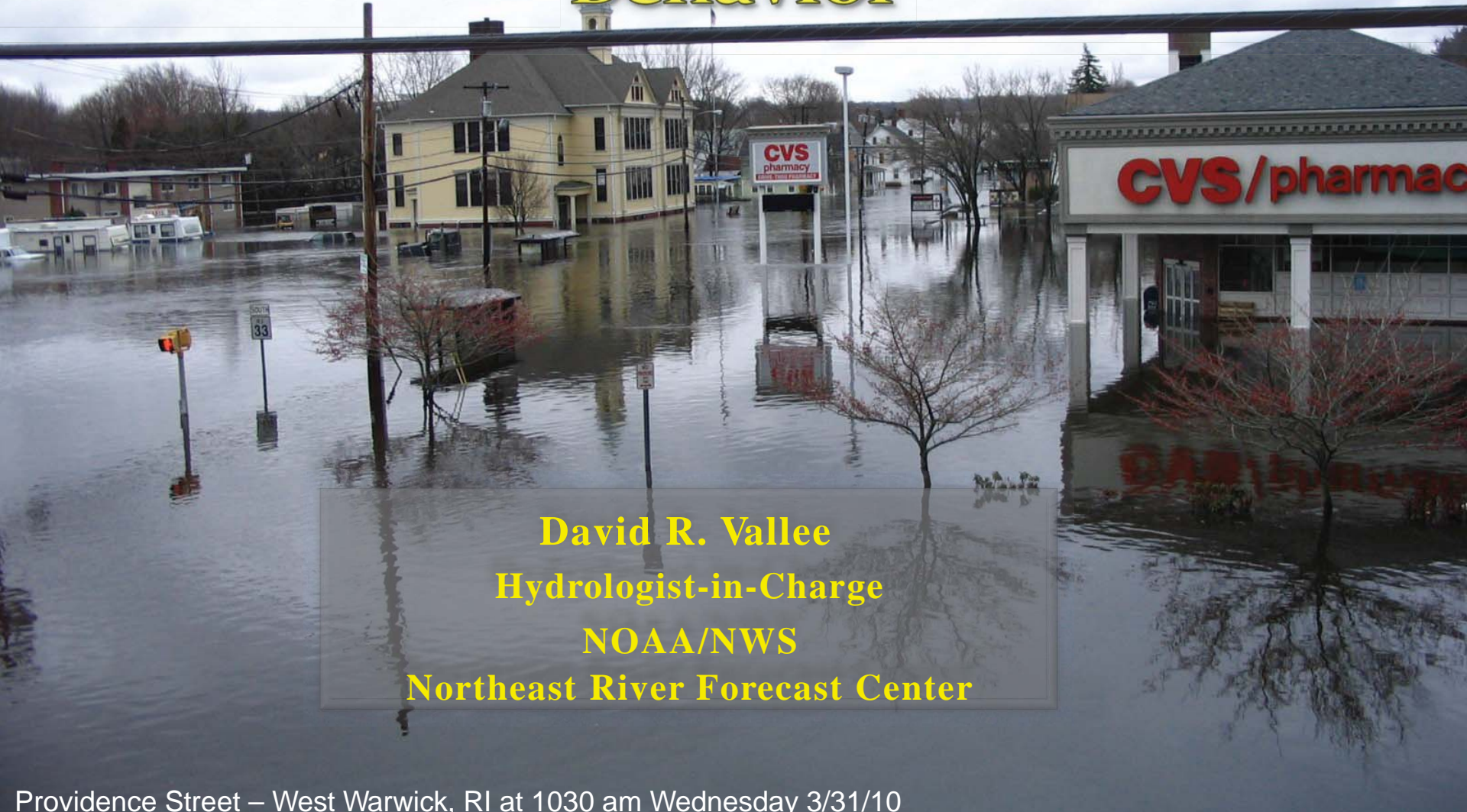


Climate Trends in Rhode Island and Its Impact on Riverine & Coastal Flood Behavior



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

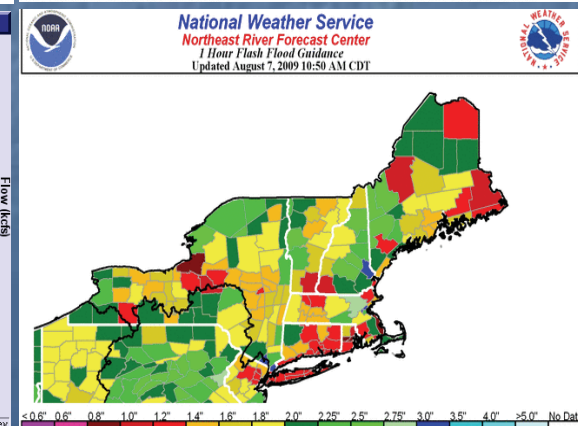
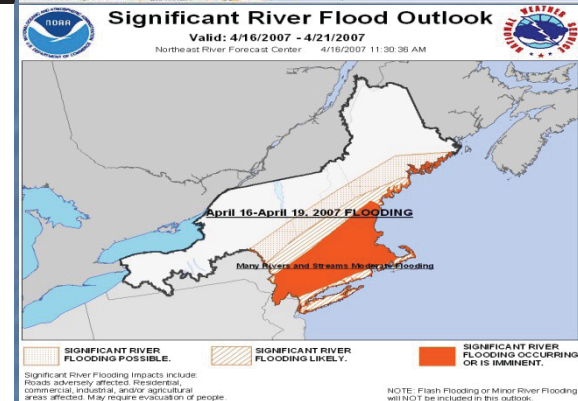
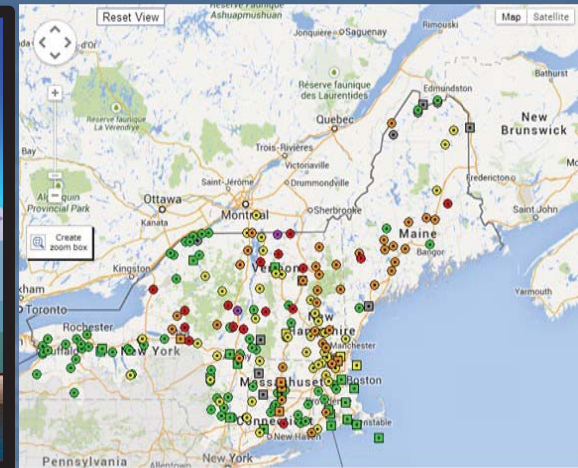
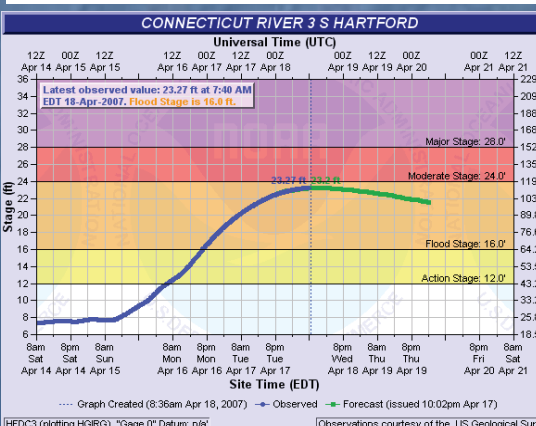
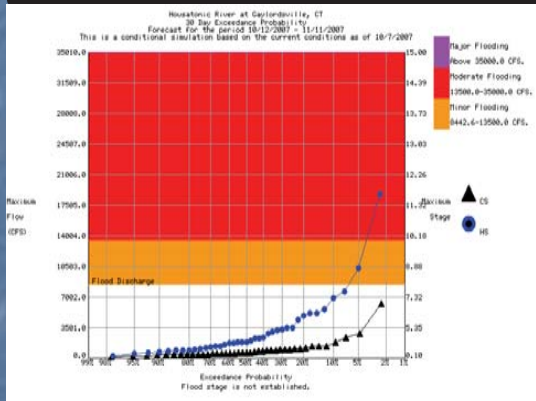
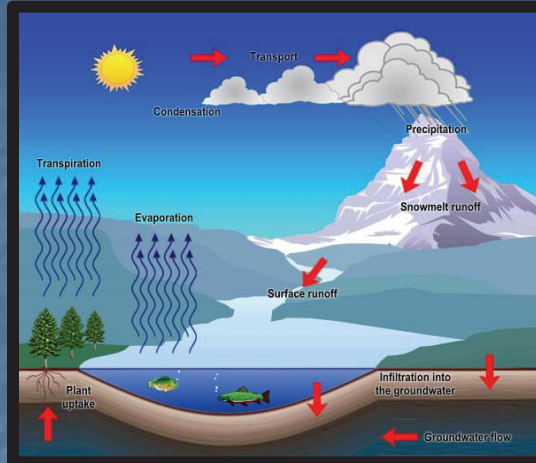
Outline

- From a “Practitioner’s Perspective”
- Two Parts:
 - Part I: Rainfall/Temperature trends and changes in flood behavior
 - Part II: The coastline and its vulnerability; lessons from Sandy
- But first...a bit about NWS services in the basin

River Forecast Center Responsibilities

Calibrate and implement variety of hydrologic and hydraulic models and produce temperature and precipitation forecasts 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
- ■ Reservoir Inflow Forecasts



Moderate flooding - Connecticut River at Portland, CT.

Partnerships are key

- NWS provides forecasts & warnings
 - Establish flood stages, watch/warning dissemination, AHPS web service, decision support to Federal, State & Local authorities
- NWS relies on other agencies for stream gaging & reservoir data
 - USGS is a huge partner - they maintain many of the river/stream gages NWS relies on
 - USACE provides data for their flood control reservoirs
 - Providence Water provides data for Scituate reservoir



US Army Corps of Engineers



Wood-Pawcatuck Watershed Association

Our mission is to promote and protect the integrity of the lands and waters of the Wood and Pawcatuck watersheds



The Northeast River Forecast Center

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



NATIONAL WEATHER SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION



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[ABOUT](#)

Local forecast by
"City, St" or ZIP code

Enter location ...

Go

[Location Help](#)

News Headlines

- NERFC is transitioning our web page to a new format starting on April 9. [Info on transitioning to the new page.](#)
- There is significant flood potential this week from rain and snow melt. [Briefing slides are available here.](#)

Northeast River Forecast Center

[Weather.gov](#) > Northeast River Forecast Center

Northeast River Forecast Center

River Forecast Center

[River Observations and Forecasts](#)

[Weather Observations and Forecasts](#)

[Water Supply](#)

[Climate and History](#)

[Seasonal Interest](#)

[Additional Info](#)

FLOOD STATEMENTS

Click for details

All Locations

- ☐ River Observations
- ☐ River Forecasts

Auto Refresh is OFF



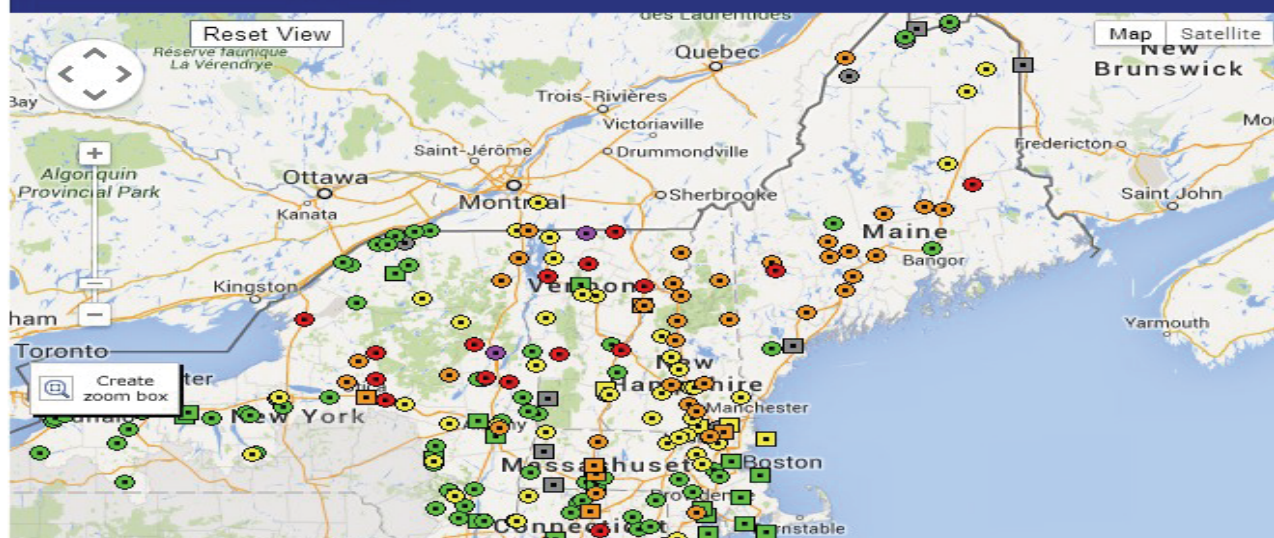
Maximum Forecast Flood Category Through: 04/25/2014 03:58:52 UTC



Entire
Period

Print this map

Reset View



Map Satellite
New Brunswick

Click on the map or select one of the data views below:

- ☐ Hydrograph Available
- ☒ Probability and Hydrograph Available

United States
NWS Weather Forecast Offices
Northeast River Forecast Center
Water Resources Regions

206 total gauges
Show all locations in flood (60)

- 2 Gauges: Major Flooding
- 16 Gauges: Moderate Flooding
- 42 Gauges: Minor Flooding
- 45 Gauges: Near Flood Stage
- 88 Gauges: No Flooding
- 0 Gauges: Forecasts older than 24 hours
- 13 Gauges: No forecast within selected timeframe
- 0 Gauges: Out of Service

Show all locations

The Taunton Weather Forecast Office

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



HOME FORECAST PAST WEATHER WEATHER SAFETY INFORMATION CENTER NEWS SEARCH ABOUT

Local forecast by
"City, ST" or ZIP code

Enter location ...

[Location Help](#)

News Headlines

- [Upcoming SKYWARN Classes - Only 2 Classes Left!](#)
- [Check Out our Latest Office Newsletter](#)

NWS Weather Forecast Office - Boston / Taunton, MA

[Weather.gov](#) > Boston, MA

Boston, MA

Weather Forecast Office

[Current Hazards](#) [Current Conditions](#) [Radar](#) [Forecasts](#) [Rivers and Lakes](#) [Climate and Past Weather](#) [Local Programs](#)

Click on the map below to zoom in.



Last Map Update: Wed, Jun. 11, 2014 at 2:43:09 pm EDT

[Watches,
Warnings &
Advisories](#)

[Small Craft Advisory](#)



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[River Forecasts](#)

[Experimental
Long-Range Flood Risk](#)

[Precipitation](#)

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Auto Refresh is OFF

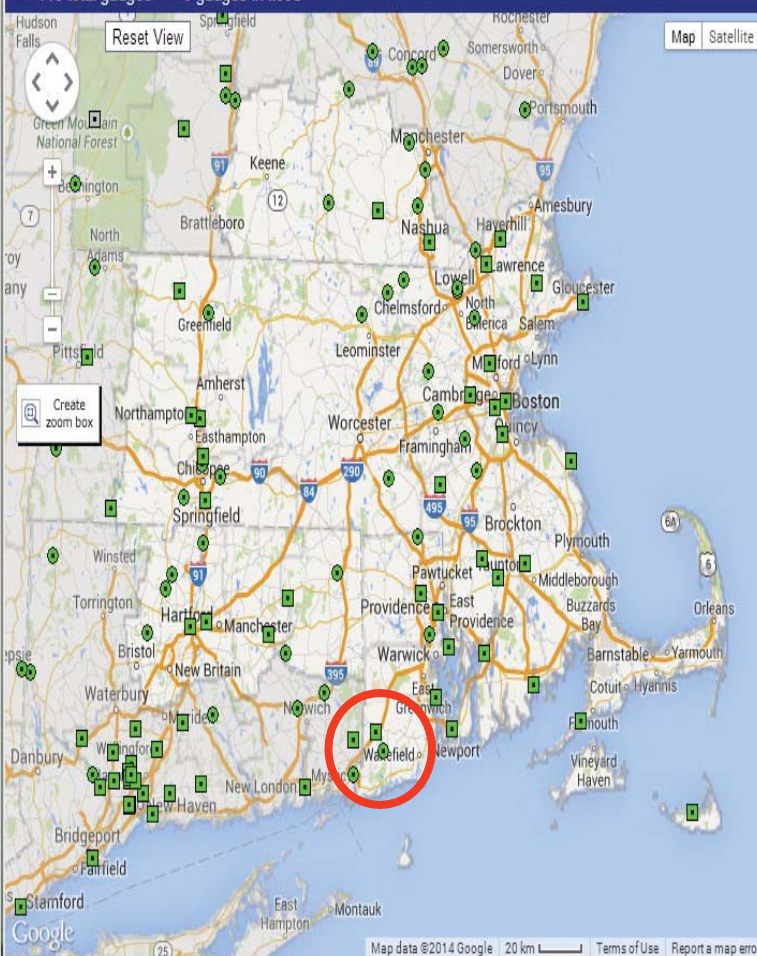


Print this map

[Permalink](#)

[BOOKMARK](#)

118 total gauges 0 gauges in flood



☐ Hydrograph
Available

☐ Probability
and Hydrograph
Available

☐ Major Flooding

☐ Moderate
Flooding

☐ Minor Flooding

☐ Near Flood Stage

☐ No Flooding

☐ Observation More
Than 24 Hours
Old

☐ Out of Service

Last map update: 06/20/2014
at 01:38:34 pm EDT
06/20/2014 17:38:34 UTC

[What is UTC time?](#)

[Disclaimer](#)



Map data ©2014 Google 20 km [Terms of Use](#) [Report a map error](#)

The Advanced Hydrologic Prediction Service AHPS

Northeast River Forecast Center

[Weather.gov](#) > Northeast River Forecast Center

Northeast River Forecast Center

River Forecast Center

[River Observations and Forecasts](#)

[Weather Observations and Forecasts](#)

[Water Supply](#)

[Climate and History](#)

[Seasonal Interest](#)

[Additional Info](#)

FLOOD STATEMENTS
Click for details

All Locations

- ☐ River Observations
- ☐ River Forecasts

Auto Refresh is OFF

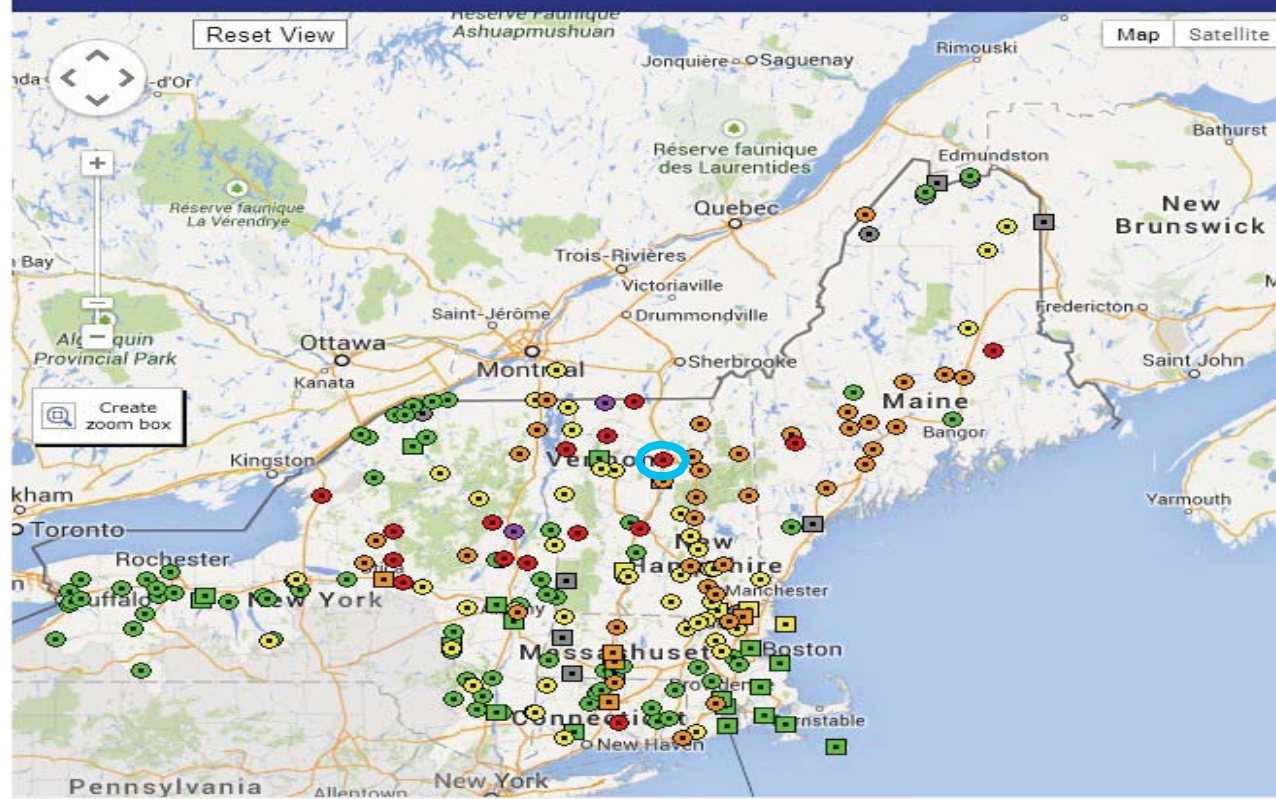


Maximum Forecast Flood Category Through: 04/25/2014 03:28:08 UTC



Entire
Period

Print this map



Click on the map or select one of the data views below:

- ☐ Hydrograph Available
- ☐ Probability and Hydrograph Available

United States

NWS Weather Forecast Offices

Northeast River Forecast Center

Water Resources Regions

206 total gauges

Show all locations in flood (60)

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- 0 Gauges: Forecasts older than 24 hours
- 13 Gauges: No forecast within selected timeframe
- 0 Gauges: Out of Service

Show all locations

Last map update: 04/15/2014 at 11:28:08 pm EDT
04/16/2014 03:28:08 UTC

What is UTC time?

Disclaimer



Flood Warning

Flood Watch

[View all valid statements/warnings](#)

Hydrograph

River at a Glance

Download

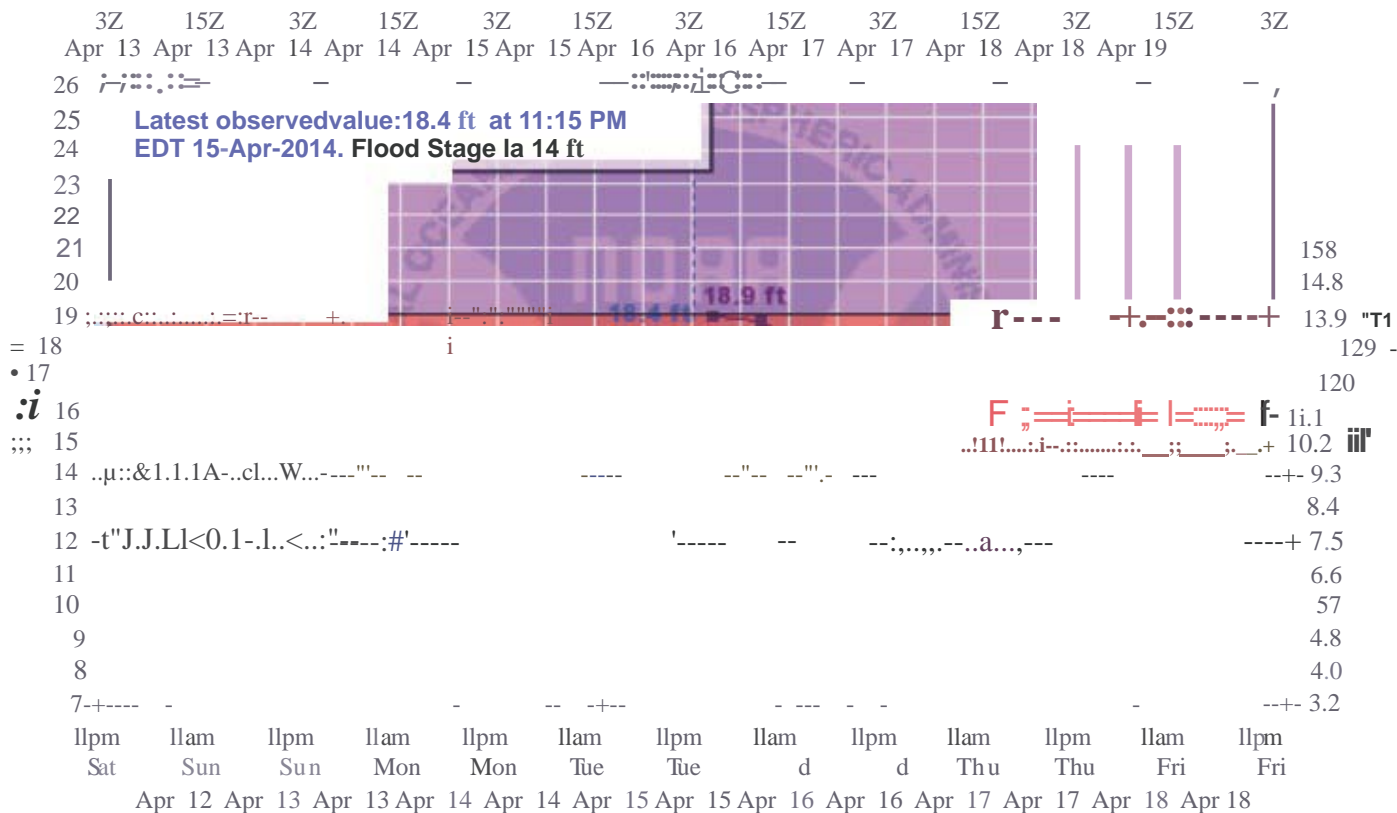
Probability Information

Auto Refresh is OFF



PASSUMPS/ C RIVER AT PASSUMPS/ C

Universal Time (UTC)



Site Time (EDT)

--- Graph Created (11:31PM Apr 15, 2014) -- Observed ---- Forecast (issued 11:06PM Apr 15)

Text Products

Flood Warning

FLOOD STATE.MENT

NATIONAL WEAT3:ER SERVICE 3URLINGTON VT PM EDT TUE APR
1140 15 2014

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CALEDONIA VT-ESSEX

1140 PM EDT TUE APR 15 2014

...T::ie FLOOD WARN::::NG REL INS IN EFFECT UNTI=- 545 Al"'! EDT WEDNESDAY FOR ORT:!!EASTERN
N CALEDONIA COUNTY IN NORT:!!EAST VERMONT ...AND WEST CENTRAL
ESSEX COUNTY IN NORT:!!ERN VERMONT ...

AT 1132 PM EDT ...T3:E EAST 3RANC3 OF T3:E PASSOMPSIC RIVER NEA-"1 EAST
HAVEN 3AS CRESTED. WATER LEVELS WILL SLOWLY FALL AFTER MIDNIG3T IN LYNDON ALONG T:i:E PASSUMPSIC
RIVER. 30MES AND 3USI SSES ALONG ROUTE
5 T3ROUG3 SAINT J03NS3URY WI=-L CONTINUE TO EXPERIENCE FLOOD IMPACTS
T3.ROUG3 MID-MORNING WEDNESDAY UNTIL T:i:E RIVER RECEDES .

LOCATIONS IN T3E WARNING INC=-UDE 3UT A-"1E NOT LIMITED TO ST. vos3URY ...LYNDON
CENTER ...AND LYNDONVILLE .

IF YOU ENCOUNTER OODING ...SEEK 3IG3:ER GROUND IMMEDIATELY. W3EN YOU CAN DO SO SAFE LY
P:....EASE REPORT ANY FLOODING TO T3:E NATIONAL WEAT3ER SERVICE 3Y CALLING TOL=- FREE ...1 800 8 6 3 4
2 7 9...0R 3Y SU3MITTING
A STORM REPORT AT WEAT3:ER .GOV/3URLINGTON .

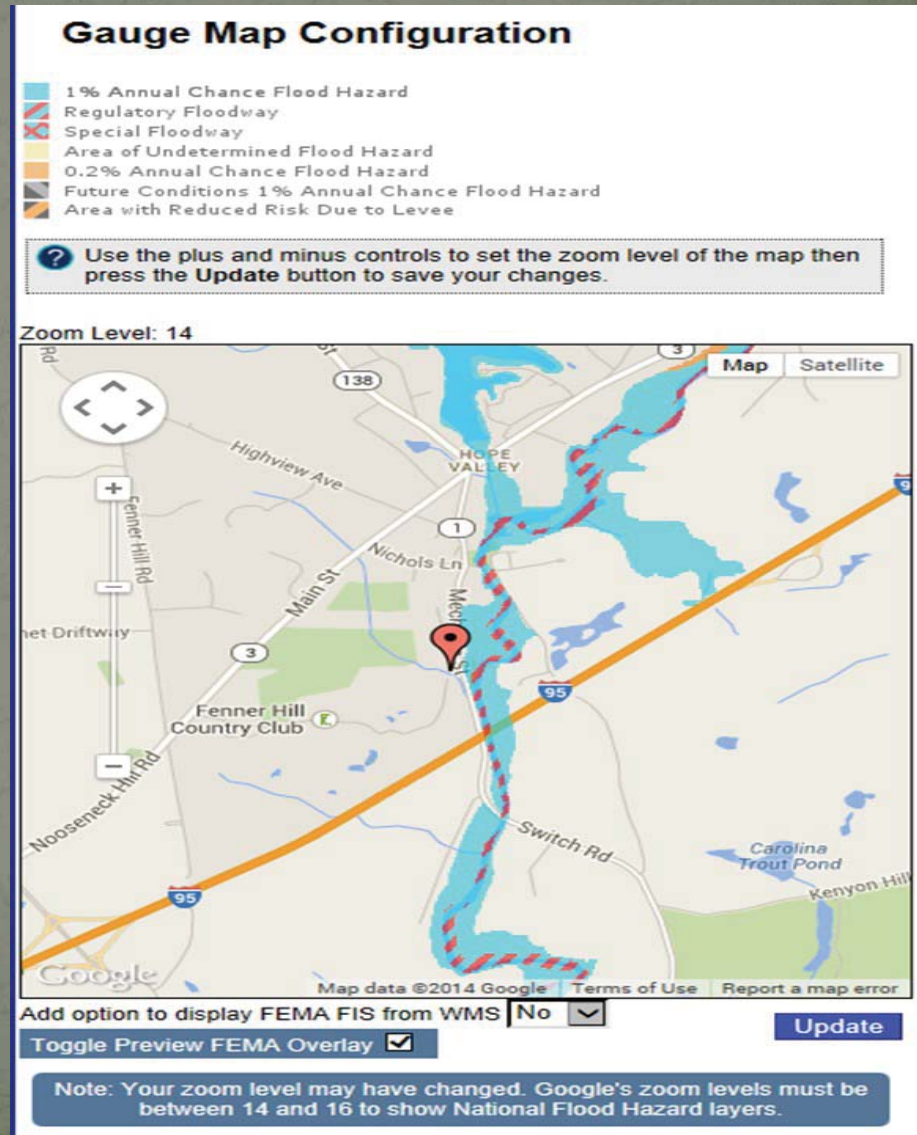
PRECAUTIONA-"1Y/PREPA-"1EDNESS ACTIONS...

3E ESPECIALLY CAUTIOUS AT NIG3T W:-il:N IT IS 3ARDER TO RECOGNIZE T:i:E DANGERS OF FLOODING .

DO ON...IN...OR NEAR RIVERS AND STREAMS. T.3:E 3IG3 WATER LEVELS D FAST FLOWS CAN
AN CREATE DEADLY CONSEQUENCES FOR PERSONS W30 VENTURE
TO OU CLOSE AND 3ECOME CAUG3T IN FLOODWATERS 3Y ACCIDENT ...OR
IN INTENTIONALLY TRY TO SWIM OR 3OAT ON FLOODED WATERWAYS. W:"i:EN YOU PUT OURSELF IN 3ARMS WAY T3E LIFE
YO YOU RIS:K IS NOT O Y YOUR OWN ...YOU
AL SO RIS?: T3:E LIVES OF RESCUE PERSONNEL.

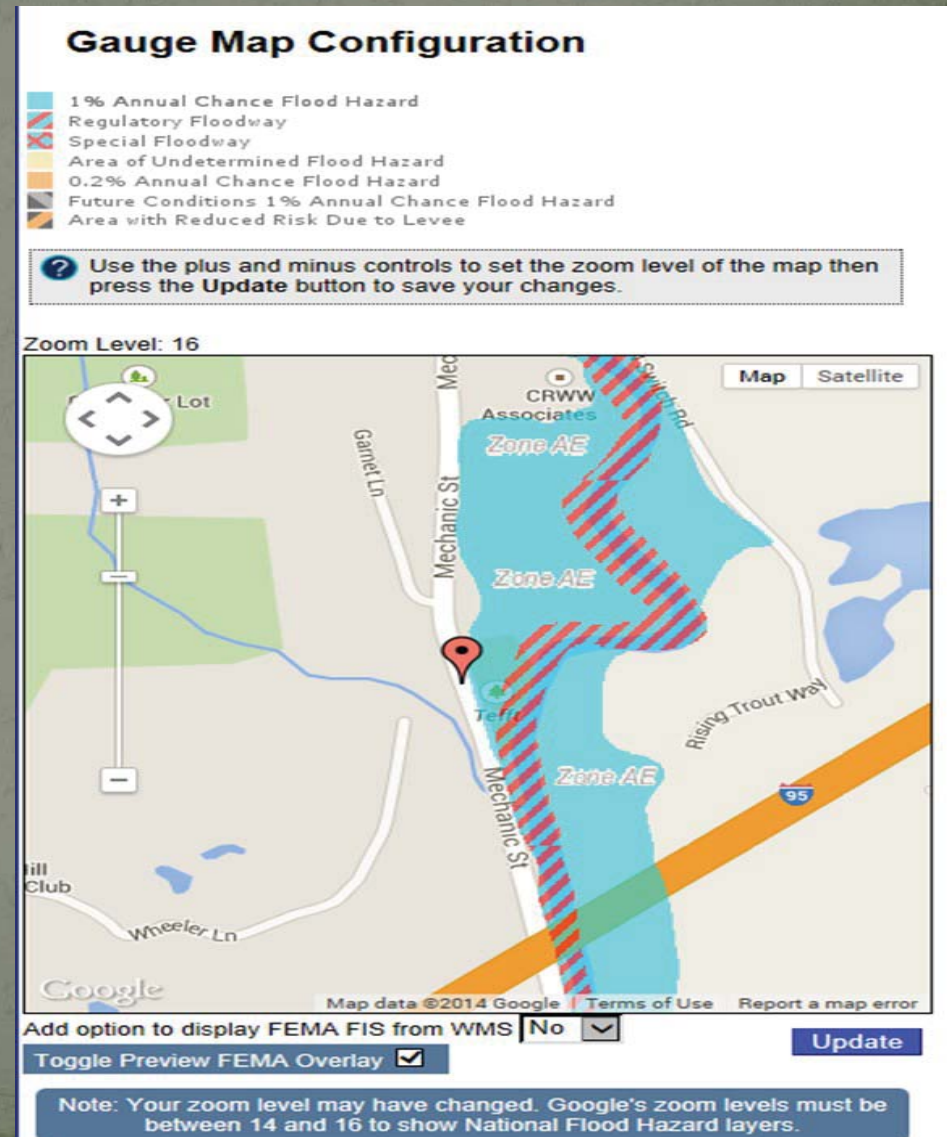
Current & future service locations in RI and a new AHPS capability

- Pawcatuck River
 - Wood River Junction
 - Westerly
- Pawtuxet River
 - Cranston
- Blackstone River
 - Woonsocket
- Later this summer we add the Wood River!
- At Hope Valley



Current & future service locations in RI and a new AHPS capability

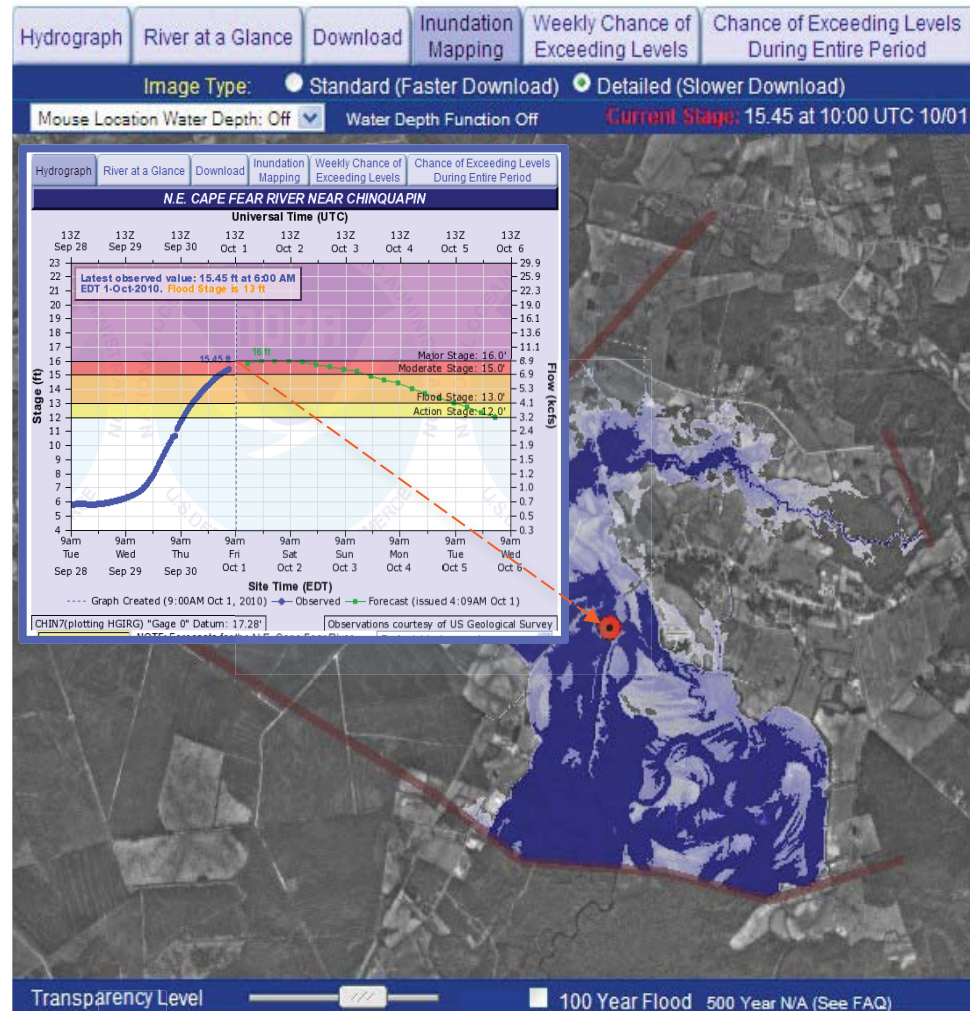
- Pawcatuck River
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 - Cranston
- Blackstone River
 - Woonsocket
- Later this summer we add the Wood River!
 - At Hope Valley



Enhancing Hydrologic Decision Support Inundation Mapping

Flood Inundation Mapping

- Provide spatial extent & depth of flood waters
- Display inundation maps for levels from minor flooding through flood of record
- Better mitigate impacts of flooding and build more resilient communities
- Libraries include NWS flood severity categories and regulatory FEMA flood frequency maps
- Integrated Water Resource Science & Services (IWRSS) initiative – a tri-agency effort (NOAA, USGS, USACE) working collaboratively to share resources and move this type of mapping forward
- NERFC participates on a QA/QC regional team for inundation map validation



I've been a little busy these past 7 years!
Job Security in the face of changing flood behavior!!



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



St-Jansur-Rachelieu, Quebec, Canada, 5/6/11
Photo: AP//Canadian Press, R. Remoiz



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

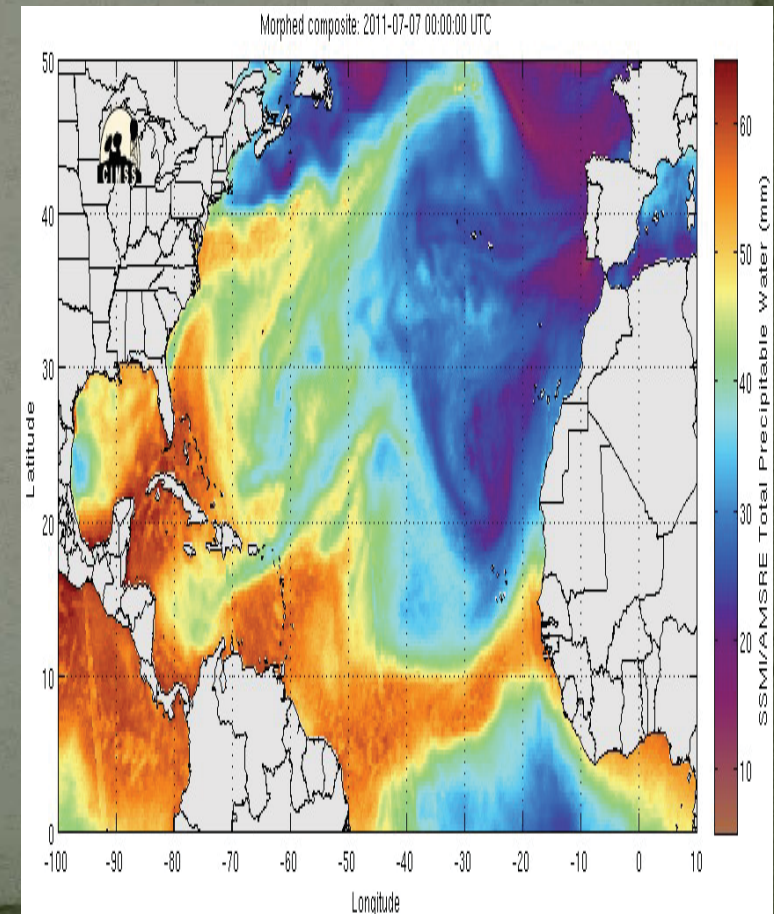
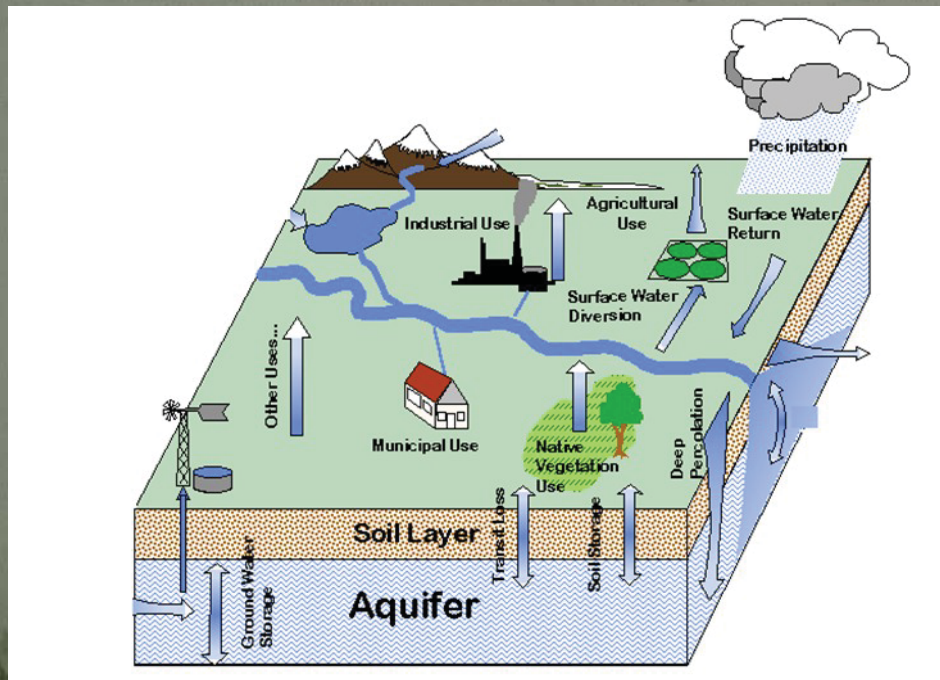


Home washed off its foundation along the Schoharie Creek, Prattsville, NY – Tropical Storm Irene

Is there a common theme to recent ?

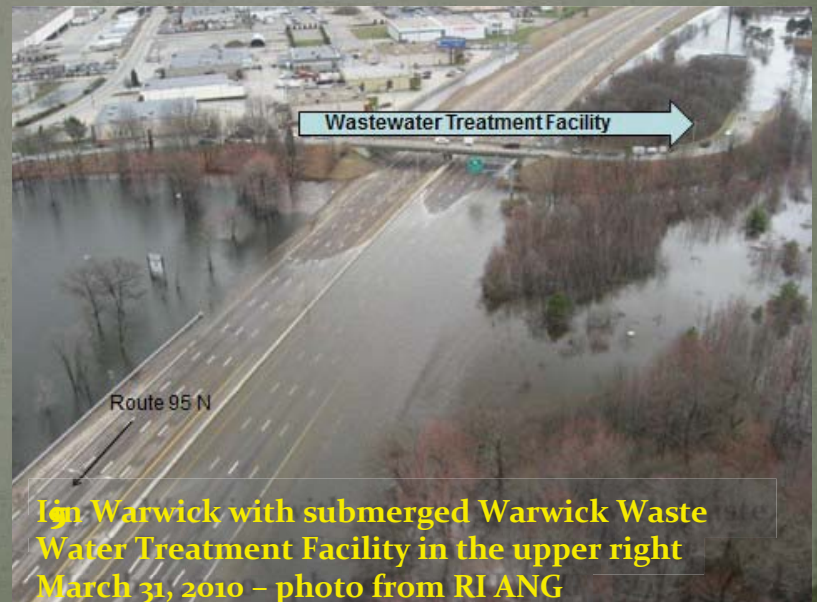
- Several:

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



The Changing Climate

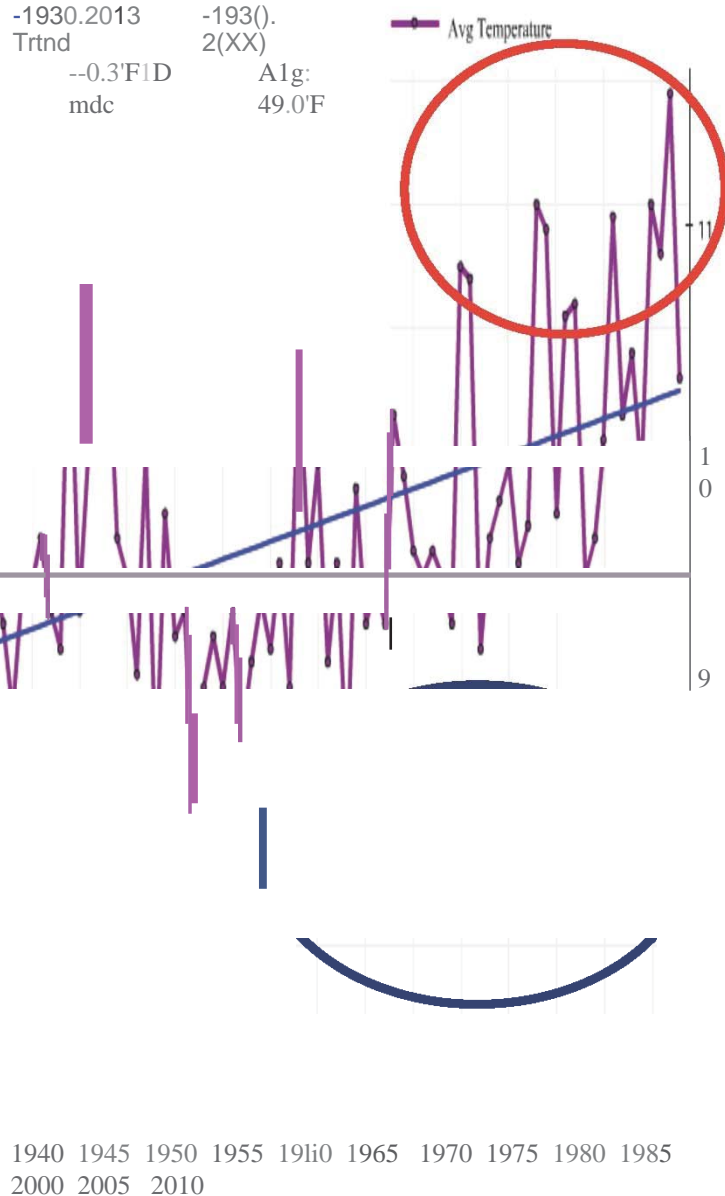
- Common themes across New England:
 - Increasing annual precipitation
 - Increasing frequency of heavy rains
 - Warming annual temperatures
 - Wildly varying seasonal snowfall
- Shift in precipitation frequency (50, 100 yr – 24 hr rain)
- For smaller (<800 sq mi) basins – trend toward increased flood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



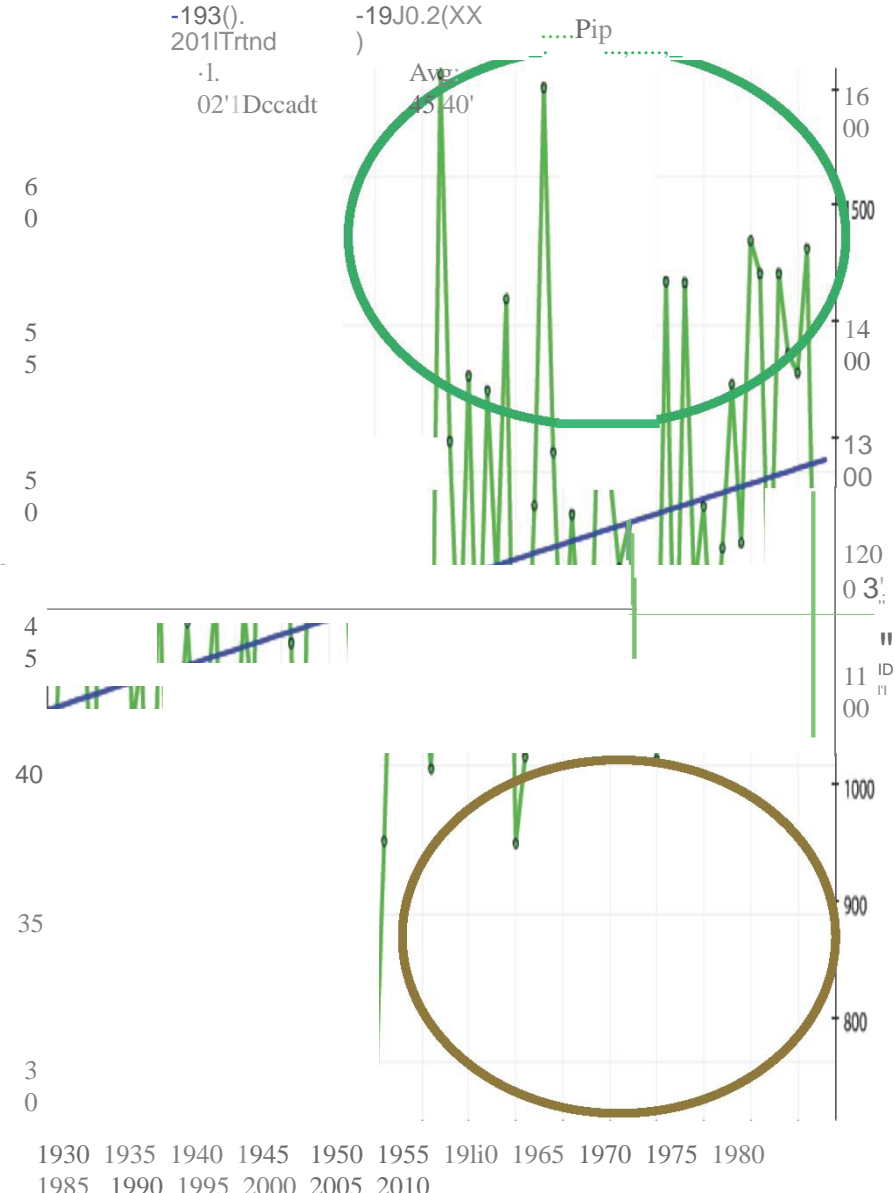
A Look at Temperature and Precipitation Trends

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

Roanoke, Average Temperature, January-December

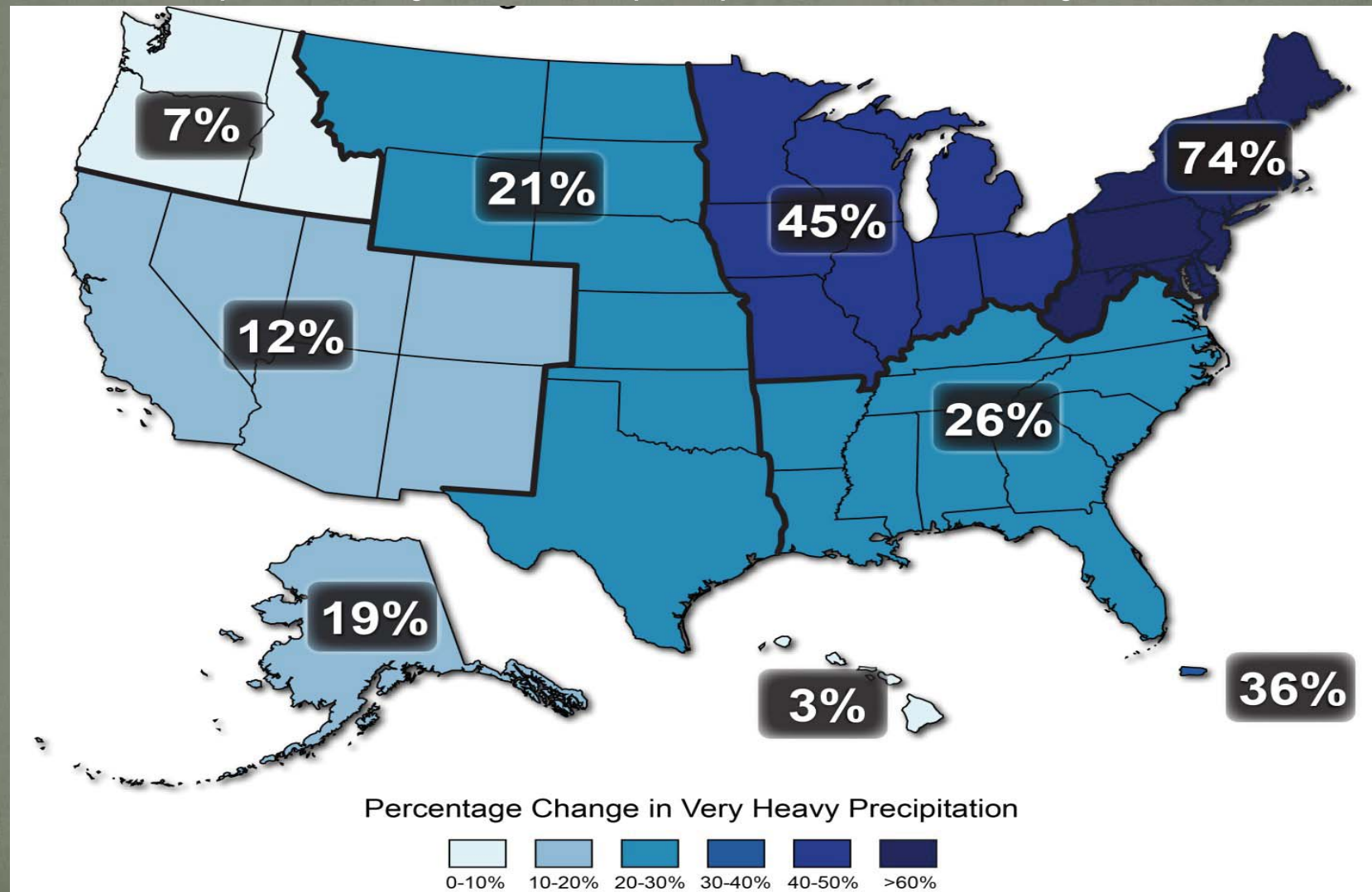


Roanoke, Precipitation, January-December



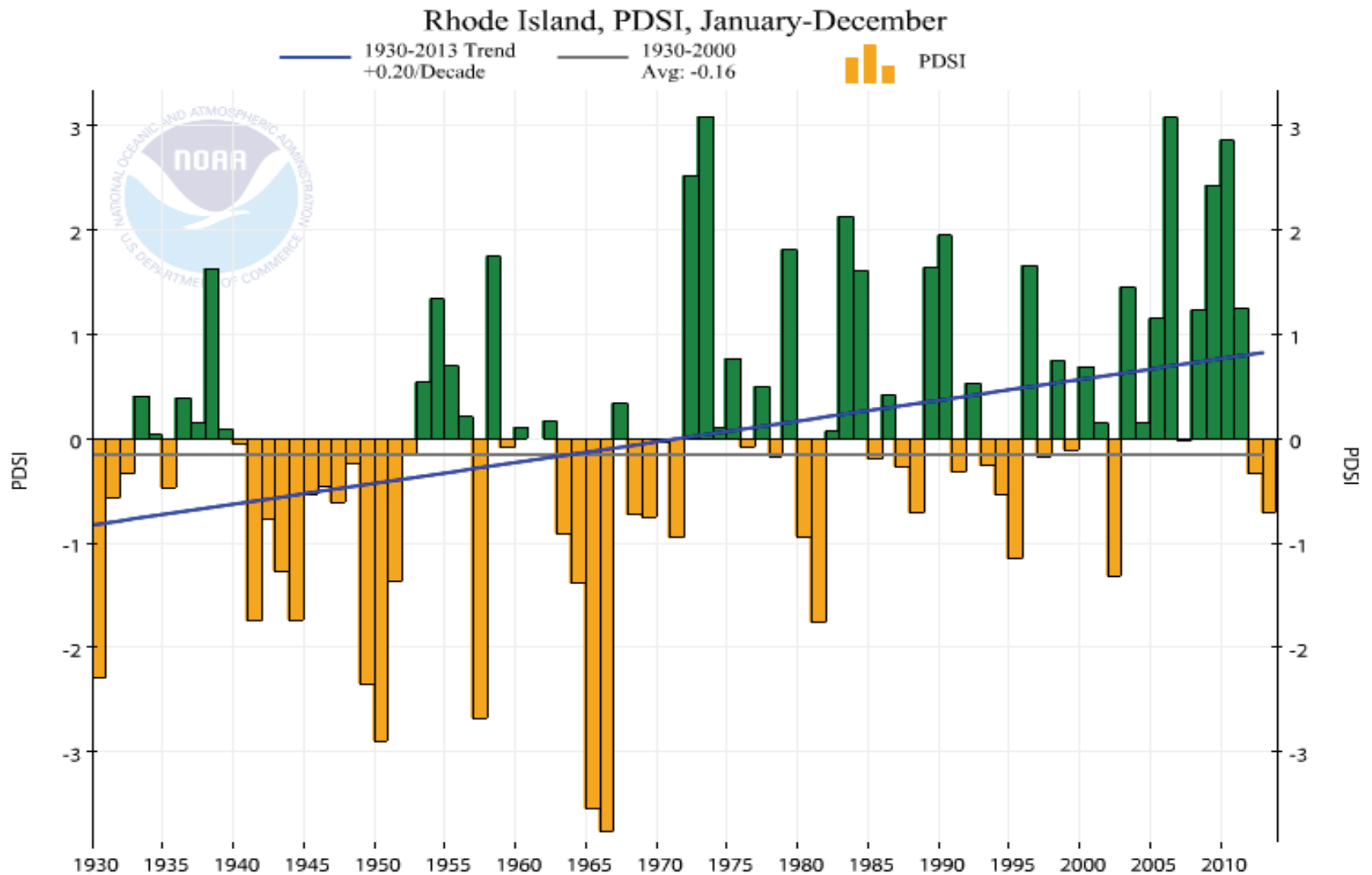
Change in Precipitation Patterns

Intense precipitation events (the heaviest 1%) in the continental U.S. increased by 20% over the past century while total precipitation increased by 7%.



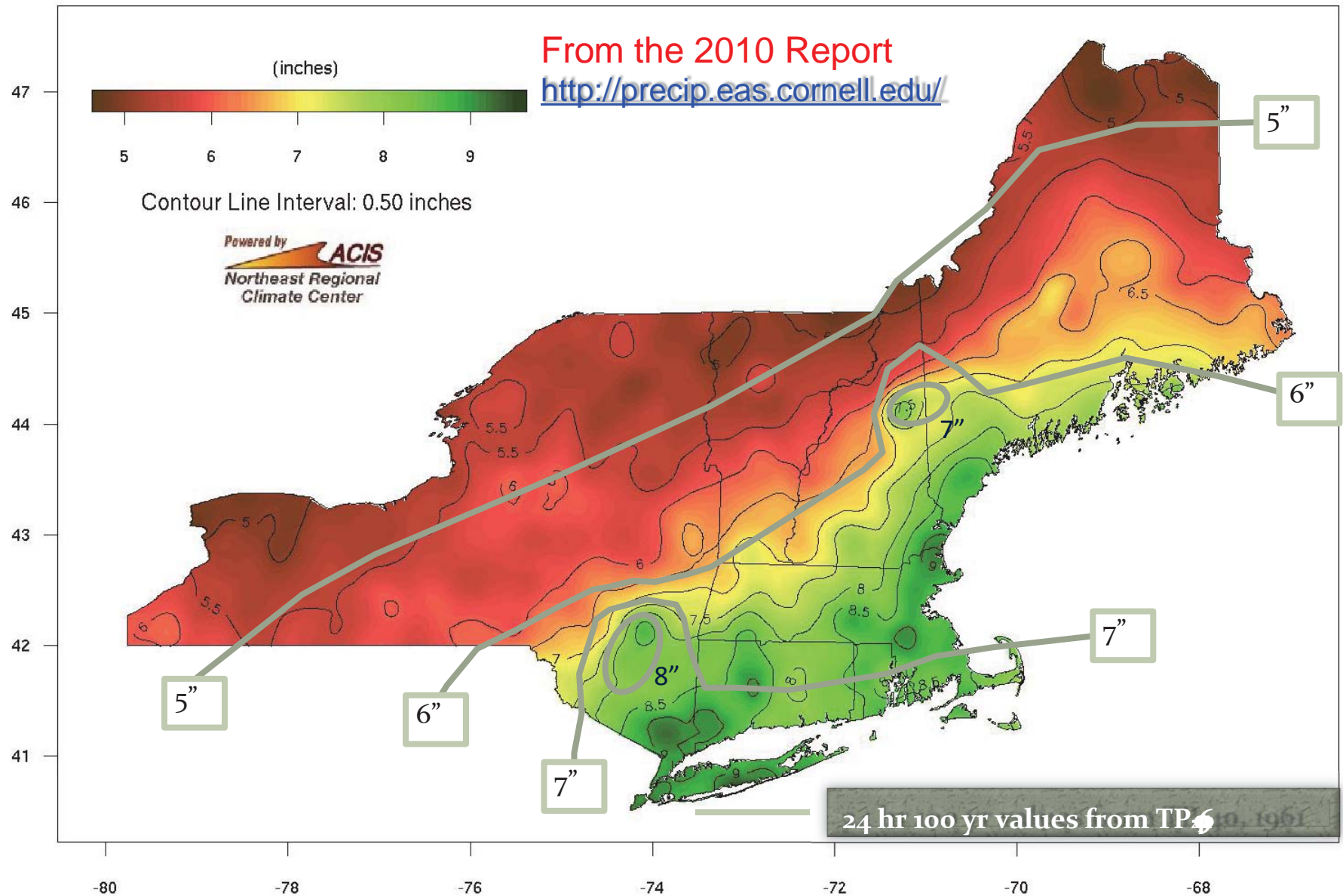
Source: <http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts>

Changes in the Palmer Drought Index



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

Extreme Precipitation Estimates 24hr 100yr



Southeast ½ of NE experience a 1 to 2 inch upward shift!

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





Number of Floods per Year by Flood Category for the Pawtuxet River at Cranston, RI 1940 - 2013



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
1955 & 1955
construction

Flood Category

- Major flood
- Moderate flood
- Minor flood

Number of floods

1940 1944 1948 1952 1956 1960 1964 1968 1972 1976 1980 1984 1988 1992 1996 2000 2004 2008 2012



Number of Floods per Year by Flood Category for the Pawcatuck River at Wood River Junction, RI 1941 - 2013

Data provided by



Minor floods (5 - 5.99 feet) over period of record: 21
Moderate floods (6 - 6.99 feet) over period of record: 9
Major floods (7 feet or more) over period of record: 3

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Flood
Category

- Major Flood
- Moderate Flood
- Minor flood

Flood of record: 11.16 feet
on March 31, 2010

Number of Floods per Year by Flood Category for the Wood River at Hope Valley, RI

1936 - 2014

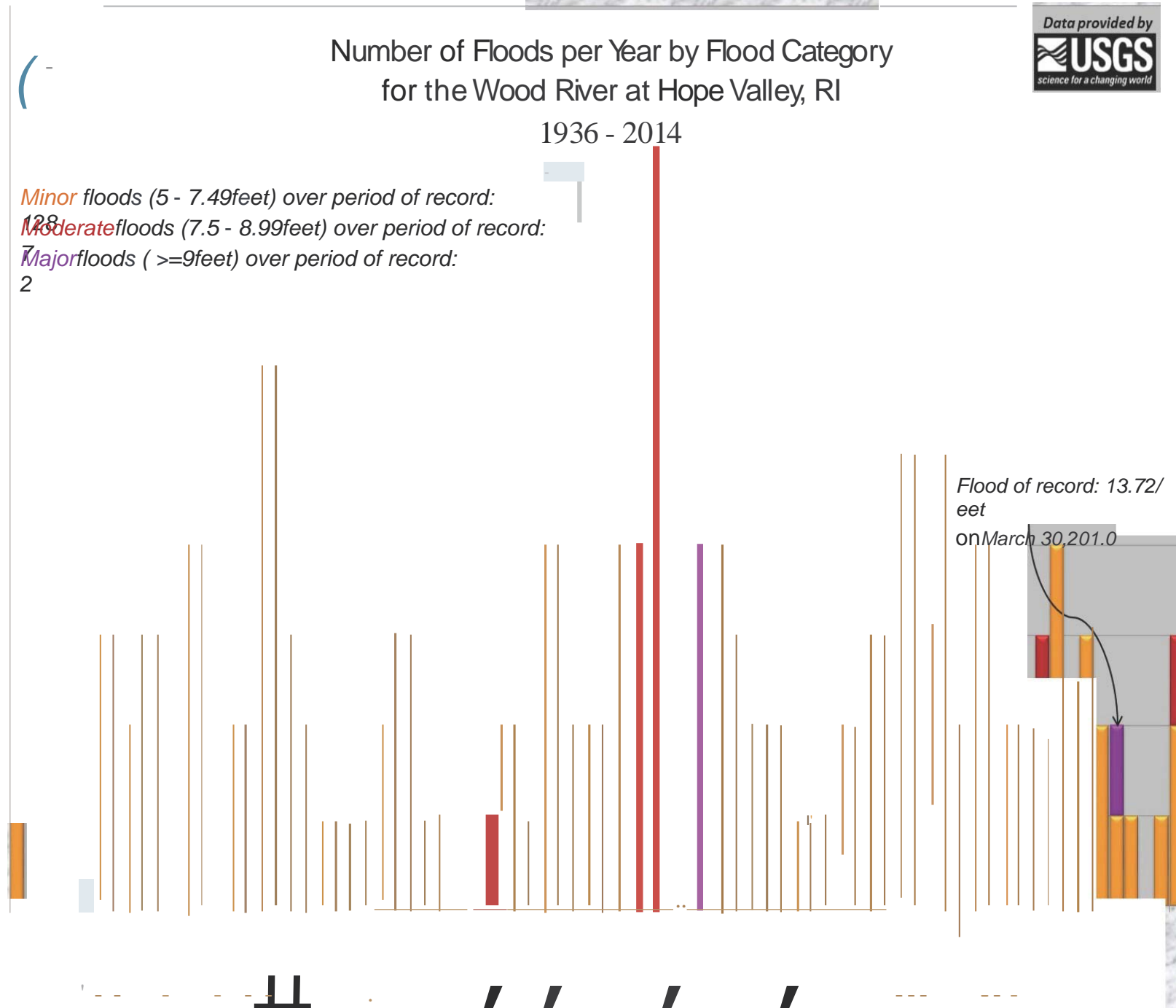
Minor floods (5 - 7.49feet) over period of record: 128
 Moderate floods (7.5 - 8.99feet) over period of record: 7
 Major floods (>=9feet) over period of record: 2

Flood Category

- Major flood
- Moderate flood
- Minor flood

Flood of record: 13.72/feet
 on March 30, 2010

Number of floods





Number of Floods per Year by Flood Category for the Pawcatuck River at Westerly, RI 1936 - 2013

Data provided by

t j ! } ! j

*Flood of record: 15.38 feet
on March 30, 2010*

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Minor floods (7 - 8.99 feet) over period of record: 44
Moderate floods (9.0 - 10.99 feet) over period of record: 12
Major floods (11 feet or more) over period of record: 4

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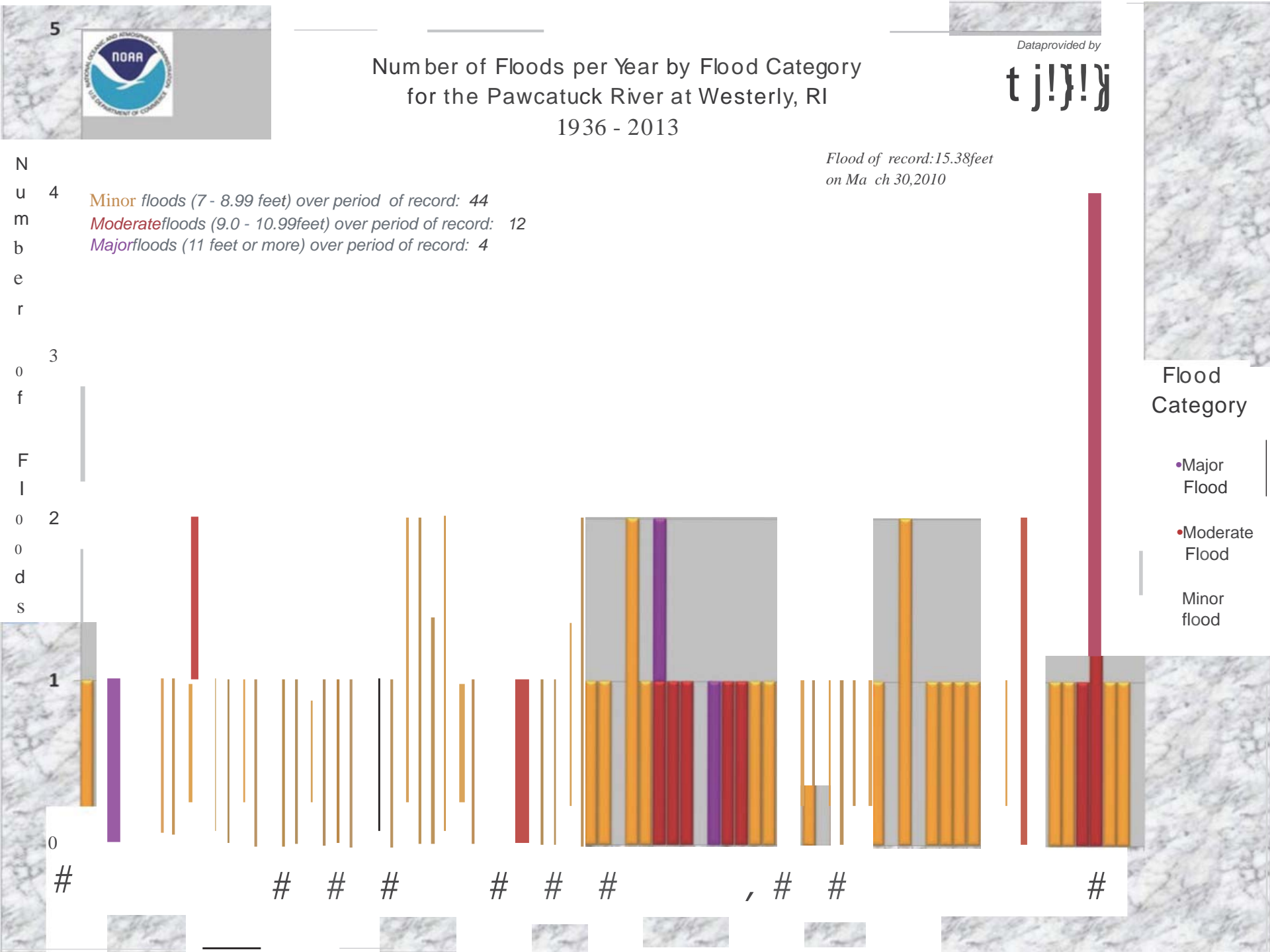
#

Flood
Category

Major
Flood

Moderate
Flood

Minor
flood



Normalized Flood Frequency

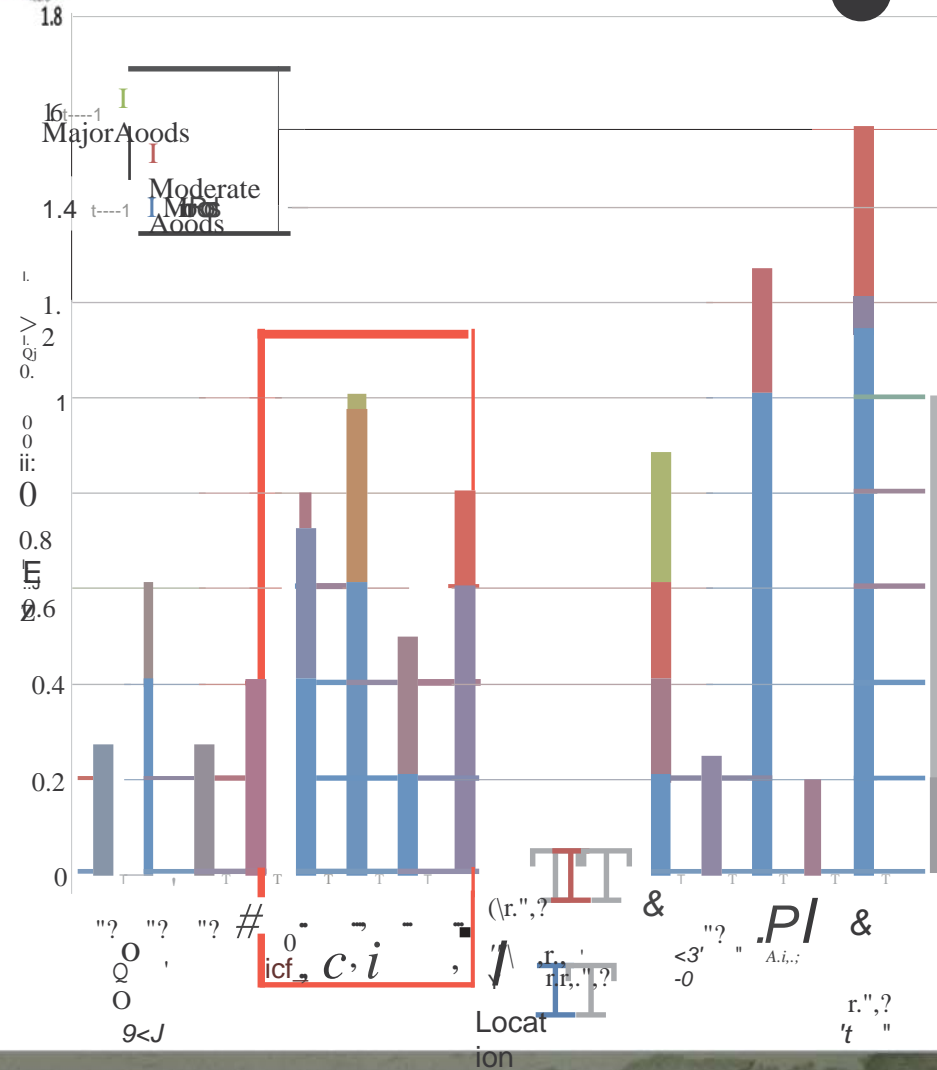
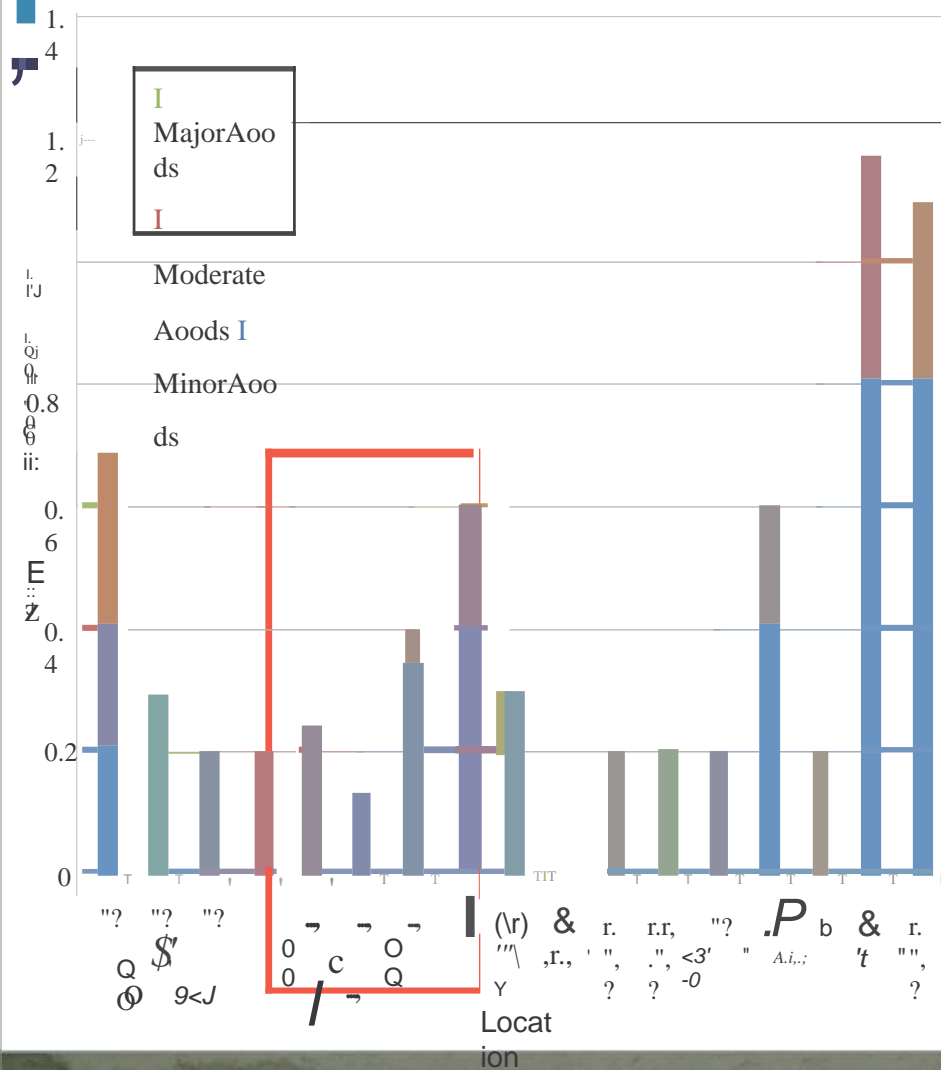
Southern New England River Basin Normalized Number of Minor, Moderate, and Major Floods Prior to 1970

Data provided by
USGS
science for a changing world



Southern New England River Basin Normalized Number of Minor, Moderate, and Major Floods from 1970-2013

Data provided by



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
 - Southeast New England has 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

Part II: Coastal Vulnerability– Lessons to learn from Sandy



IRENE

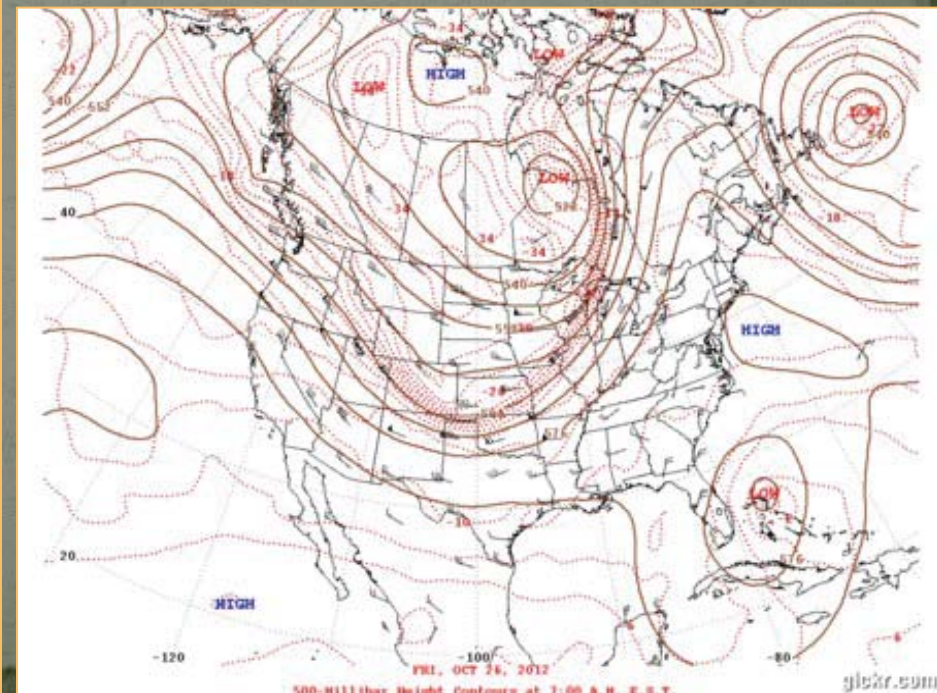
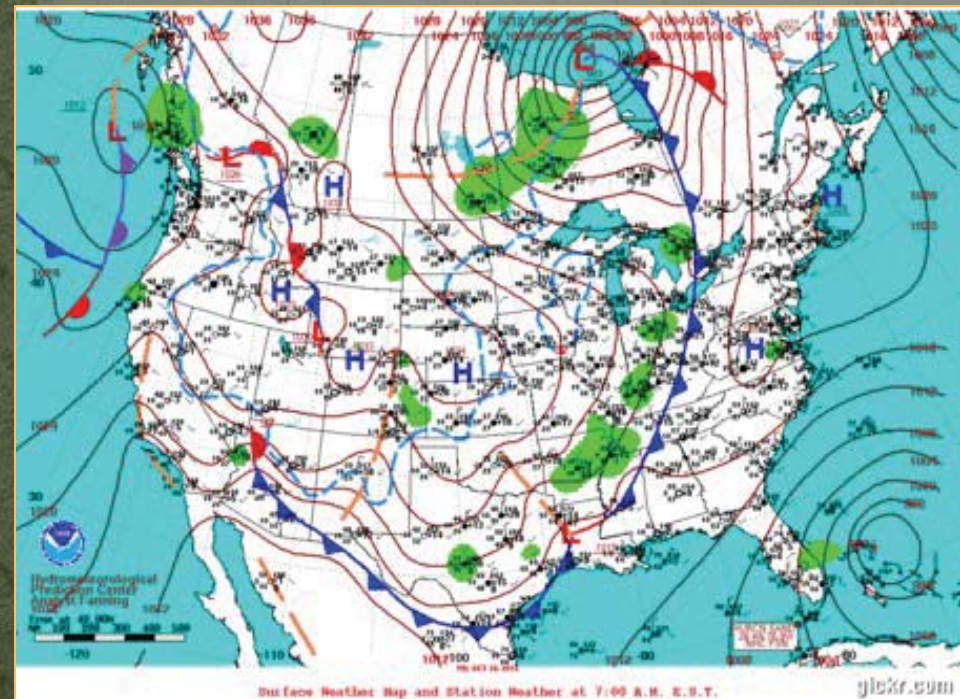


SANDY

- 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~~pe~~pe dual jet stream set up (classic for a New England Hurricane)
 - Captured Sandy & blocked her attempt to race out to sea



Sea Levels Online

East Coast

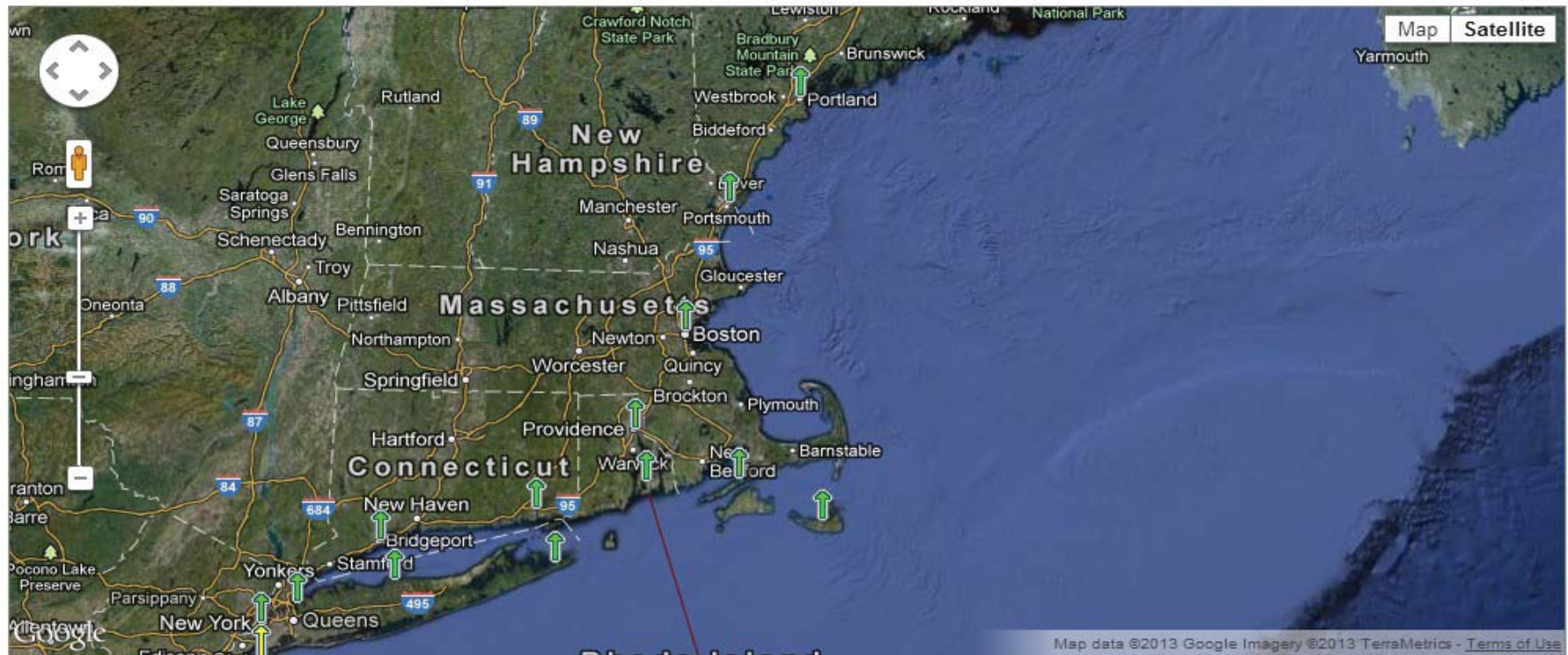
West Coast

Gulf Coast

Alaska

Hawaii

Global



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)

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



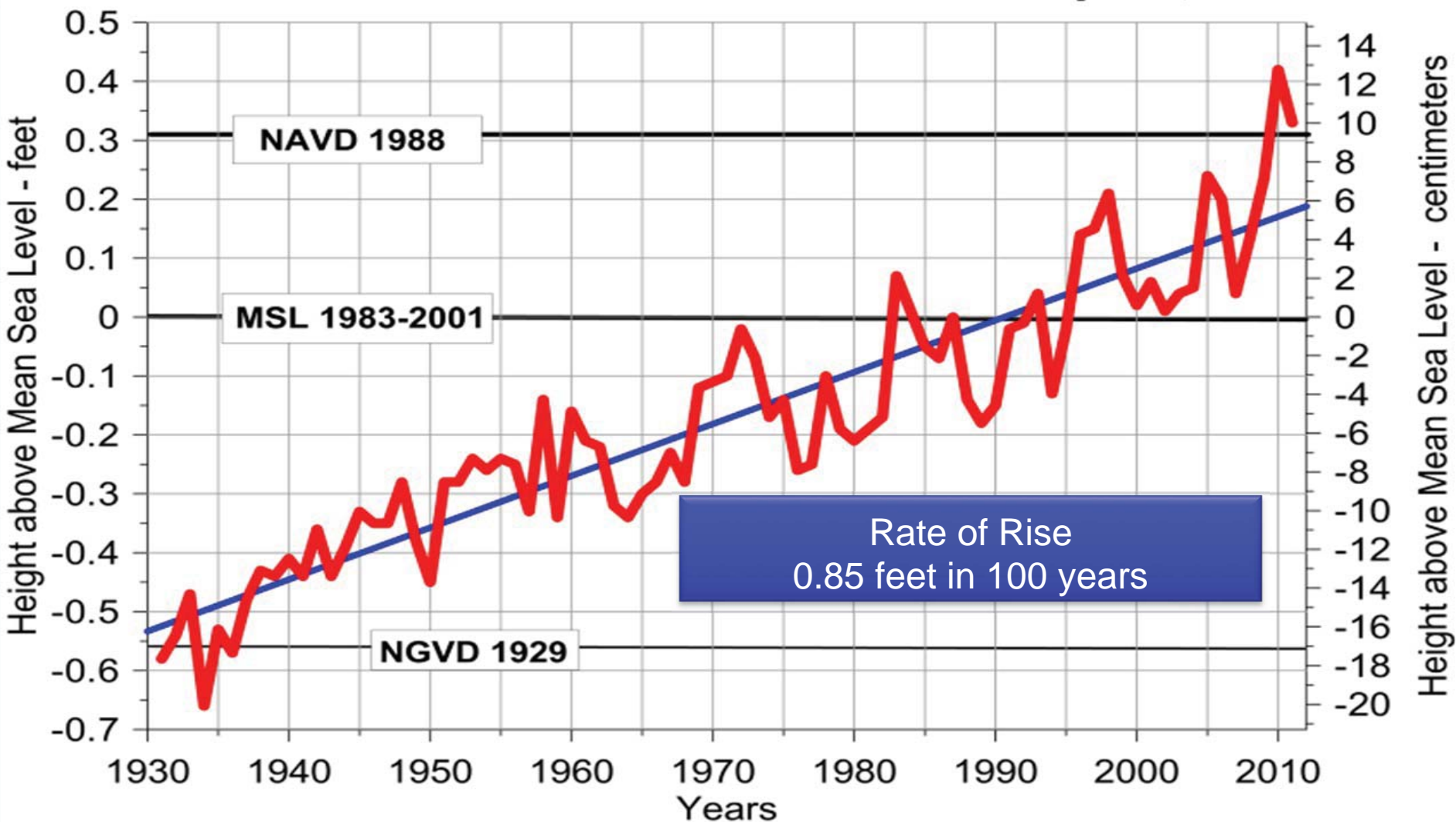
National Oceanic and Atmospheric Administration's
National Weather Service

Northeast River Forecast Center



Sea Levels Are Increasing

HISTORIC SEA-LEVEL RISE - Newport, RI



Frontal Erosion 1939-2012 - Browning Cottages, Moonstone Beach, RI



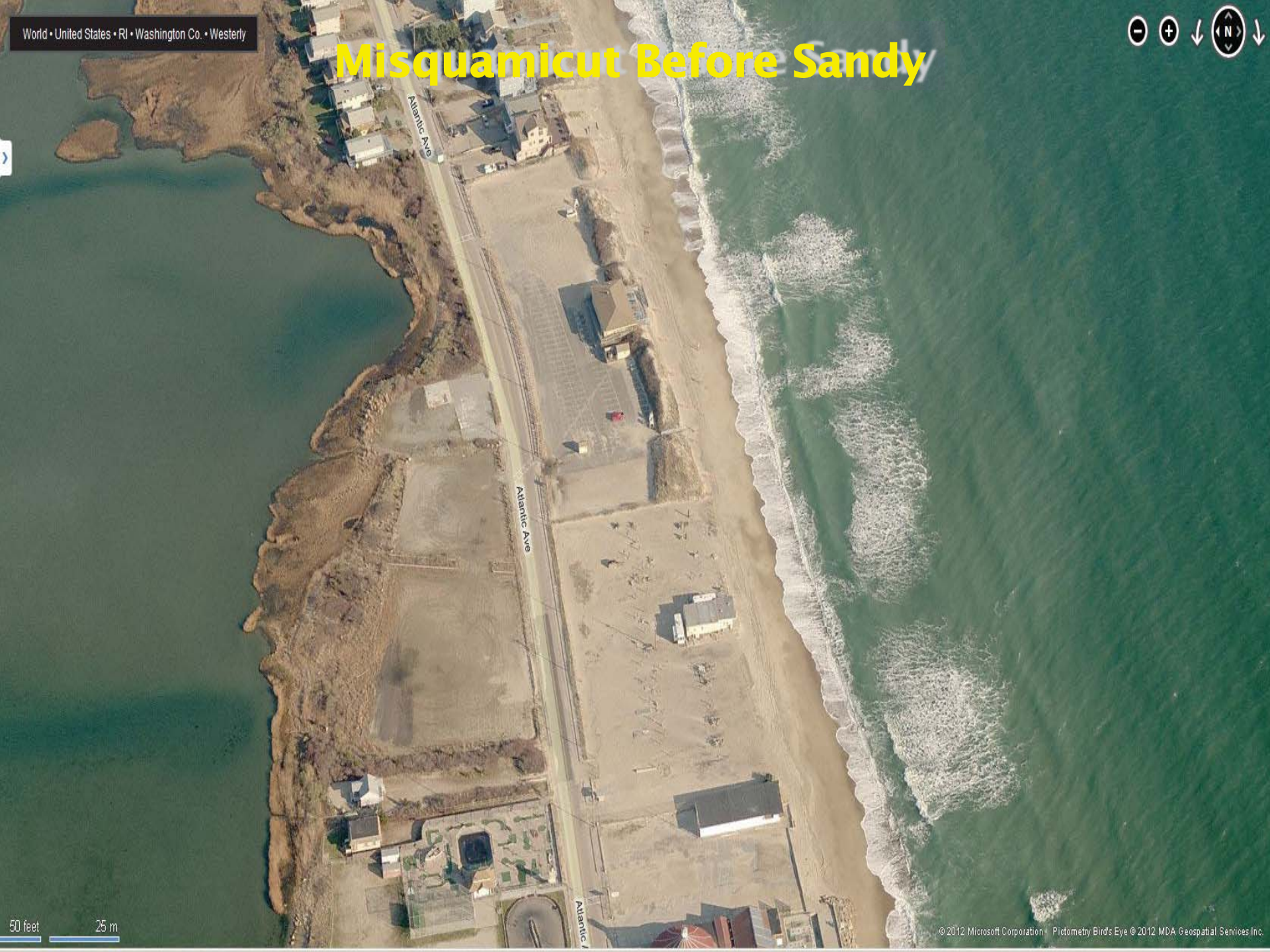
Superstorm Sandy - Browning Cottages



30 Oct 2012

<http://fema.maps.arcgis.com/home/webmap/viewer.html?webmap=>

Misquamicut Before Sandy



Misquamicut After Sandy



Damage along Atlantic Avenue

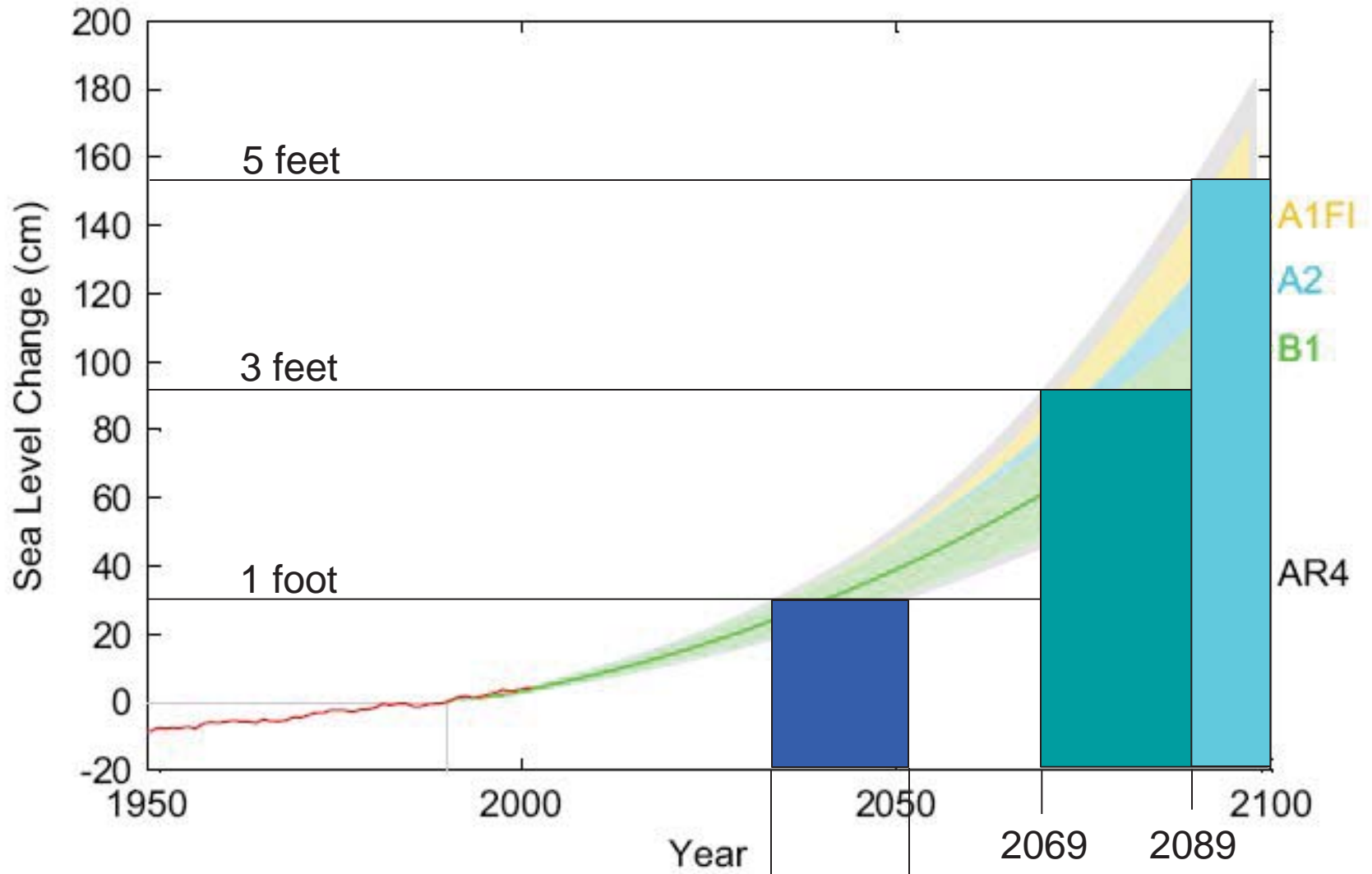
What went in the ocean side – came out the street side!



What did it look like?



Future Sea level Rise



Vermeer and Rahmstorf, 2009

2033

2052



Imagery

Streets

Share Map

Zoom to: State or Territory



Coastal Services Center Sea Level Rise Viewer
Current sea level

<http://www.csc.noaa.gov/slviewer/>

NOAA Digital Coast

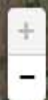


Imagery Streets Share Map

Zoom to: State or Territory

USA RI CT VT NH ME

Coastal Services Center Sea Level Rise Viewer
Inundated Areas with 3 feet of Sea Level Rise
<http://www.noaa.gov/sl-viewer>



Imagery Streets Share Map

Zoom to: State or Territory

USA icons for various states and territories.

Pawcatuck

Coastal Services Center Sea Level Rise Viewer
Pawcatuck River – Tidal portion with 6 feet of sea level rise
<https://coast.noaa.gov/sl-viewer/>



Hospital

Summary



IRENE



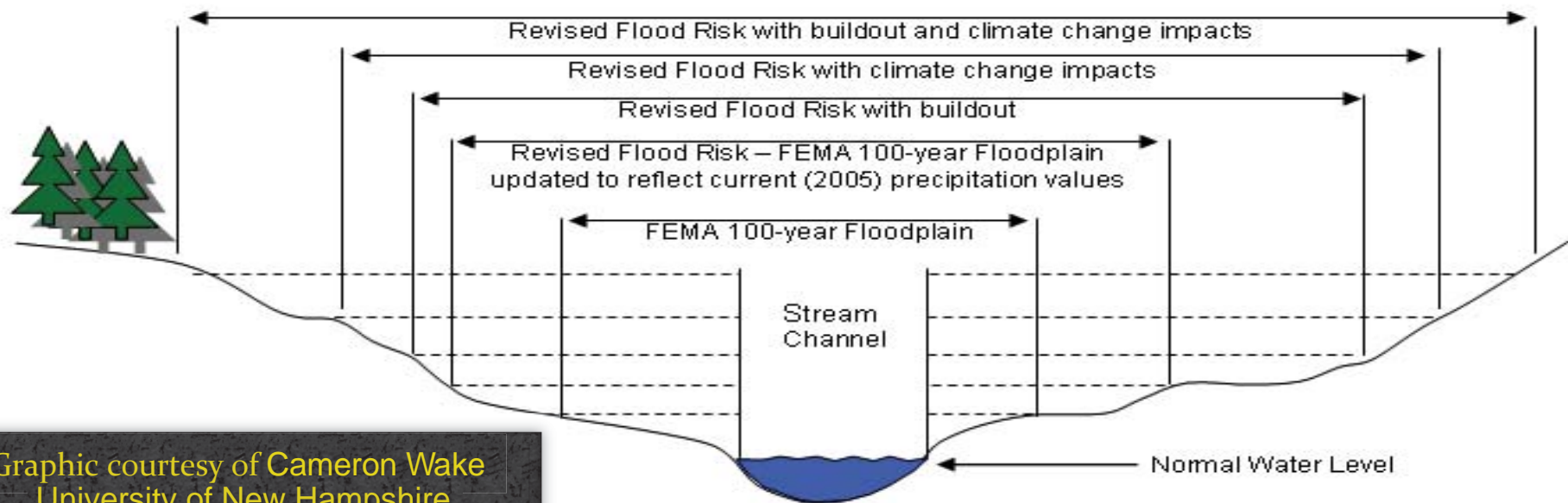
SANDY

- We are a tremendously vulnerable region
 - Planning is of the utmost importance – it must reflect storm events that will undoubtedly far exceed the damage from Irene & Sandy
- Shifts in precipitation frequency & inland flood behavior
 - Expect heavier rain events and an increase in flood events
- Impacts of Sea Level Rise and Erosion
 - Consider: Category 2 Hurricane producing inundation & damage comparable to what a Category 3 would have done 50 years ago!

Far reaching implications:

Protect, Adapt or Retreat???

- Floodplain, land use, infrastructure, dam spillway requirements, drainage requirements, nonpoint 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?



Climate Trends in Rhode Island and Its Impact on Riverine & Coastal Flood Behavior



THANK YOU!

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