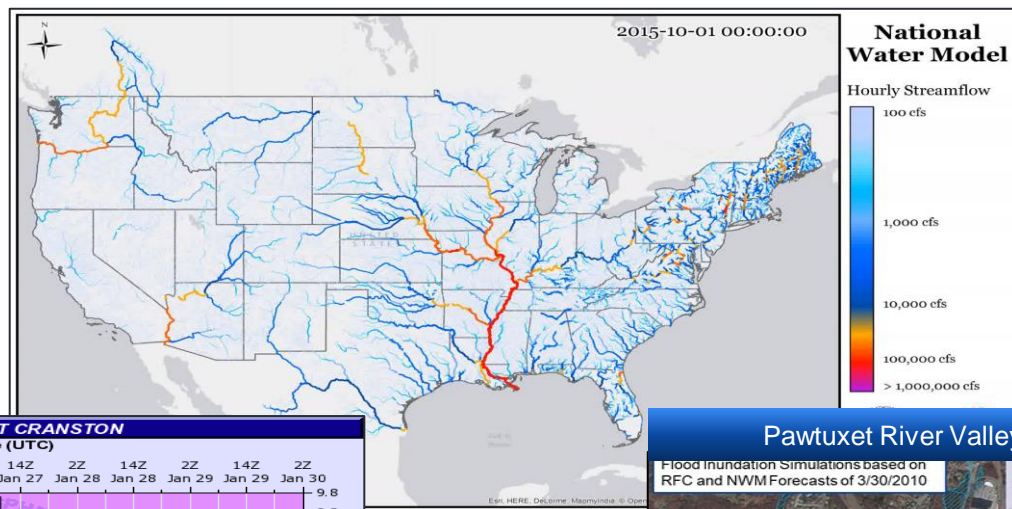
*Additional coverage includes population served with National Water Model hydrography downstream from a subset of NWS official forecast locations throughout the continental U.S., plus populations in the NWS Northeast River Forecast Center National Water Model locations.*

- Including two tabletop exercises:

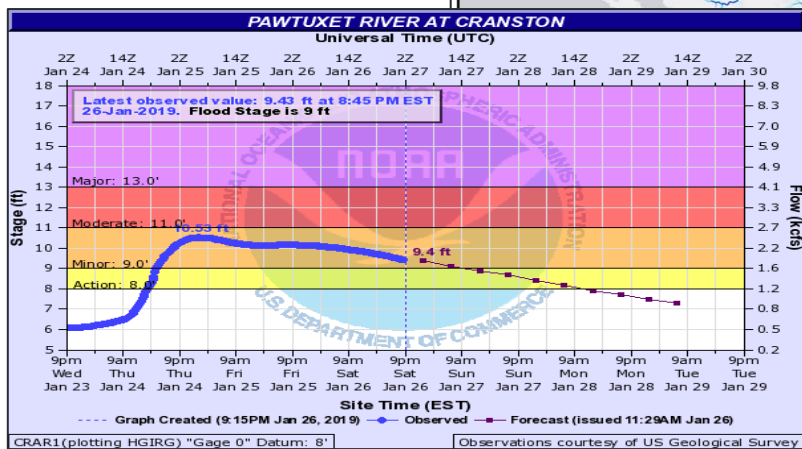
- ✓ 1. *Rhode Island – rerunning the late March 2010 Floods*
- ✓ 2. *New York – rerunning Tropical Storm Irene in the Schoharie Valley*

# Key Investment to Becoming a Water-Ready Nation:

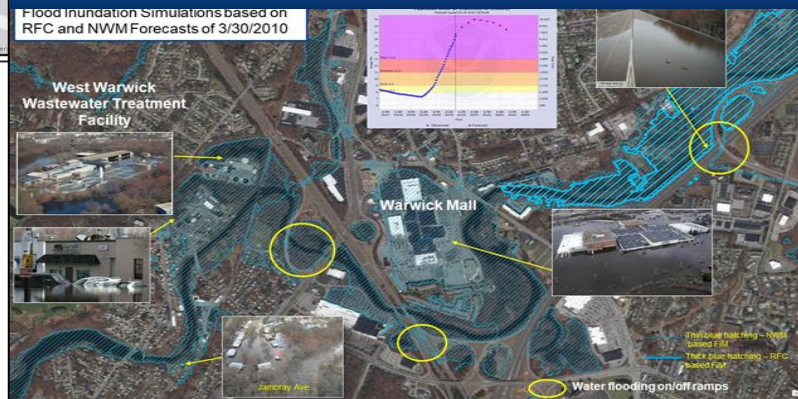
## *The National Water Model & Efforts to Deliver Forecast Inundation Services!*



### RFC Forecasts



### Pawtuxet River Valley – West Warwick/Warwick



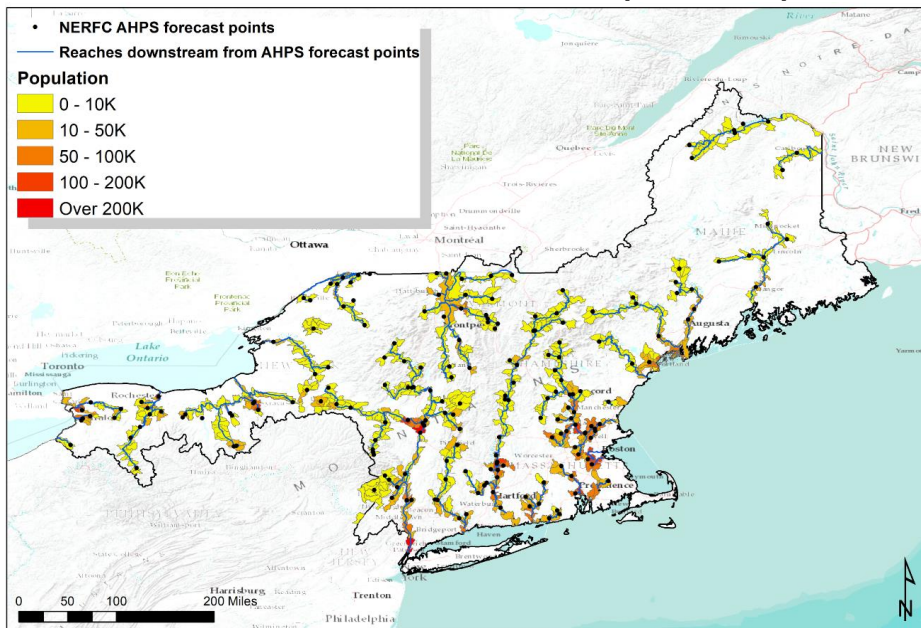
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# Two Sources for Inundation Guidance: RFC Forecasts & the NWM

## River Forecast Center based FIM (RFC FIM)

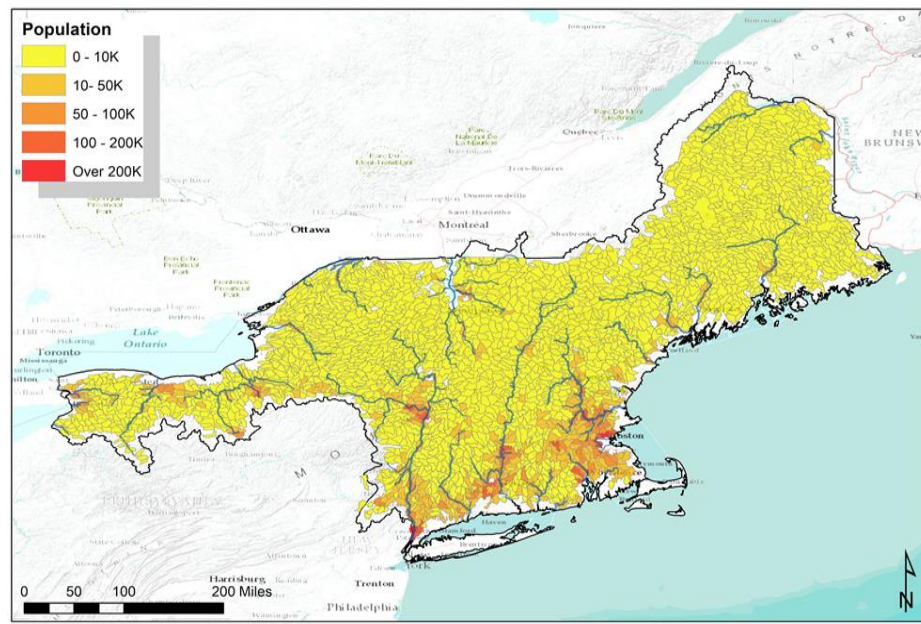


Total Population: 12,474,187

2017 Census Estimates

Higher confidence – as it is based off our official forecasts

## National Water Model FIM (NWM FIM)



Total Population: 15,271,484

2017 Census Estimates

Lower confidence – based off one of two weather model's rainfall forecast which may not represent our official forecast

\*Population totals based on 2017 population (327M) in adjacent hydrologic areas, defined by Hydrologic Unit Code (HUC) 12 delineations. Tidal areas will not be included at this time.

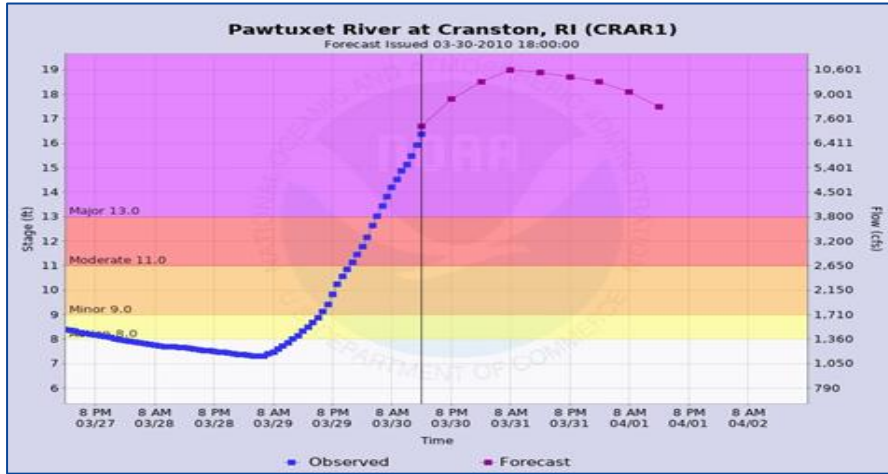


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# An Example: In 2010 for the Pawtuxet Basin: *Cranston, Warwick, West Warwick*



- 14.5 Evacuations are likely near the Pawtuxet river in Warwick and Cranston. Both homes and businesses will be impacted from this flood event. Businesses and homes will be impacted on streets including but not limited to the following, in Warwick, Pioneer Avenue, Bellows Street, Venturi Avenue and River Street. In Cranston, Wellington Avenue and Avery Road. In West Warwick, Daisy Street, the lower ends of Canna, Begonia and Aster Streets, and portions of Providence Street to Route 2.
- 12 Evacuations are likely near the Pawtuxet River in Warwick and Cranston. Both homes and businesses will be impacted from this flood event. Businesses and homes will be impacted on streets including but not limited to the following, in Warwick, Pioneer Avenue, Bellows Street, Venturi Avenue, and River Street. In Cranston, Wellington Avenue and Avery Road. In West Warwick, Daisy Street, the lower ends of Canna, Begonia and Aster Streets, and portions of Providence Street to Route 2.
- 11.5 Homes and businesses are impacted in low lying sections of Warwick, West Warwick and Cranston. Affected roads in Cranston include Avery Road and Wellington Avenue. Affected roads in Warwick include Pioneer Avenue, River Street, Bellows Street and Venturi Avenue. In West Warwick, affected areas include Daisy Street and the lower ends of Canna, Begonia and Aster Streets.
- 11 Structures and homes are impacted in low lying sections of Warwick. Affected areas include homes and businesses on Wellington Avenue and Avery Road in Cranston, as well as Pioneer Avenue, Bellows Street, Venturi Avenue and a portion of River Street in Warwick.
- 10 Flooding will occur along Pioneer Avenue, Bellows Street and Venturi Avenue in Warwick. Some homes are impacted on Avery Road and Wellington Avenue in Cranston.
- 9.5 Parking lots and roads are flooded in low lying areas of Warwick and Cranston near the Pawtuxet River. Impacted roads include River Street, Pioneer Avenue, Bellows Street and Venturi Avenue in Warwick.
- 9 Minor lowland flooding will occur along the river as it flows through Warwick and Cranston.

- County based generic flood warnings which provided timing information but lacked any specifics on impacts
- Conference calls with the state & local communities where we tried to leverage the FEMA Flood Insurance Rate Maps as our Guide for potential impacts



# Our Future Forecast Inundation Services...



Pawtuxet River Basin

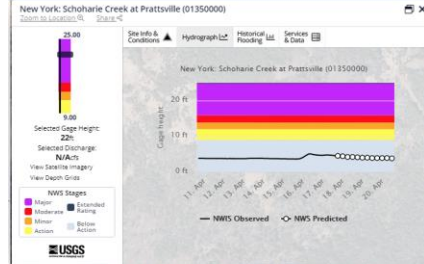


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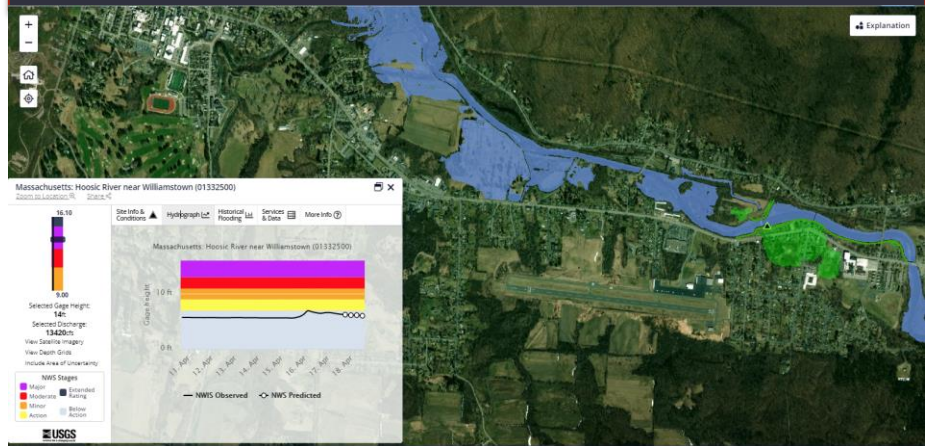


# Leveraging the outstanding work by the USGS

- USGS static inundation libraries and their studies have informed the NWS approach
- Being used as validation of our HAND method for inundation production
- National effort to integrate these analyses where available into one NOAA led integrated national inundation projection (iFIM)



Available at <http://fim.wim.usgs.gov/fim> and at <https://water.weather.gov/ahps2/index.php?wfo=aly>



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# Prototype Forecast of Inundation

- Based off the Northeast River Forecast Center forecast at Yantic for Ida
- A picture really is worth a thousand words!

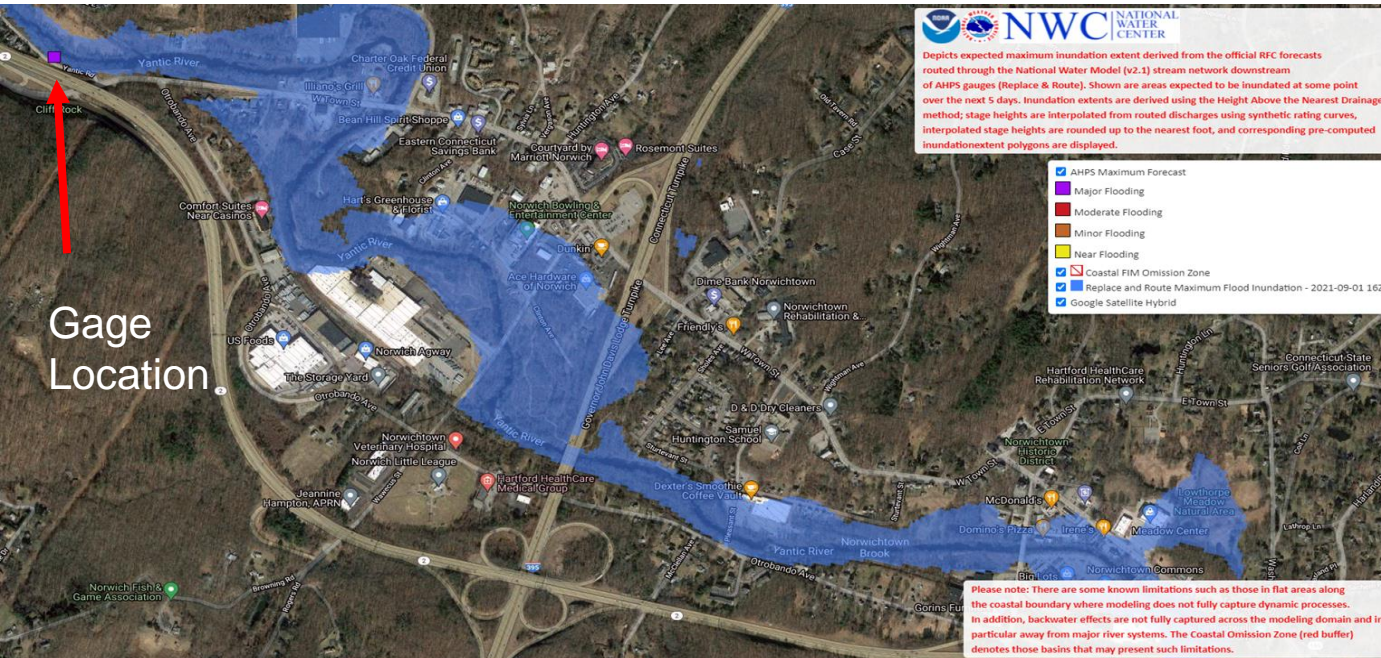
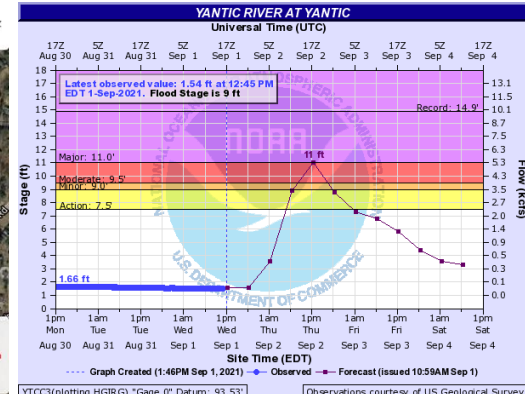


Image at left is the RFC FIM from Ida on the Yantic River (noon, September 1st, 2021) -- note the inundation extent

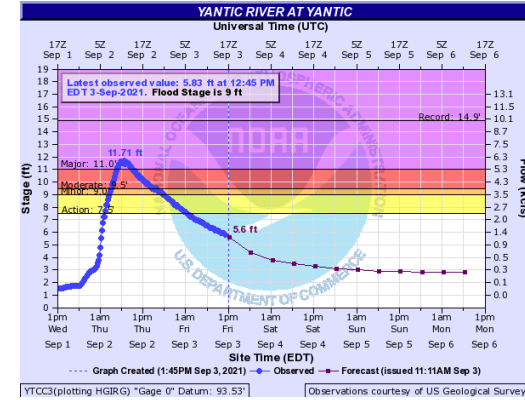
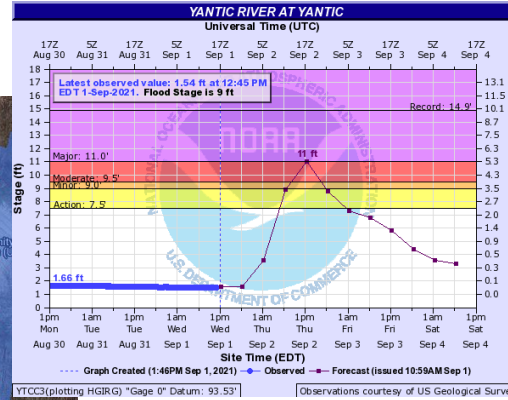


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# Prototype Forecast of Inundation

How accurate were the forecasts and maps?



River ended up ~ $\frac{3}{4}$  foot higher than forecast

Maps look a little overdone, at least based on this picture, but not too bad!  
The hair salon across the parking lot from Domino's had water inside it



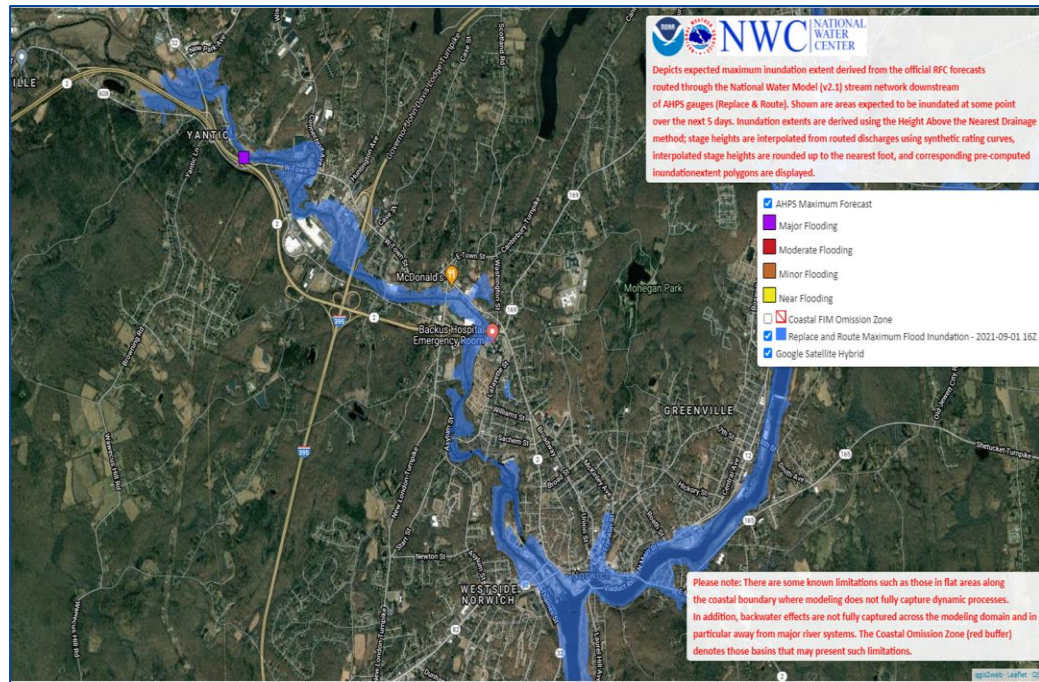
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# Our immediate challenges and pathway forward...

- The techniques for producing FIM forecasts and analyses continue to evolve
- More robust validation is required to continue to build confidence in these services
- Significant training effort required for both NWS forecasters & our partners
- Over the next year we will be developing a Concept of Operations for the delivery of services
- Continuing to expand our evaluation of these new services and the tools to do so





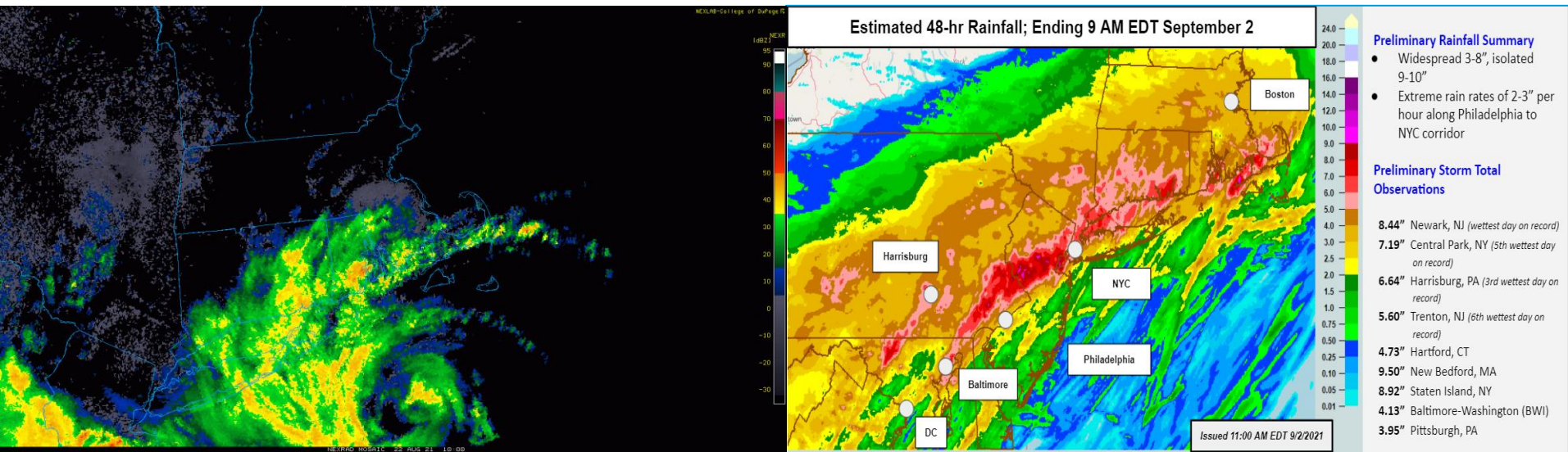


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## *Torrential Rains from Slow Moving Tropical Systems; Is This the New Normal?*



Henri making landfall – August 22<sup>nd</sup>, 2021

Ida's devastating rainfall – Sept 1-2, 2021

David R. Vallee  
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NOAA/NWS Northeast River Forecast Center