Droughts and Floods in Massachusetts?
Now what?!?

UMASS AMHERST

The Center *for* Agriculture, Food and the Environment

Christine E. Hatch

Assistant Professor, Department of Geosciences

Extension Assistant Professor of Water Resources and Climate Change

Envirothon Workshop #17

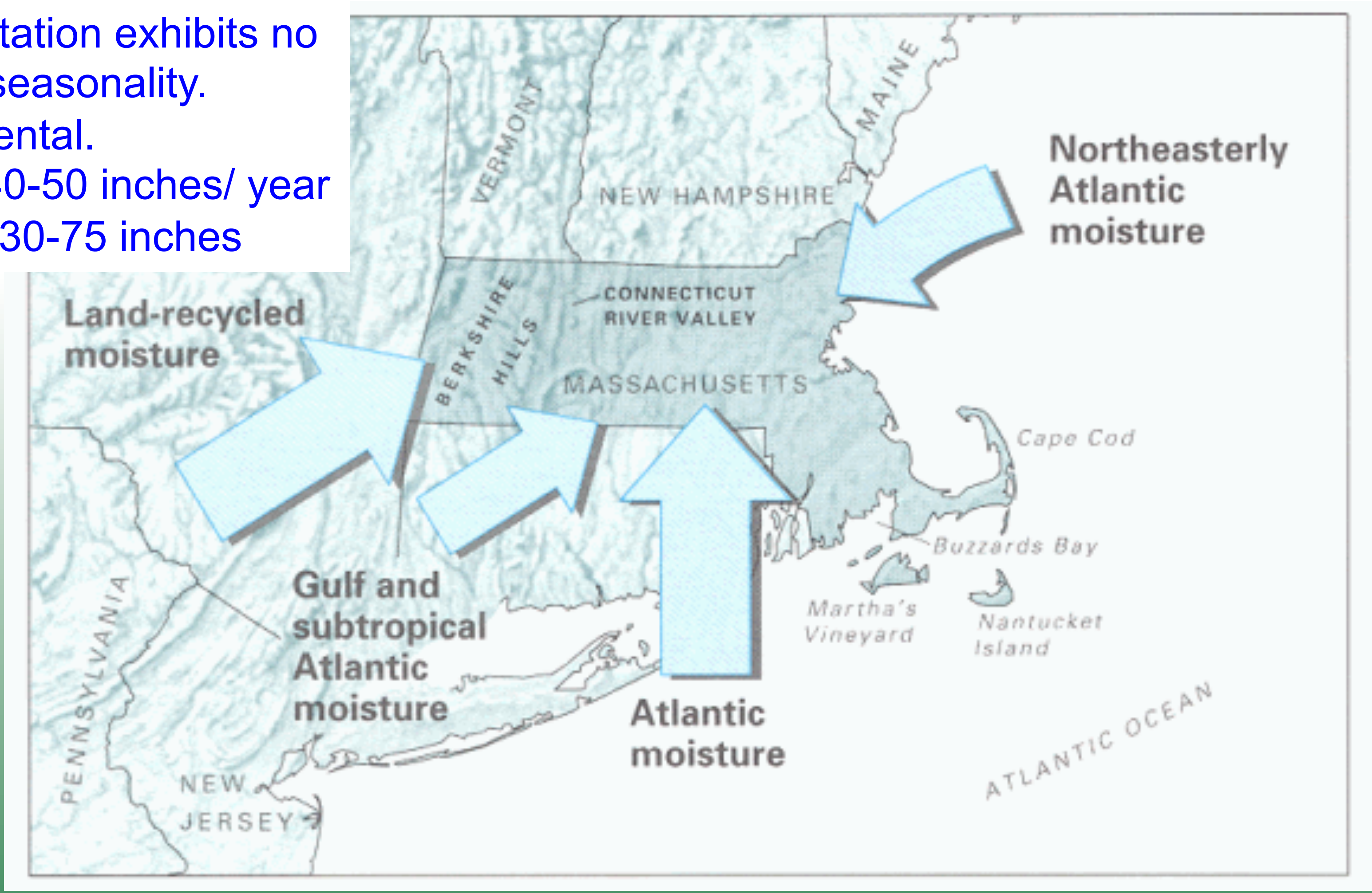
November 16, 2016

Where do droughts and floods come from? Why do they happen? Do they happen in New England? Often? Regional scale climate models for the northeastern United States predict changes in precipitation patterns, quantities, and intensity in the coming decades. Agricultural practices in Massachusetts and infrastructure for managing stormwater were designed based on weather patterns over the last 100 years or more. This workshop will present an overview of climate science today, predictions for our changing local climate with specific attention to the extremes. We will discuss the effects climate change may have on water resources and agricultural practice. ***The solutions are up to you.***

- The weather in Massachusetts
- Do we have droughts and floods in New England? How often?
- Is this weather or climate?
- Let's talk drought
- How big is the flood?
- Resilience to drought and floods
- Being river-smart and lessons from floods

Blessed by rain…

- Precipitation exhibits no distinct seasonality.
- Continental.
- Rain: 40-50 inches/ year
- Snow: 30-75 inches

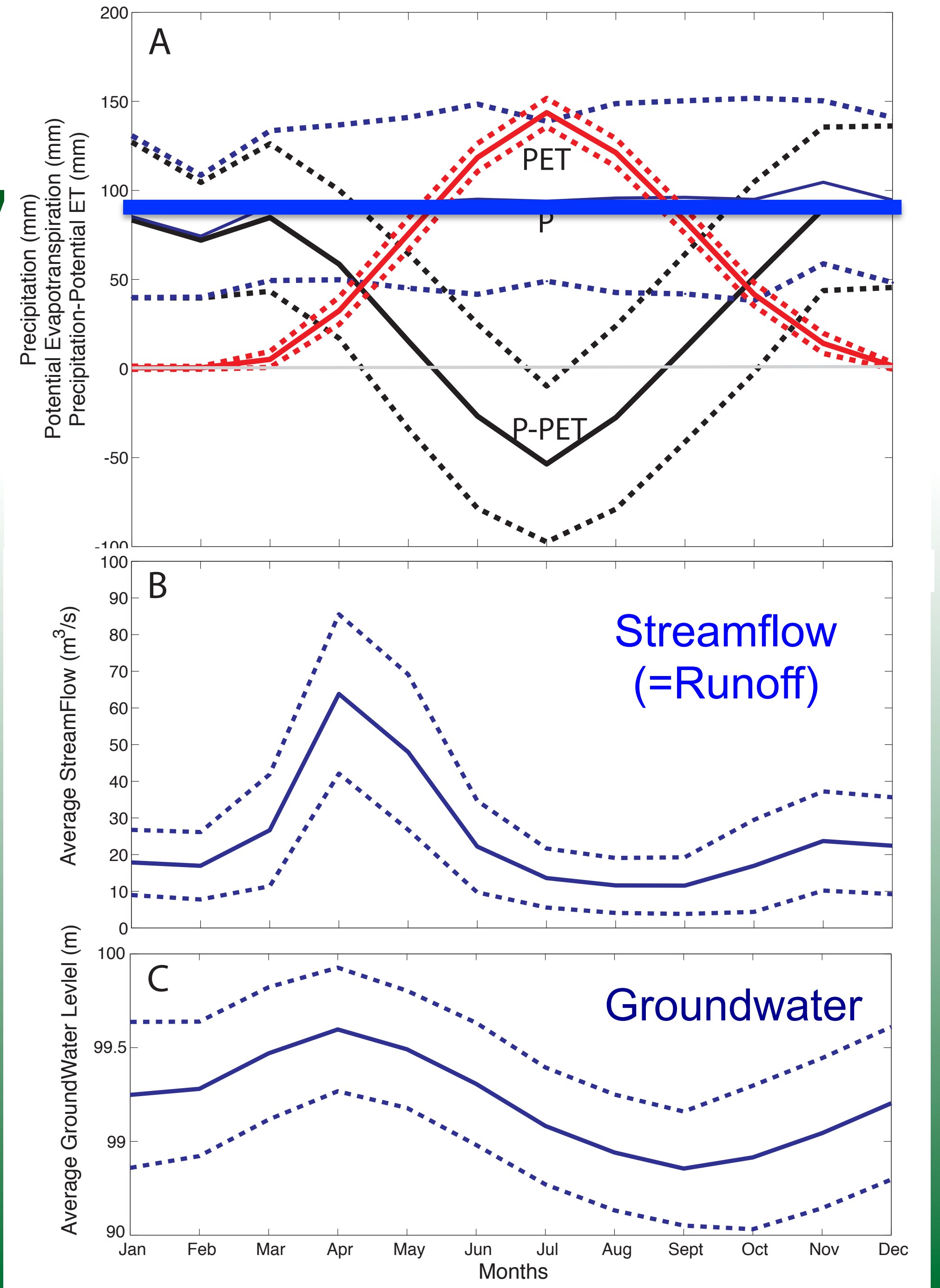


Principal sources and patterns of delivery of moisture into Massachusetts. (Clark and Lage, Wisconsin Geological and Natural History survey)

New England HydroClimatology

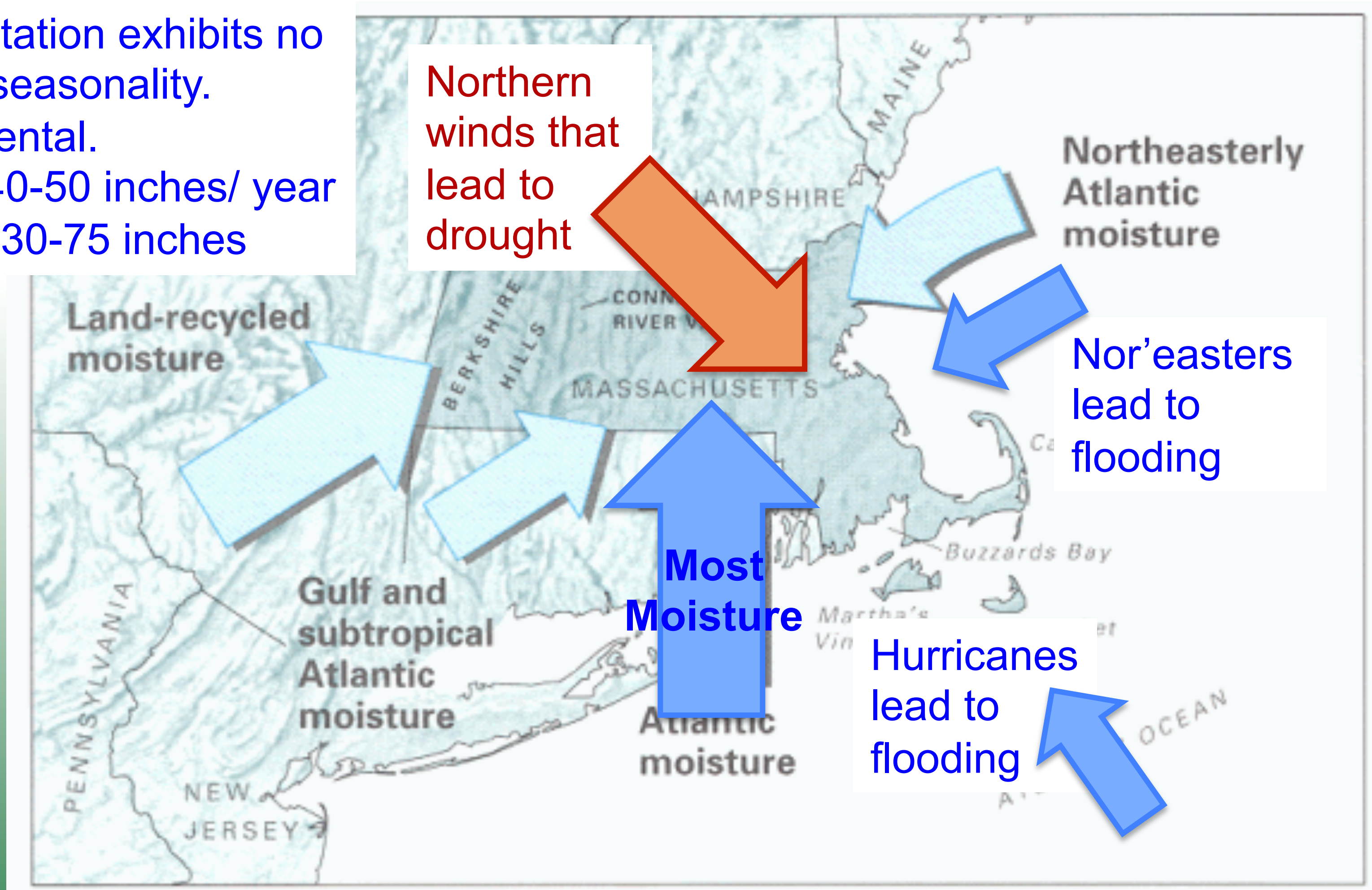
Long-term average of monthly precipitation is essentially constant across seasons

Annual stream flow and ground water trends are controlled by P-PET and snow melt



Climate of Massachusetts

- Precipitation exhibits no distinct seasonality.
- Continental.
- Rain: 40-50 inches/ year
- Snow: 30-75 inches



http://md.water.usgs.gov/publications/wsp-2375/ma/

U.S. Geological Survey Water-Supply Paper 2375

National Water Summary 1988-89--Floods and Droughts:

MASSACHUSETTS Floods and Droughts

Frequent weather changes and abundant precipitation in Massachusetts result from frontal systems or storms that move across the continent and exit through the northeastern United States. Dominant airmasses that affect national weather patterns are polar continental, tropical maritime, and, to a lesser degree, polar maritime. Widespread ***flooding is caused by intense rainfall and snowmelt, northeasters, and tropical storms***. A combination of intense rainfall and snowmelt caused the floods of March 1936, March 1968, and March-April 1987. Hurricanes or tropical storms caused the floods of November 1927, September 1938, and August 1955. The floods of 1936 and 1938 affected the largest area of the State. Droughts of 1929-32, 1939-44, and 1980-83 were widespread but not as severe as the 1961-69 drought, which was the severest on record. ***Floods and droughts have affected the water-management and planning activities of several State and Federal agencies.*** Water management at the State level is coordinated by the Massachusetts Water Resources Commission, which recently adopted water-use and supply-management measures. Potential drought conditions are reviewed by State and Federal agencies. ***Development in the flood plain is controlled by the State and most local governments.***

Floods and Droughts

riversmart communities

Date	Area	RI (years)	Remarks
1927	Multistate	10 to 100	Conditions created by torrential rains from tropical storm and Oct. rainfall.
1929-32	Statewide	10 to >50	Water-supply sources altered in 13 communities. Multistate.
1936	Statewide	5 to >100	Large snowfall, frozen ground, and two major rainstorms in Mar., $36 million.
1938	E. MA	5 to 40	Series of showers and thunderstorms July 17-25 produced 10 inches of rain..
1938	MA	40 to >100	Intense rains, hurricane, and tidal surge. Estimated deaths, 500; damage, $330 million in Northeastern United States.
1939-44	Statewide	15 to >50	More severe in eastern and extreme western Massachusetts. Multistate.
1944	SE MA	Unknown	Hurricane wave surge arrived before low tide but produced record tidal levels along the southern coast.
1948	W MA	5 to >100	Intense rainfall of 5-12 inches. Snow cover did not affect peak flows.5 Deaths
1954	SE MA	Unknown	Hurricane Carol.
1955	S. MA	5 to >100	Hurricanes Connie and Diane. Multistate. Deaths, 12; damage, $133 million.
1955	W. MA	5 to 30	Intense rainfall from localized storms. Damage, $790,000.
1957-59	Statewide	5 to 25	Record low water levels in observation wells, northeastern Massachusetts.
1961-69	Statewide	35 to >50	Water-supply shortages common. Record drought. Multistate.
1968	E MA	5 to >100	Multistate. Damage, $35 million.
1978	E MA	Unknown	Record tidal levels. Multistate. Deaths, 54 in NE. Major disaster declared.
1979	Cent-E. MA	5 to 40	Intense rains Jan. 21-25. Multistate. Disaster declared. Damage, $30 million.
1980-83	Statewide	10 to 30	Most severe in Ipswich and Taunton River basins; Nashua R, Multistate.
1984	Statewide	5 to 80	Prolonged 6-day storm left 5-9 inches of rain. Flooding on Connecticut, Housatonic, and Merrimack Rivers. Multistate.
1987	Multistate	10 to >100	Intense rains Mar. 30-Apr. 2 and snowmelt. Major disaster declared.
1985-88	Housatonic	25	Duration and severity as yet unknown. Streamflow showed mixed trends.

http://waterwatch.usgs.gov

Flood Years in Massachusetts:

1928 (#4)

1938 (#5)

2006 (#1)

2009 (#7)

2011 (#11)

The Hoosic River tears down a building in North Adams, MA, in 1927 (now the site of River Street Package Store). Photo from the North Adams Transcript.

riversmart communities

http://waterwatch.usgs.gov

Flood Years in Massachusetts:

1928 (#4)

1938 (#5)

2006 (#1)

2009 (#7)

2011 (#11)

Rapid floodwaters from the Swift River in Ware, MA, destroy a stone bridge and flood buildings (NOAA)

http://waterwatch.usgs.gov

Flood Years in I

1928 (#4)

1938 (#5)

2006 (#1)

2009 (#7)

2011 (#11)

Hurricane Irene flood waters in the Cold and Deerfield River undercut hillslopes causing up to 900 ft slides along MA Route 2 (Fellows/ Condit), dumping large amounts of sediment into the Connecticut River, seen from space (NASA)

http://waterwatch.usgs.gov

Drought Years in Massachusetts:

1965-66 (#1-2)

1981 (#5)

1985 (#3)

2002 (#4)

2016 (#13)

Quabbin reservoir pump intake station during the historic drought of 1965-1966

riversmart communities

http://waterwatch.usgs.gov

Drought Years in Massachusetts:

1965-66 (#1-2)

1981 (#5)

1985 (#3)

2002 (#4)

2016 (#13)

Water shortage a worry in N.E.

By MIKE STANTON
Associated Press Writer

In the northwestern Massachusetts town of North Adams, a shortage of water means that ice skating rinks won't be flooded this year.

Growers in the state's cranberry belt are worried about enough rainfall to fill their bogs and keep out killing frosts.

In East Greenwich, R.I., townspeople get their drinking water out of a fire hydrant next to the Frenchtown Baptist Church.

Residents in many New England towns are feeling the effects of the worst drought to hit the region since 1965.

"For the first time in my memory, I didn't have to wear my rain suit, and I've been farming since 1941," says Frank Clegg, a Seekonk, Mass., farmer.

The U.S. Geological Survey reports extremely low water supplies in eastern Massachusetts, northwestern Vermont and most of Rhode Island. Rainfall this year is down 7 inches in eastern Massachusetts, 5 inches in central Massachusetts and anywhere from 1 to 4 inches in the rest of the region, according to

'Everyone takes water for granted — the normal guy in Lenox doesn't care if our water supply has one day's reserve left or 100 days, as long as he can still get water out of his tap.'

restaurant down the road must do without the customary glass of ice water.

New England's water troubles are shared by some Mid-Atlantic states. Mandatory conservation has been ordered in northern New Jersey, an emergency has been declared in northeastern Pennsylvania, and in Philadelphia and New York City voluntary conservation has been recommended.

A wet October helped in places. South of Boston, the system supplying Braintree, Holbrook and Randolph had dipped to a 30-day reserve at the end of

George Lagarce, head of the Lenox Department of Public Works, concedes that local officials have not planned ahead because their hands were tied by public apathy and a lack of money.

"Sure, we should have anticipated the water problem in the 1960s, but municipal government reacts to crises and there were always greater crises that needed the money," Largarce said. "Everyone takes water for granted — the normal guy in Lenox doesn't care if our water supply has one day's reserve left or 100 days, as long as he can still get water out of his tap."

One reason water is taken for granted, officials agree, is that it costs so little in most places. One means of increasing water conservation awareness is to raise rates so they reflect the true cost of water, which is often subsidized by local government.

Rate increases are under review in many water-starved Masssachusetts communities, even though officials concede public reaction will be harsh.

"People don't want to know that there's another shortage coming at them," said Godfrey, who compares the public's attitude toward water to the feeling 10 years ago that gasoline was abundant.

officials are
es by banding
similar to the
at furnishes

oin the MDC,
sive Quabbin
t the commis-
being drained
s safe supply

voir to serve
estern Massa-
ington Moun-
ervoir serving

by objections
Brook project
e last drought
ed.

The (UMass) Amherst Campus itself became a dramatic example of the problem in early September (1980) when nearly 19,000 students were sent home for three days because the water ran out.

http://waterwatch.usgs.gov

Drought Years in Massachusetts:

1965-66 (#1-2)

1981 (#5)

1985 (#3)

2002 (#4)

2016 (#13)

Massachusetts
Wetlands
Protection Act

Timeline of Water Policy and Regulations

1972
Clean Water Act
Establishes basic structure for regulations on pollutant discharge

Massachusetts Water Management Act
Allows Mass DEP to regulate quantity of Surface and Groundwater withdrawal
1986

1992
Water Conservation Standard
Was created to aid MA water suppliers with water efficiency

Water Policy Act uses previous policies to influence economic growth and sustainable water use
2004

2006
Water Conservation Standard based on previous standard but involves everyone

USGS Scientific Investigative Reports published
2009 - 2011

2012
Sustainable water Management Initiative Framework Released

SWMI Pilot project Case studies
2013

2014
SWMI starts proposed permit schedule

riversmart communities

http://waterwatch.usgs.gov

Drought Years in Massachusetts:

1965-66 (#1-2)

1981 (#5)

1985 (#3)

2002 (#4)

2016 (#13)

Surface Water Management Initiative (SWMI)

Timeline of Water Policy and Regulations

1972
Clean Water Act
Establishes basic structure for regulations on pollutant discharge

Massachusetts Water Management Act
Allows Mass DEP to regulate quantity of Surface and Groundwater withdrawal
1986

1992
Water Conservation Standard
Was created to aid MA water suppliers with water efficiency

Water Policy Act uses previous policies to influence economic growth and sustainable water use
2004

2006
Water Conservation Standard based on previous standard but involves everyone

USGS Scientific Investigative Reports published
2009 - 2011

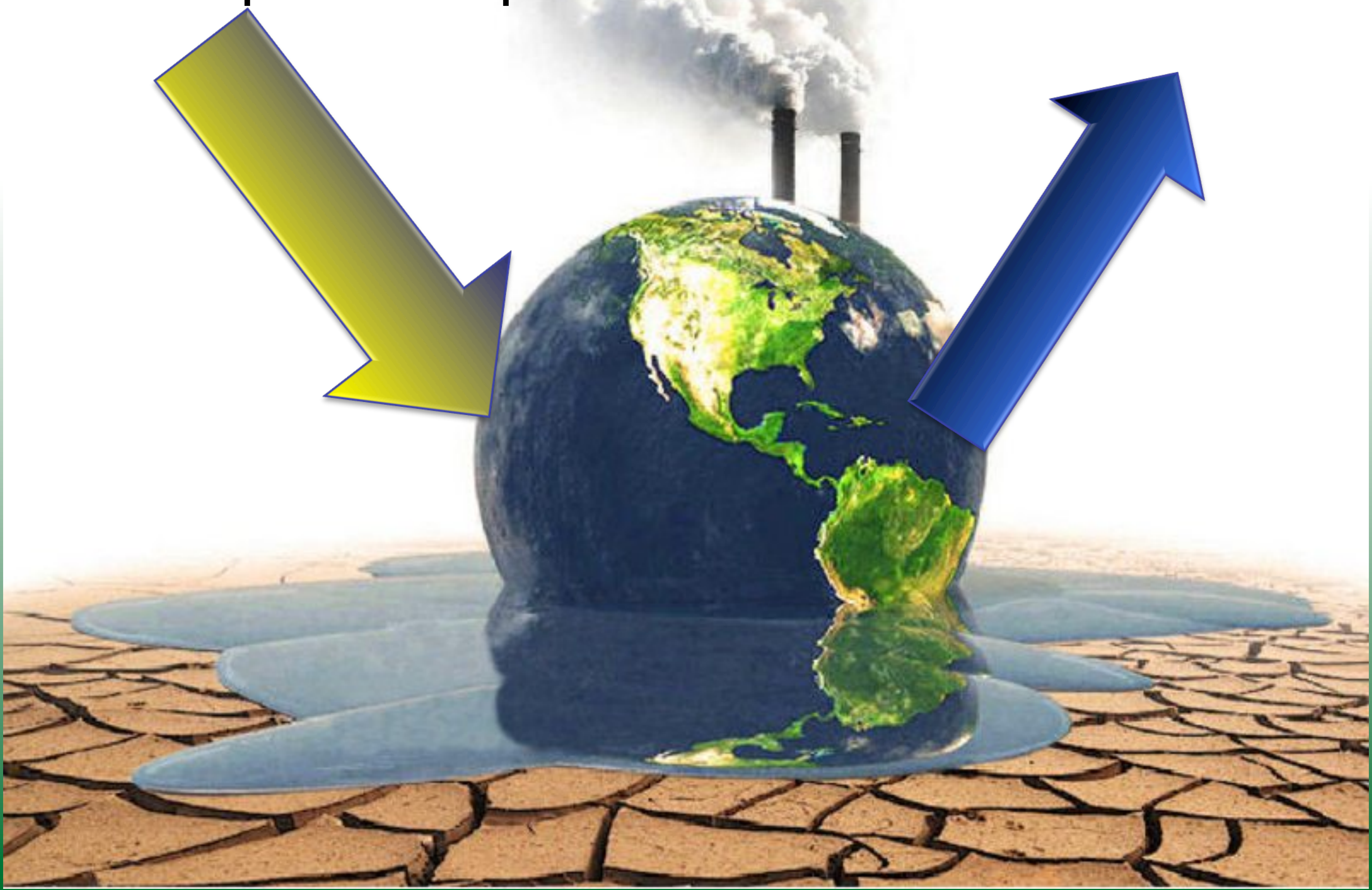
2012
Sustainable water Management Initiative (SWMI) Framework Released

SWMI Pilot project Case studies
2013

2014
SWMI starts proposed permit schedule

Energy balance of the earth

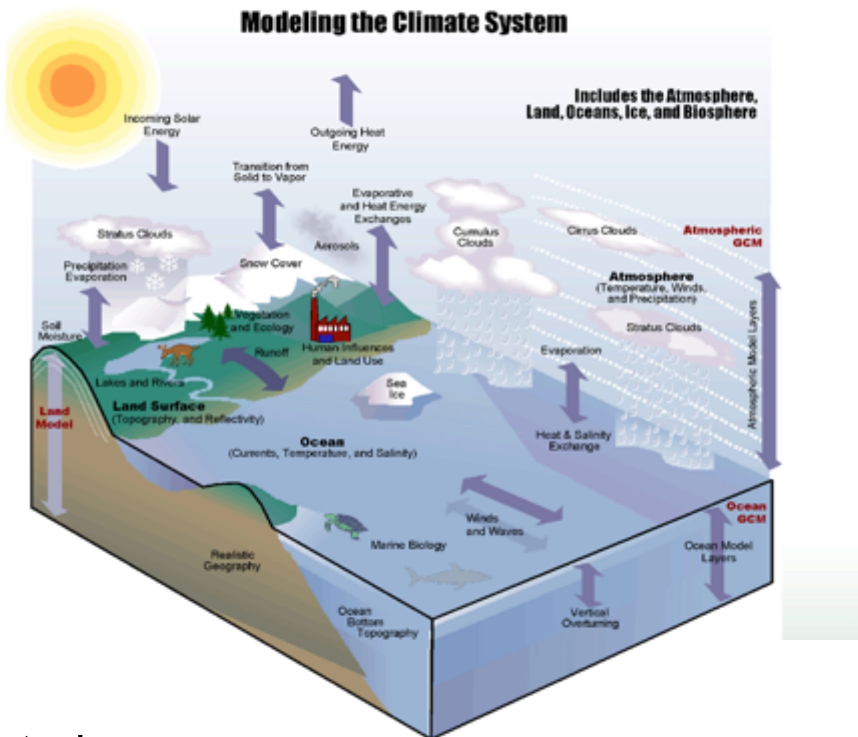
- Input – Output = Heat

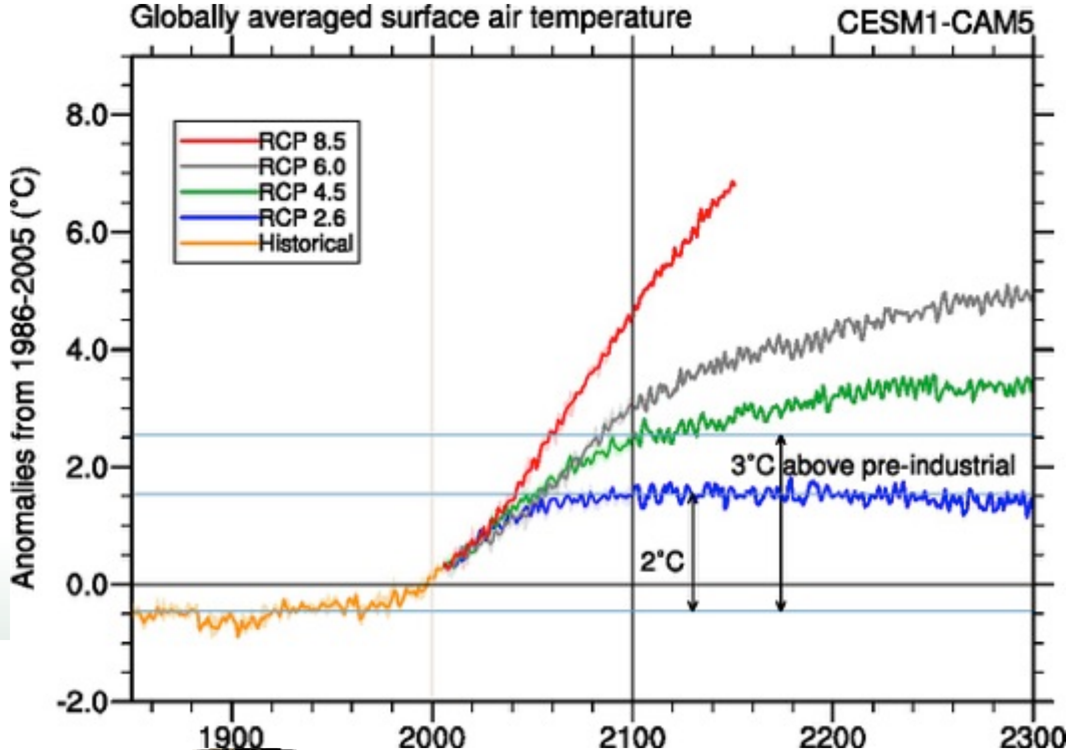


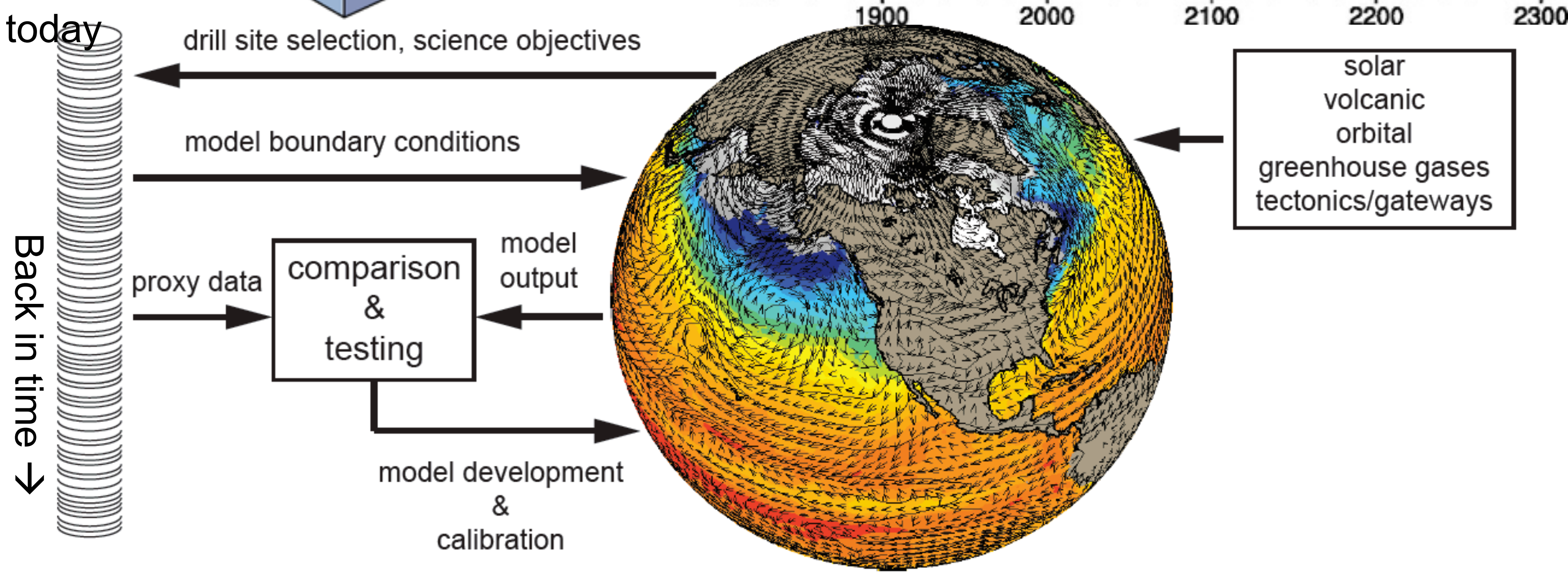
The State of Climate Science
(*this is not new…*)

Welcome to the
Anthropocene

- Global temperatures are increasing
- Sea level is rising
- These affect the hydrologic cycle
- The cause is anthropogenic


Modeling the Climate System
Includes the Atmosphere, Land, Oceans, Ice, and Biosphere
Incoming Solar Energy
Outgoing Heat Energy
Transition from Solid to Vapor
Evaporative and Heat Energy Exchanges
Stratus Clouds
Aerosols
Cumulus Clouds
Cirrus Clouds
Atmospheric GCM
Snow Cover
Precipitation Evaporation
Atmosphere (Temperature, Winds, and Precipitation)
Soil Moisture
Vegetation and Ecology
Human Influences and Land Use
Runoff
Stratus Clouds
Evaporation
Lakes and Rivers
Sea Ice
Land Model
Land Surface (Topography, and Reflectivity)
Heat & Salinity Exchange
Atmospheric Model Layers
Ocean (Currents, Temperature, and Salinity)
Ocean GCM
Winds and Waves
Marine Biology
Realistic Geography
Ocean Model Layers
Ocean Bottom Topography
Vertical Overturning

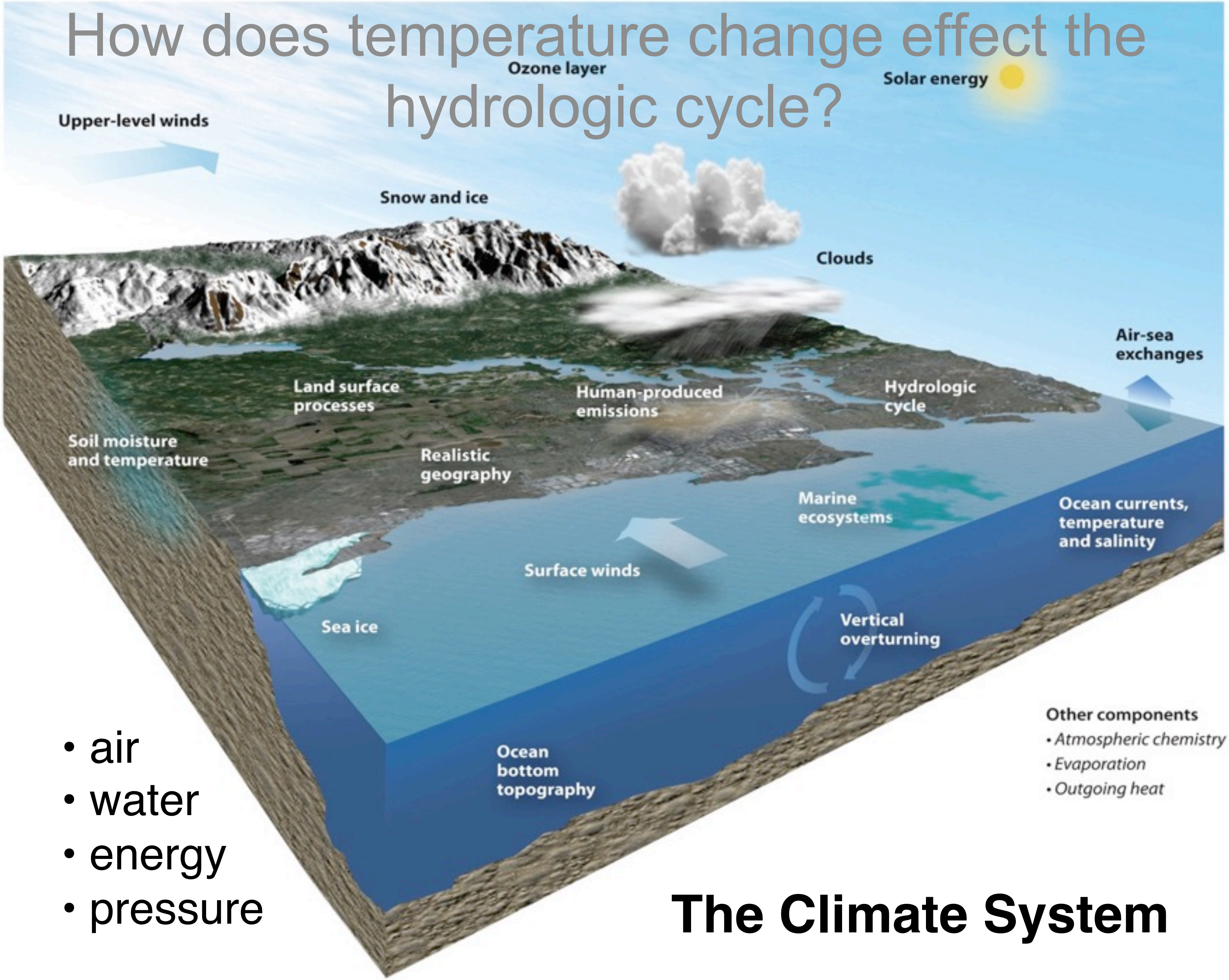

Globally averaged surface air temperature
CESM1-CAM5
RCP 8.5
RCP 6.0
RCP 4.5
RCP 2.6
Historical
Anomalies from 1986-2005 (°C)
8.0
6.0
4.0
2.0
0.0
-2.0
3°C above pre-industrial
2°C
1900
2000
2100
2200
2300


today
Back in time →
drill site selection, science objectives
model boundary conditions
proxy data
comparison & testing
model output
model development & calibration
solar
volcanic
orbital
greenhouse gases
tectonics/gateways

Climate Observations and Future Predictions: ***It Matters.***

- Weather and Climate Variables
  - Temperature, Precipitation, Winds
- Extreme Phenomena
  - Monsoons, El Niño, (Extra)tropical Cyclones
- Impacts on the Physical Environment
  - **Floods**, **Droughts**, Sealevel rise, Coastal Erosion, Permafrost melting

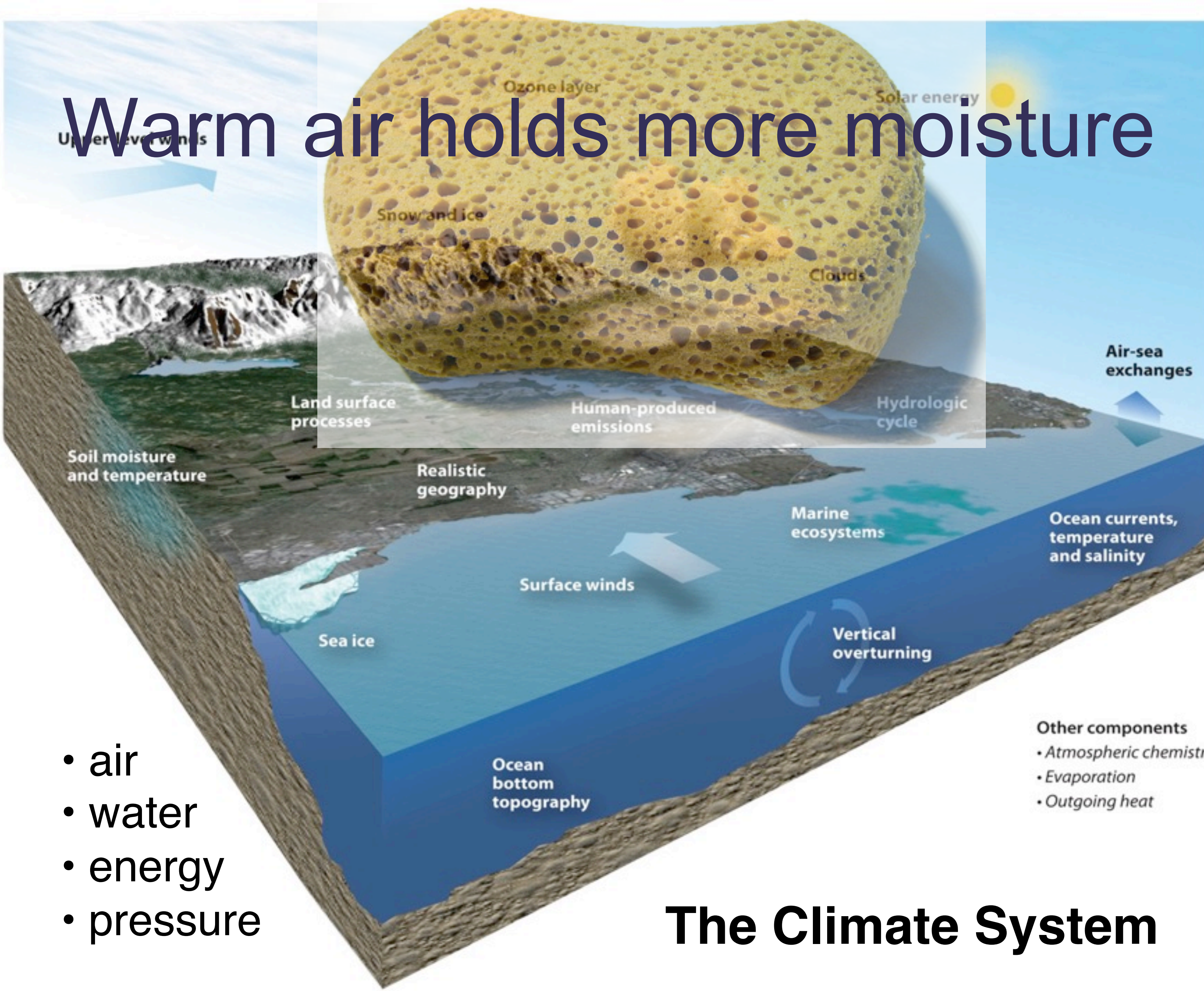
How does temperature change effect the hydrologic cycle?



- air
- water
- energy
- pressure

The Climate System

Warm air holds more moisture

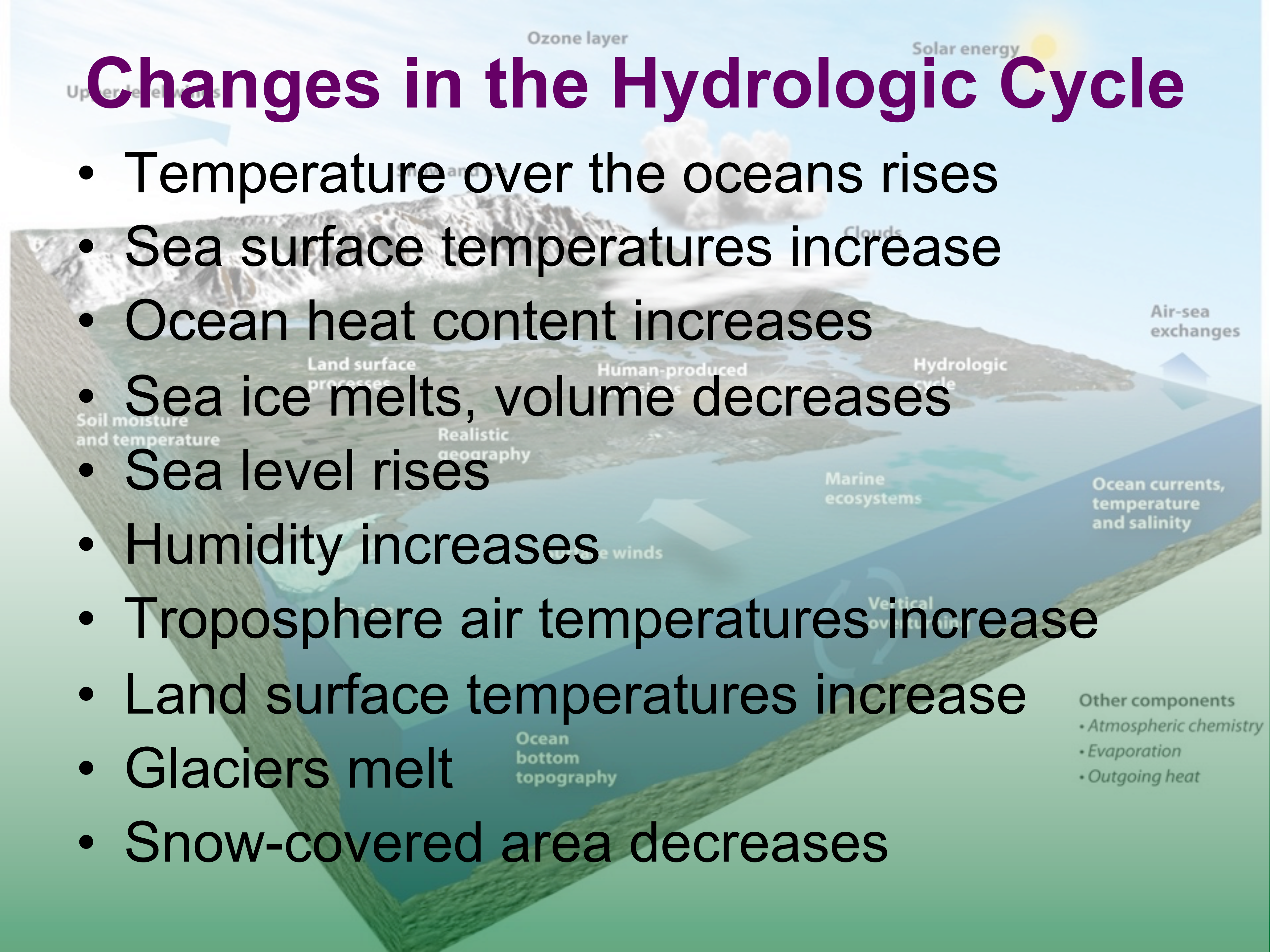


- air
- water
- energy
- pressure

The Climate System

Changes in the Hydrologic Cycle

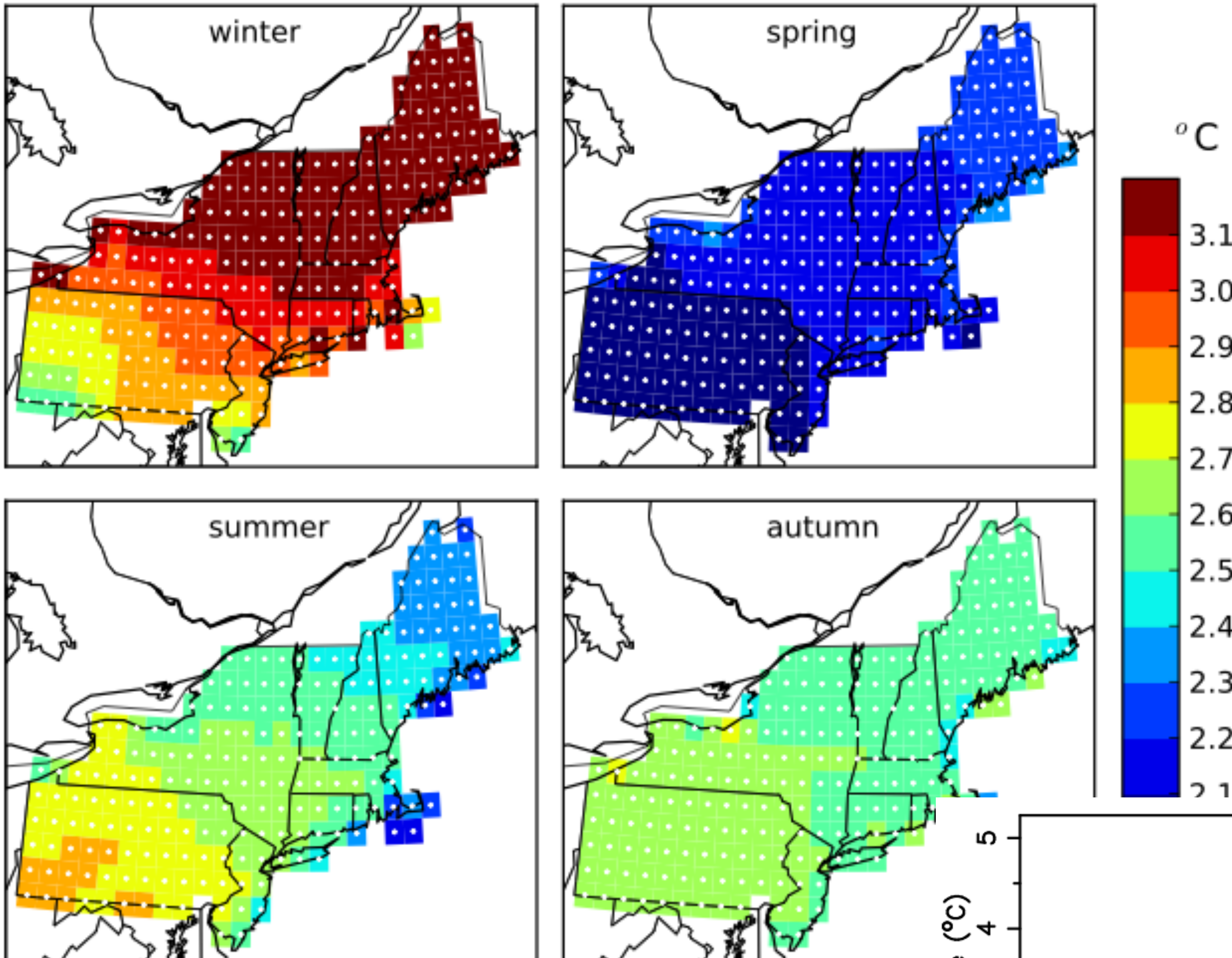
- Temperature over the oceans rises
- Sea surface temperatures increase
- Ocean heat content increases
- Sea ice melts, volume decreases
- Sea level rises
- Humidity increases
- Troposphere air temperatures increase
- Land surface temperatures increase
- Glaciers melt
- Snow-covered area decreases



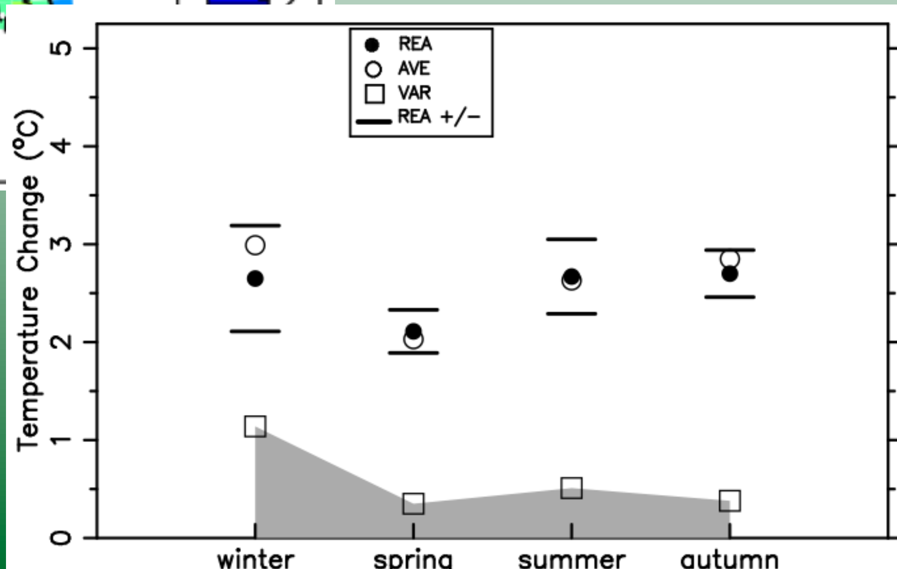
Climate change predictions for the N.E. U.S. and the hydrologic cycle

- Less snow
- Reduced extent of snow
- Shorter winter
- Earlier breakup of winter ice on lakes and rivers
- Earlier spring snowmelt
- More winter rain (4")
- Increased snow density
- More days T > 90°F
- Longer growing season
- Rising sea-surface temperatures and sea levels
- Earlier peak river flows

Summary from: *Frumhoff, et al,. 2007*. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. *NECIA, UCS*.



Temp.



(Rawlins et al., JGR 2012)

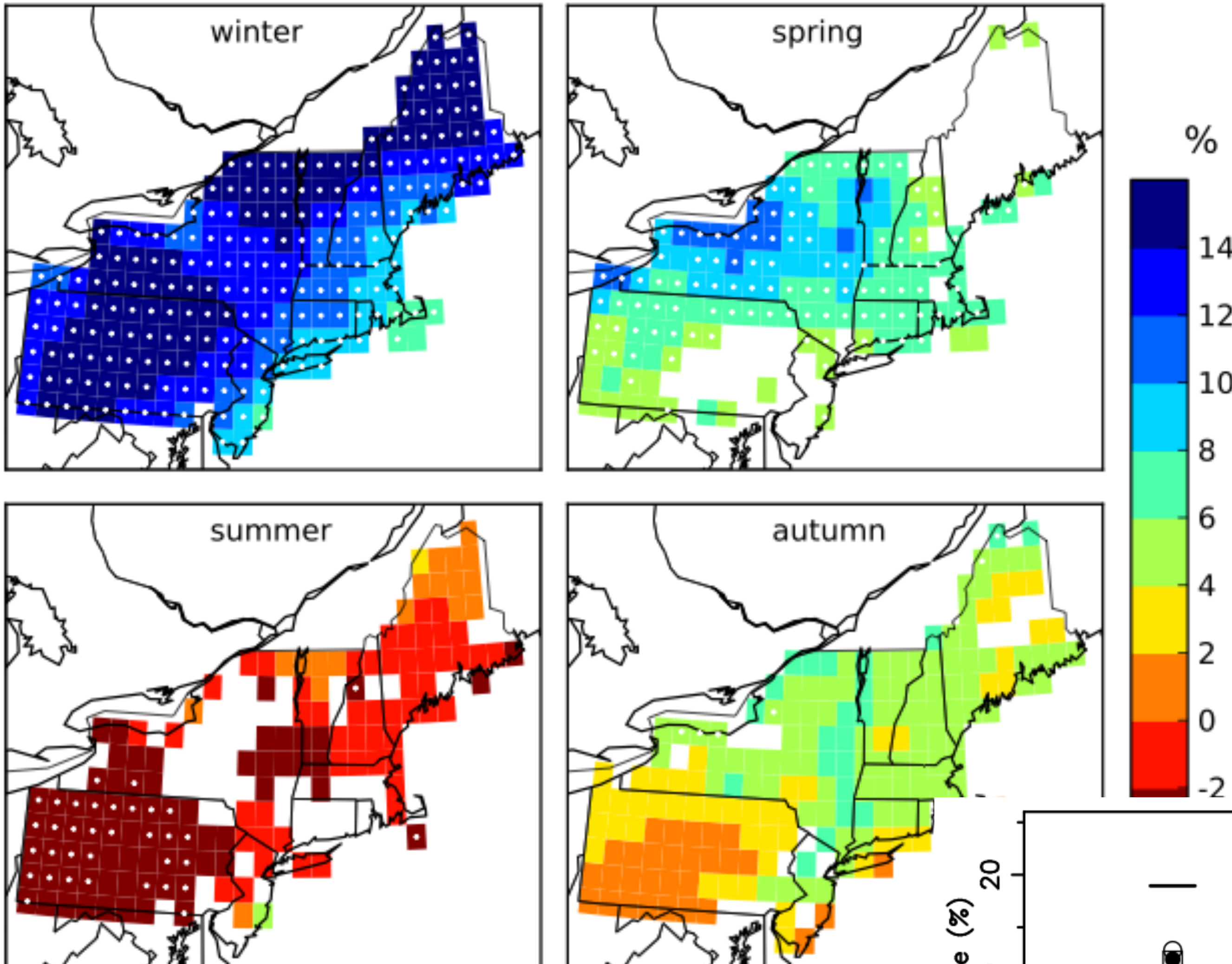
REA: ∆T (2041–2070 minus 1971– 2000),
AVE: averaged ∆T,
VAR: natural variability

Consequences of rain vs. snow:

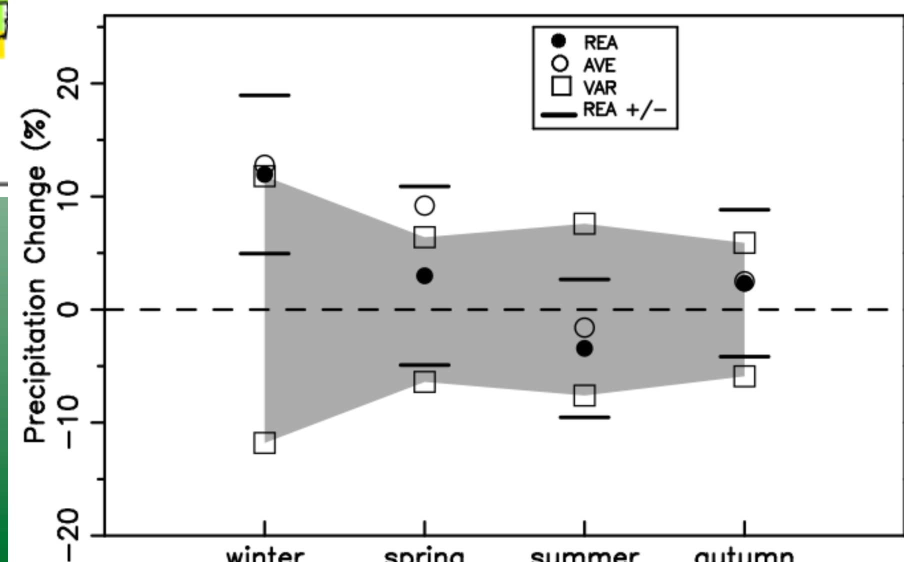
- Shorter duration winter
  - Effects on recreation and tourism
  - Less water “storage time” in snowpack
- Early, warmer spring
  - More mosquitoes (and associated illness)
  - Spring flooding
- Longer growing season
  - Forest changes
  - Some crops like it cold

Summary from: *Frumhoff, et al,. 2007*. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. *NECIA, UCS*.

Precip.



(Rawlins et al., JGR, 2012)



Consequences of rising sea level:

- Coastal flooding
- Increased damage from storm surges

Today's 100-year coastal floods are projected to recur much more often. On average, under the scenarios of:

	Higher-emissions vs. lower-emissions there will be a 100-year flood every:	
• Boston	1-2 years	1-2 years (50-100%)
• Atlantic City	1-2 years	1-2 years
• Woods Hole	9 years (11%)	21 years (5%)
• New York City	11 years (9%)	22 years (5%)
• New London	17 years (6%)	32 years (3%)

Adapted from: *Frumhoff, et al,. 2007*. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. *NECIA, UCS*.

Consequences of changing precipitation:

- Increased intensity of precipitation
  - Landslides
  - Erosion
  - Flooding
- Increased frequency of extreme events
  - Design storms are inadequate predictions
  - Storm surge damage
- Increased likelihood of droughts
  - Water shortages for crops and municipal supply

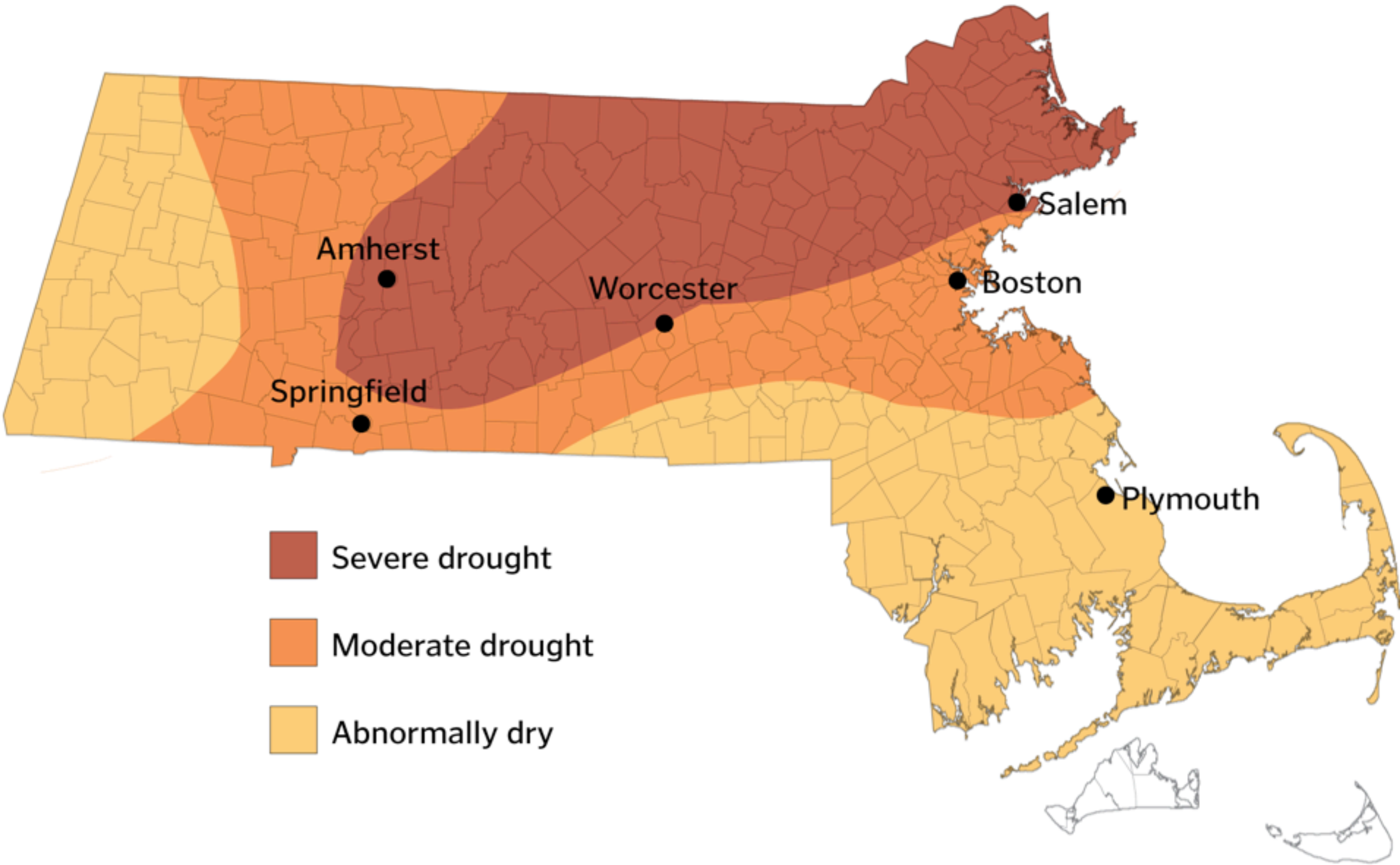
Summary from: *Frumhoff, et al,. 2007*. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. *NECIA, UCS*.

Consequences of changing precipitation:

- Increased intensity of precipitation
  - Landslides
  - Erosion
  - Flooding
- Increased frequency of extreme events
  - Design storms are inadequate predictions
  - Storm surge damage
- Increased likelihood of droughts
  - Water shortages for crops and municipal supply

Summary from: *Frumhoff, et al,. 2007*. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. *NECIA, UCS*.

Let’s talk about the drought



Drought's effects mount as dry weather continues

DINA RUDICK/GLOBE STAFF

A dead Christmas tree seedling at Smolak Farms in North Andover.

Top 10 Trending Articles

Most Viewed | Most Commented | Most Shared

- Trump's supporters talk rebellion, assassination at his rallies
- Four women in Springfield overdose on heroin
- "Whitey" Bulger won't help man claiming wrongful conviction
- Carfentanil, the newest killer in opioid epidemic, is 10,000 times stronger than morphine
- Enough is enough — scrap the third debate
- Vote all you want. The secret government won't change.
- Blowback for American sins in the Philippines
- Hillary Clinton shuns spotlight as Donald Trump spirals

Insanely Bad Summer Drought is Decimating New England Farms

By Dan Nosowitz on October 7, 2016

Scenes From New England's Drought: Dry Wells, Dead Fish and Ailing Farms

By **JESS BIDGOOD** SEPT. 26, 2016

RELATED COVERAGE

California Braces for Unending Drought MAY 9, 2016

Wayne Castonguay, the executive director of the Ipswich River Watershed Association, says it may take the area a decade or more to recover. By AINARA TIEFENTHÄLER and JESS BIDGOOD on September 26, 2016. Photo by Ian Thomas Jansen-Lonnquist for The New York Times. Watch in Times Video »

Embed

New England Drought Means Bolder Bears

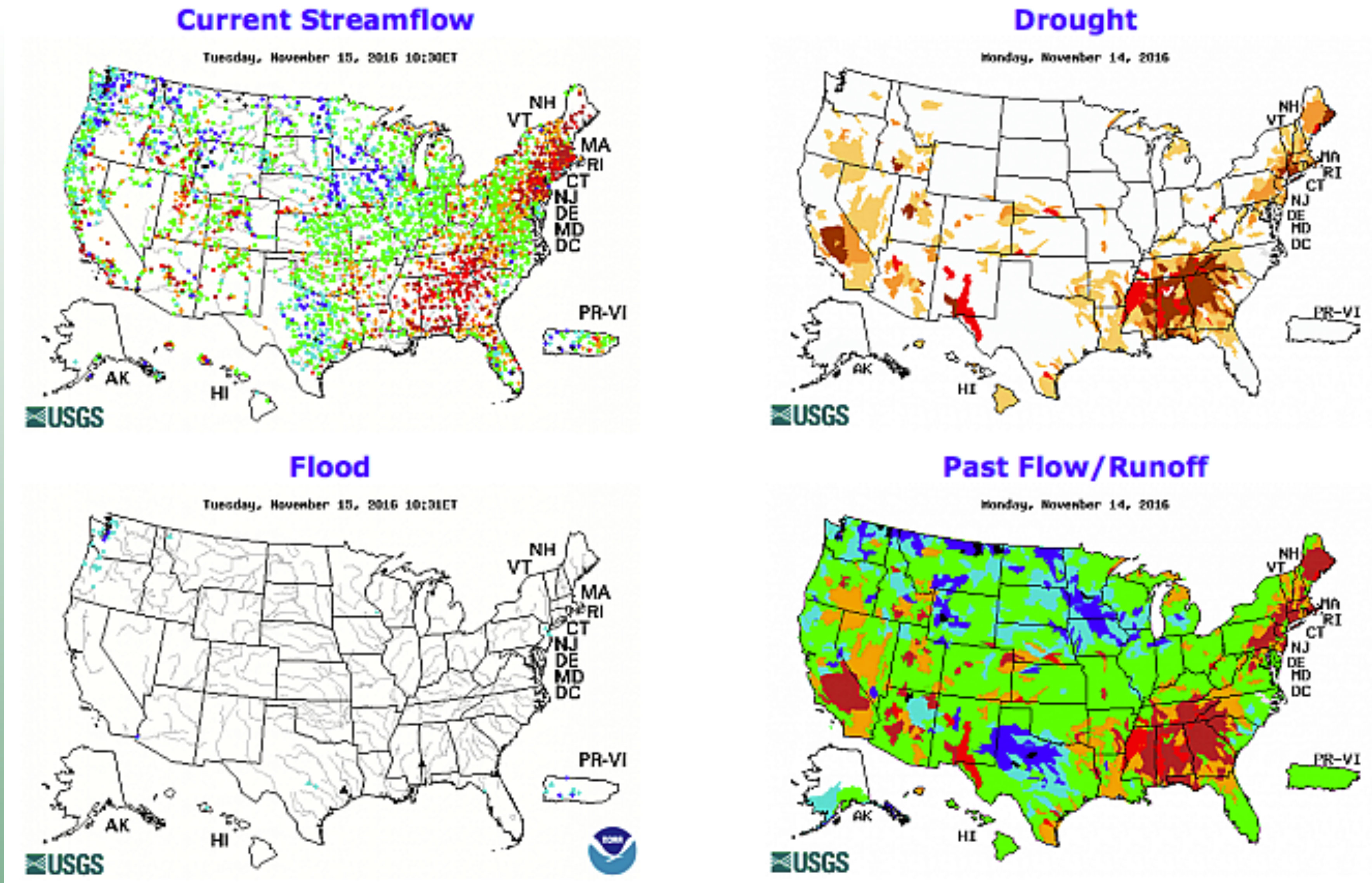
By Holly Ramer, Associated Press

August 20, 2016 3:29 PM

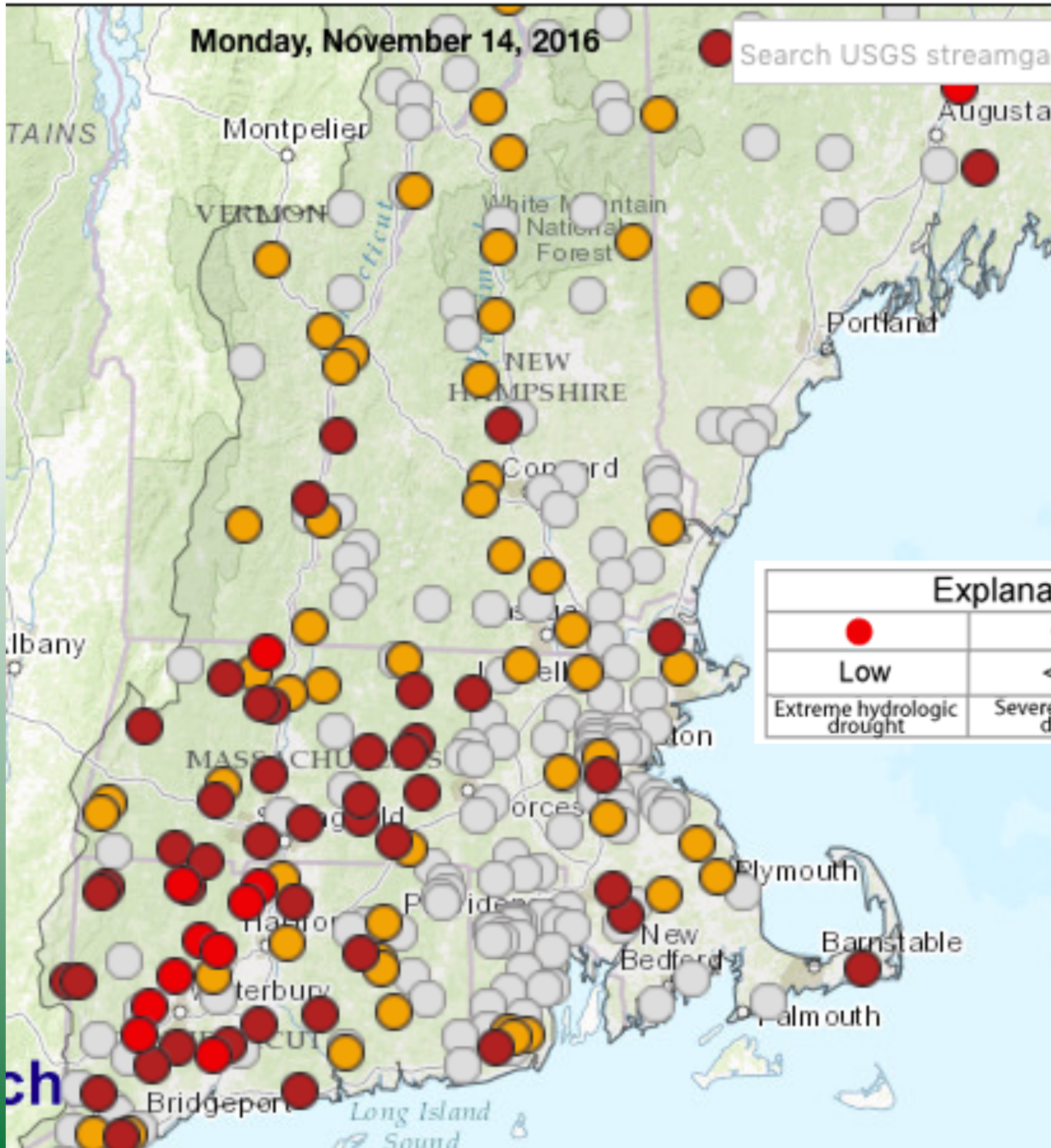
Filed Under: Bears, Drought

A black bear in an Easthampton backyard. (Photo credit: Patrick Brough)

http://waterwatch.usgs.gov



30-day average streamflows



Explanation - Percentile classes			
Low	<=5	6-9	10-24
Extreme hydrologic drought	Severe hydrologic drought	Moderate hydrologic drought	Below normal

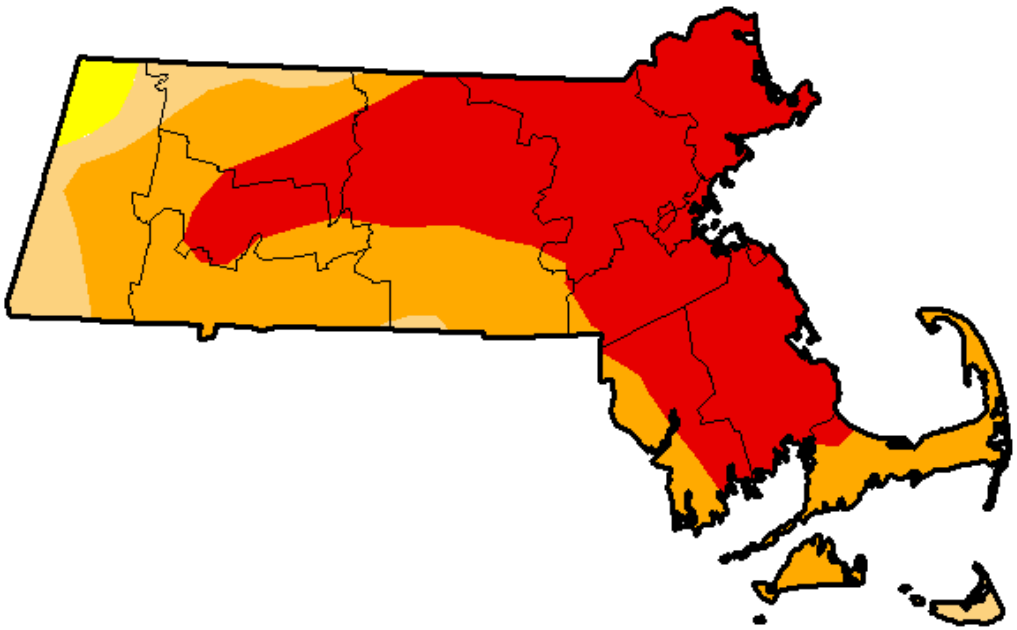
U.S. Drought Monitor

Massachusetts

September 27, 2016

(Released Thursday, Sep. 29, 2016)

Valid 8 a.m. EDT



Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.00	100.00	98.15	89.95	52.13	0.00
Last Week 9/20/2016	0.00	100.00	98.15	89.95	52.13	0.00
3 Months Ago 6/28/2016	3.60	96.40	38.91	0.00	0.00	0.00
Start of Calendar Year 12/29/2015	22.85	77.15	26.34	0.00	0.00	0.00
Start of Water Year 9/29/2015	12.90	87.10	30.43	0.00	0.00	0.00
One Year Ago 9/29/2015	12.90	87.10	30.43	0.00	0.00	0.00

Intensity:

- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

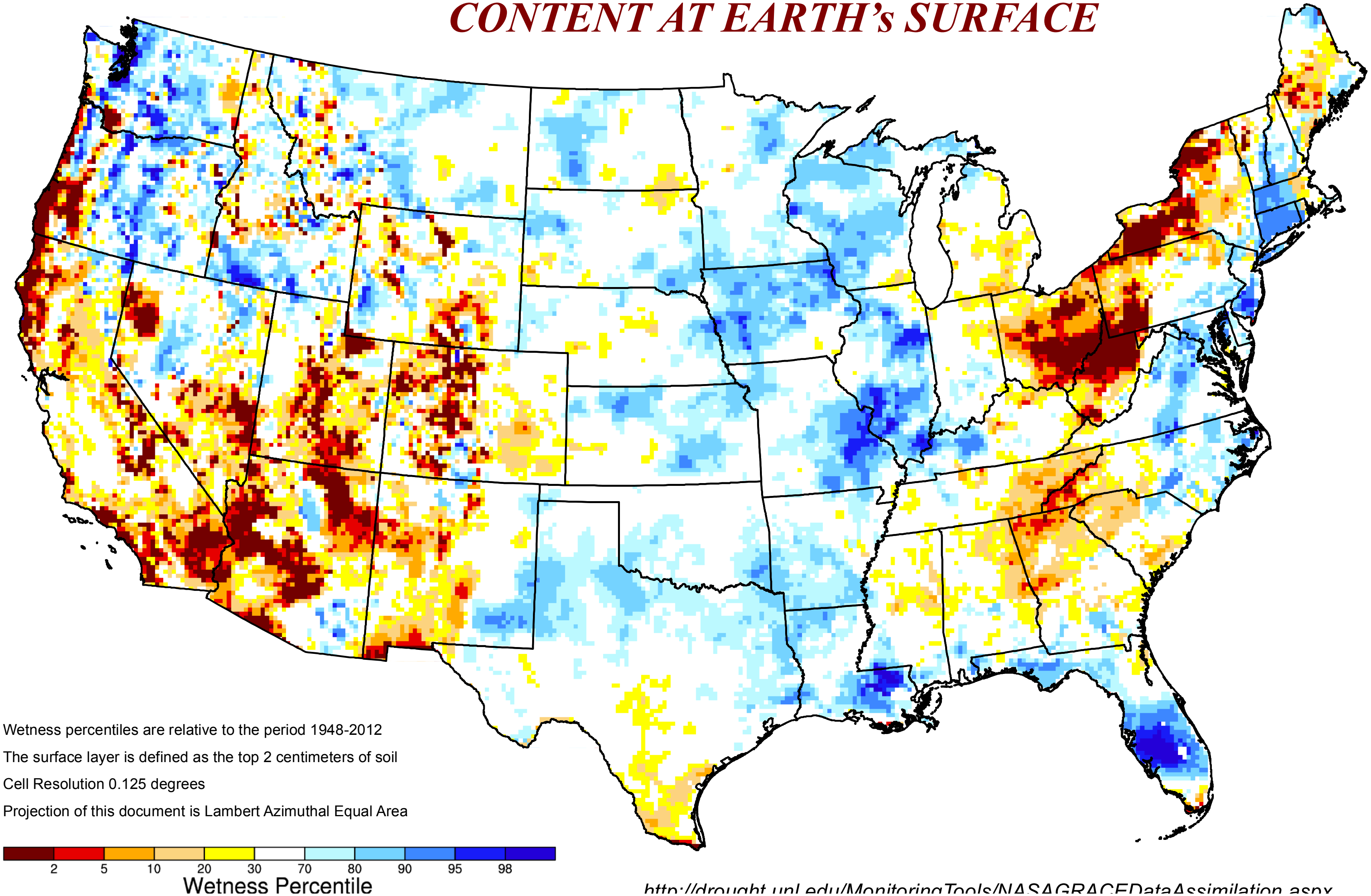
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
Chris Fenimore
NCEI/NESDIS/NOAA

http://droughtmonitor.unl.edu/

GRACE-Based Surface Soil Moisture Drought Indicator

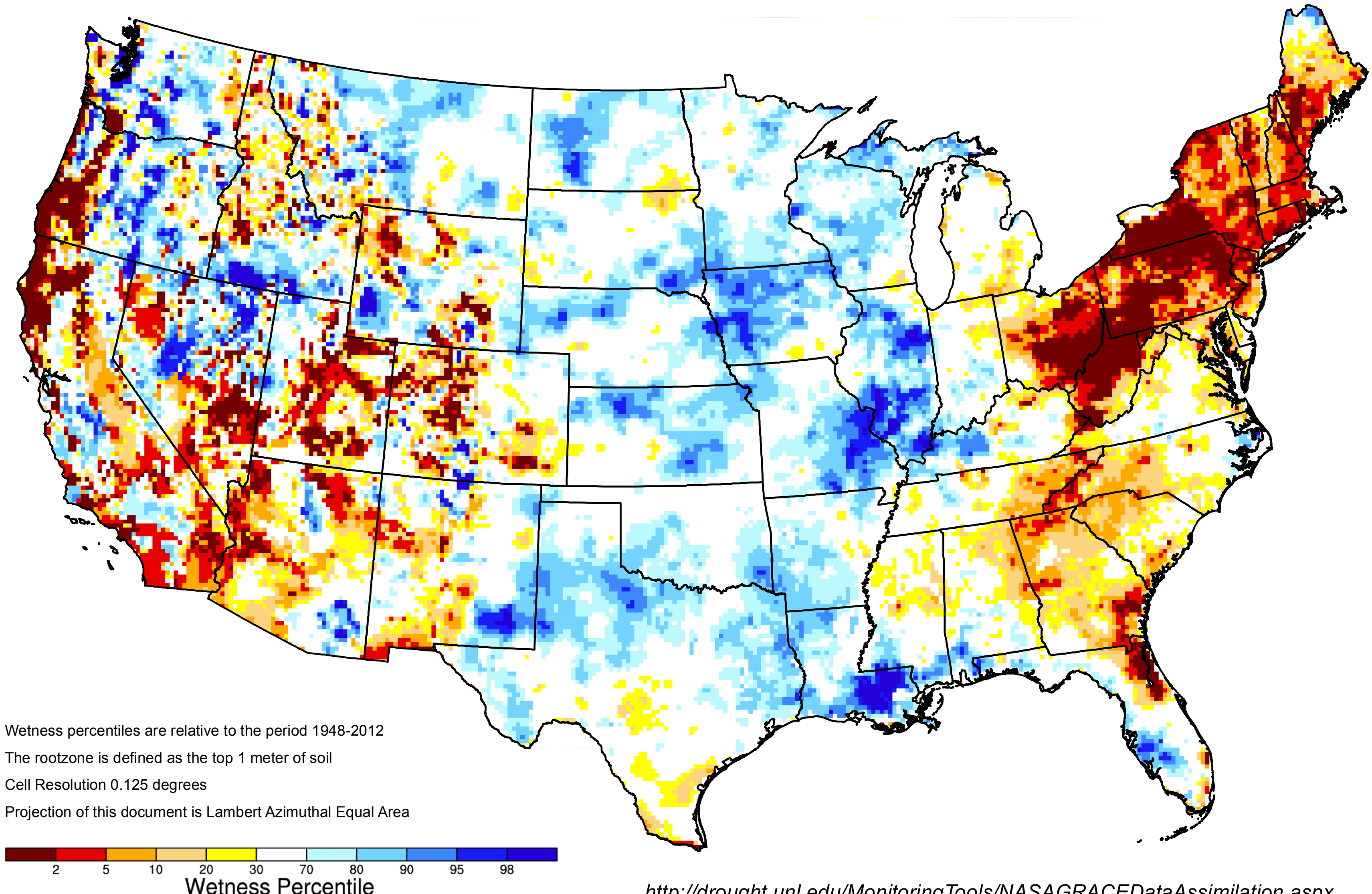
GRAVITY ANOMALIES = CHANGES IN WATER CONTENT AT EARTH's SURFACE



http://drought.unl.edu/MonitoringTools/NASAGRACEDataAssimilation.aspx

GRACE-Based Root Zone Soil Moisture Drought Indicator

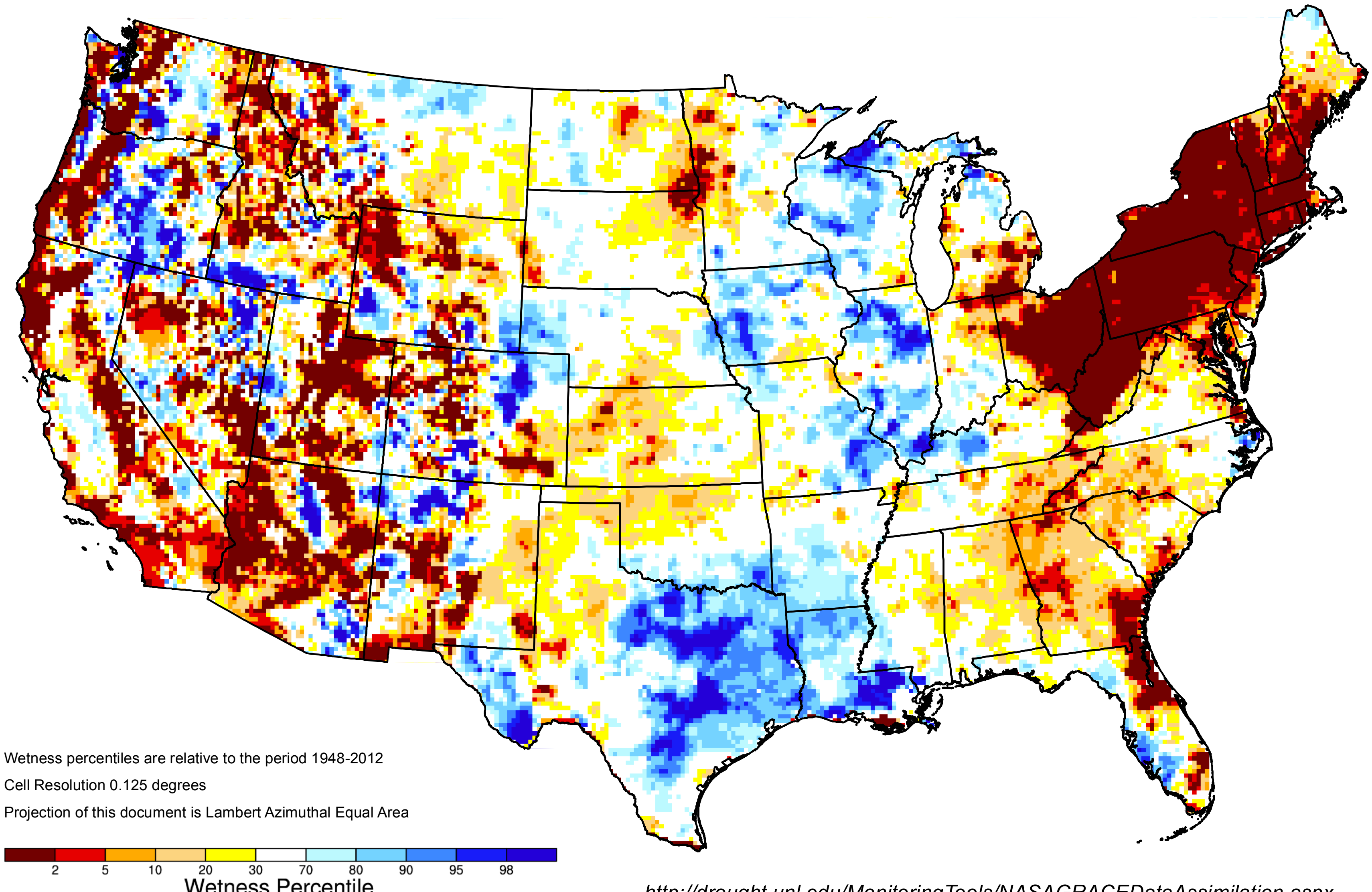
September 19, 2016



http://drought.unl.edu/MonitoringTools/NASAGRACEDataAssimilation.aspx

GRACE-Based Shallow Groundwater Drought Indicator

September 19, 2016



Wetness percentiles are relative to the period 1948-2012

Cell Resolution 0.125 degrees

Projection of this document is Lambert Azimuthal Equal Area

http://drought.unl.edu/MonitoringTools/NASAGRACEDataAssimilation.aspx

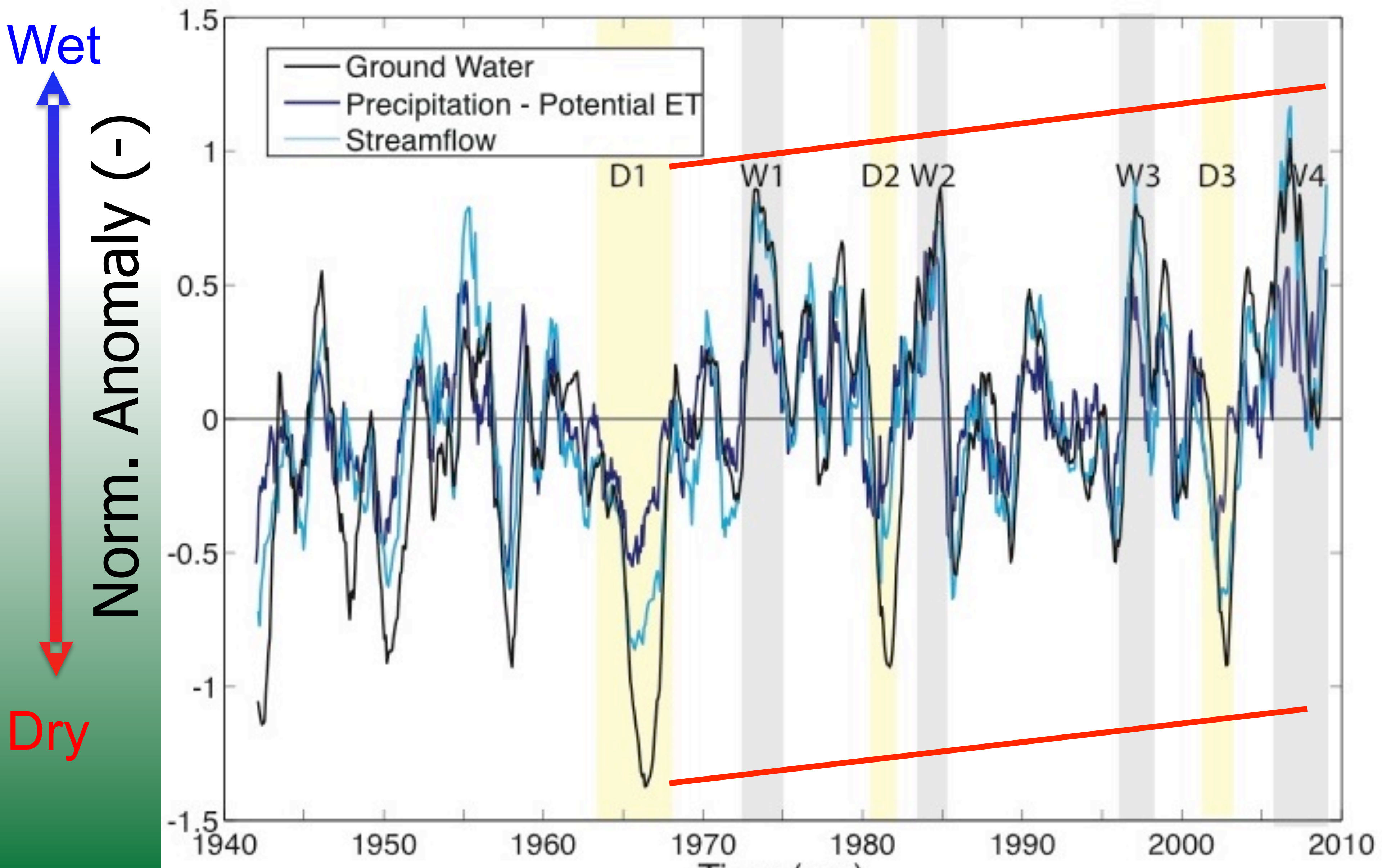
The roots of this drought go back further than you think

KEITH BEDFORD/GLOBE STAFF

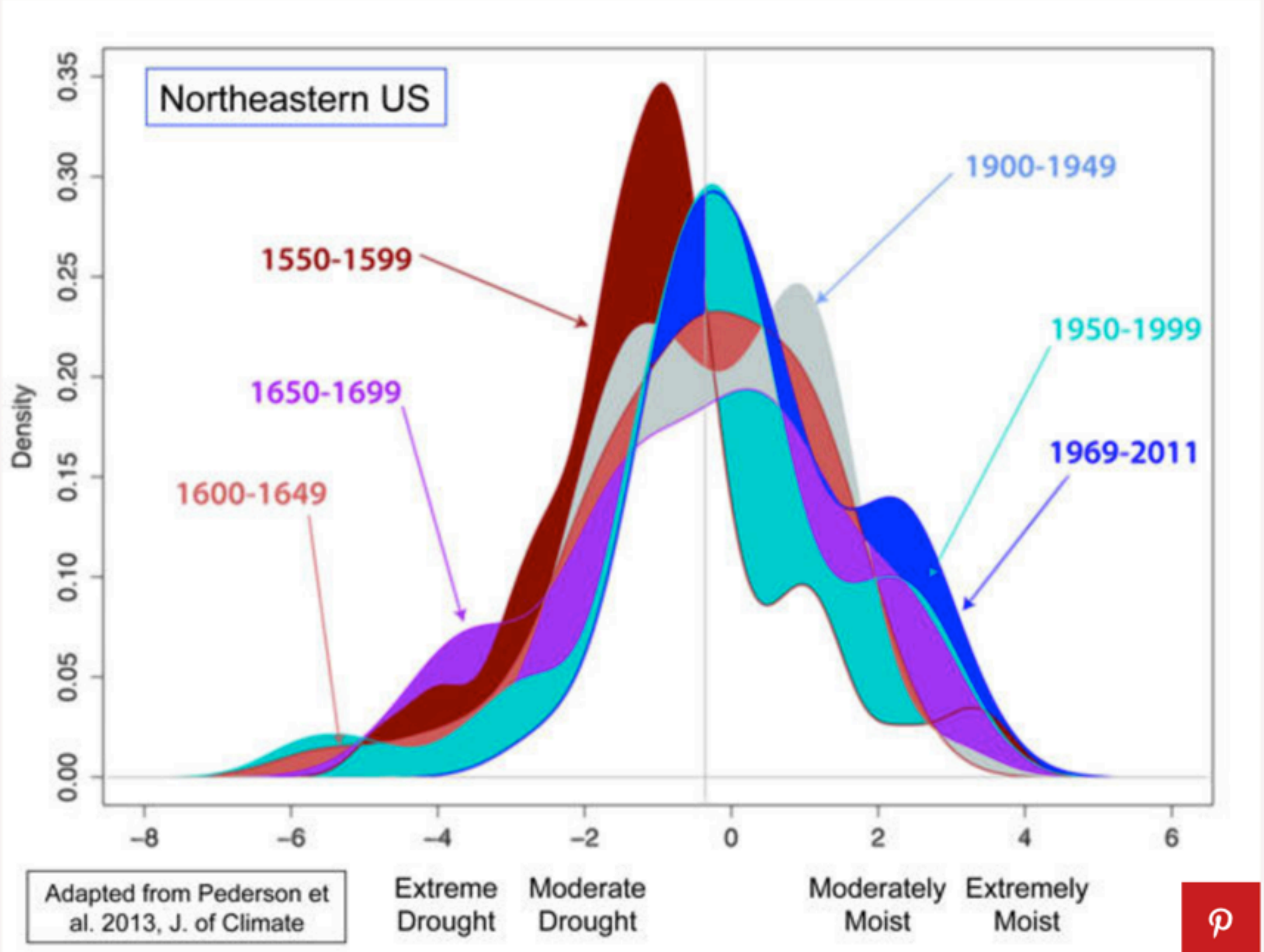
Frank Matheson walked through dried corn fields due to drought conditions at his family's farm in Littleton.

By Matt Rocheleau | GLOBE STAFF SEPTEMBER 22, 2016

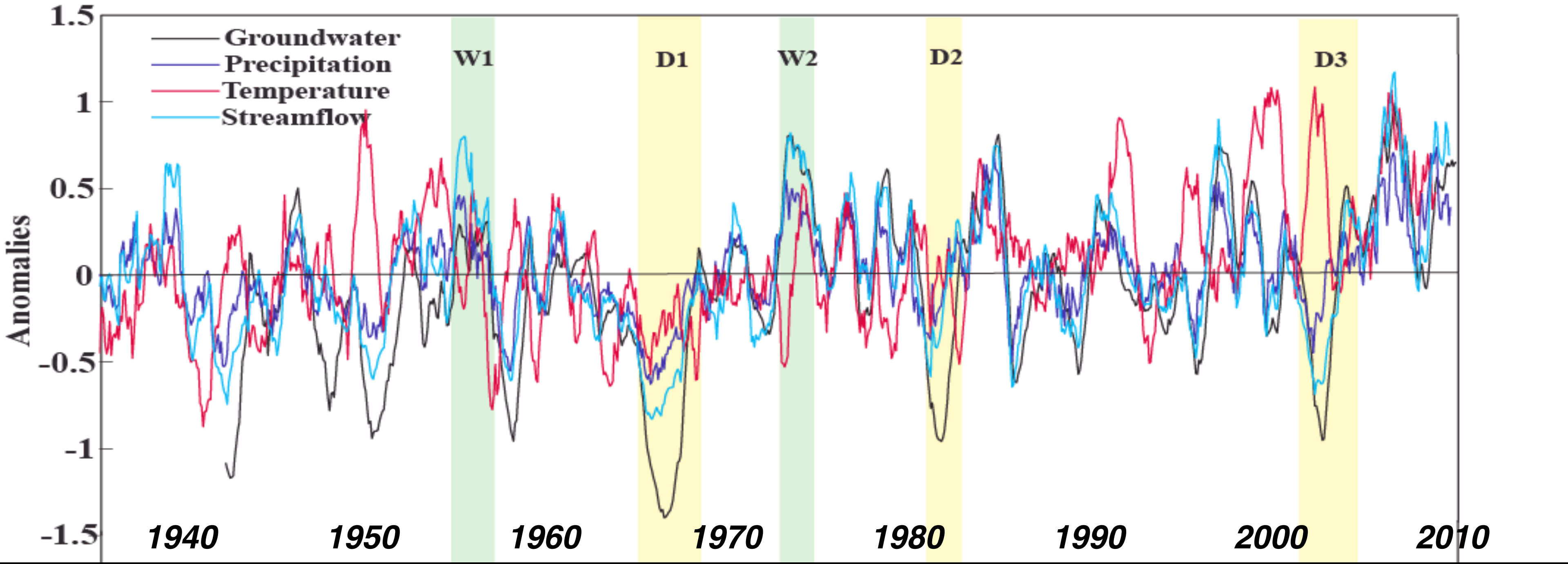
Regional Average Anomalies



Weider and Boutt, GRL, 2010



Northeastern US
1550-1599
1600-1649
1650-1699
1900-1949
1950-1999
1969-2011
Density
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
−8
−6
−4
−2
0
2
4
6
Extreme Drought
Moderate Drought
Moderately Moist
Extremely Moist
Adapted from Pederson et al. 2013, J. of Climate



Historical Context of drought in New England:
D1 (1962-1967) – Quabbin was 20 feet lower than today
D2 (1980's) – UMass was closed to conserve Amherst water supply
D3 (2000's) – SWMI discussions began

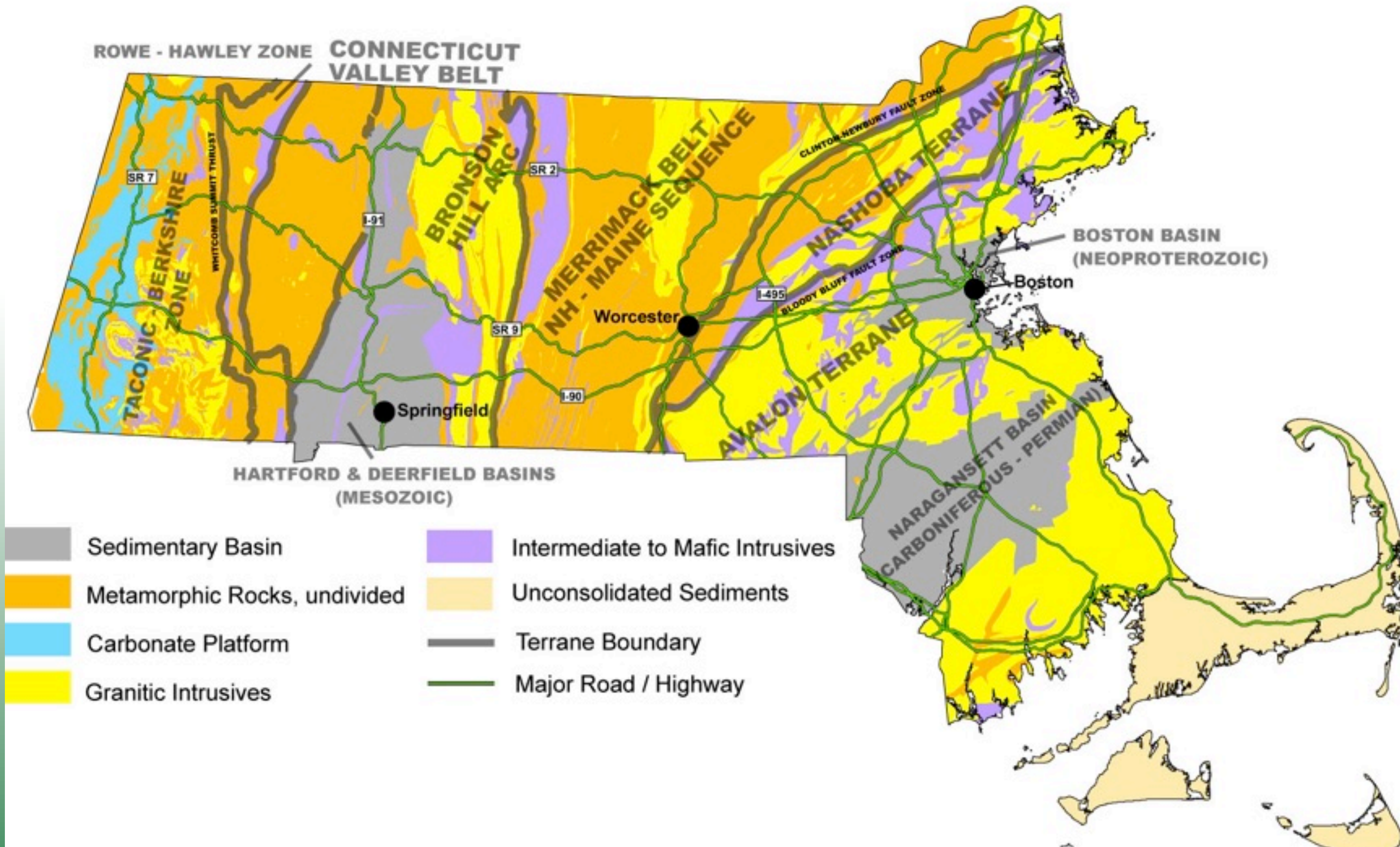
The current drought:
Not yet in the top 5
Since ~2013 (droughts are not 1 year events)
During the growing season! Impacts farmers, home owners, gardeners

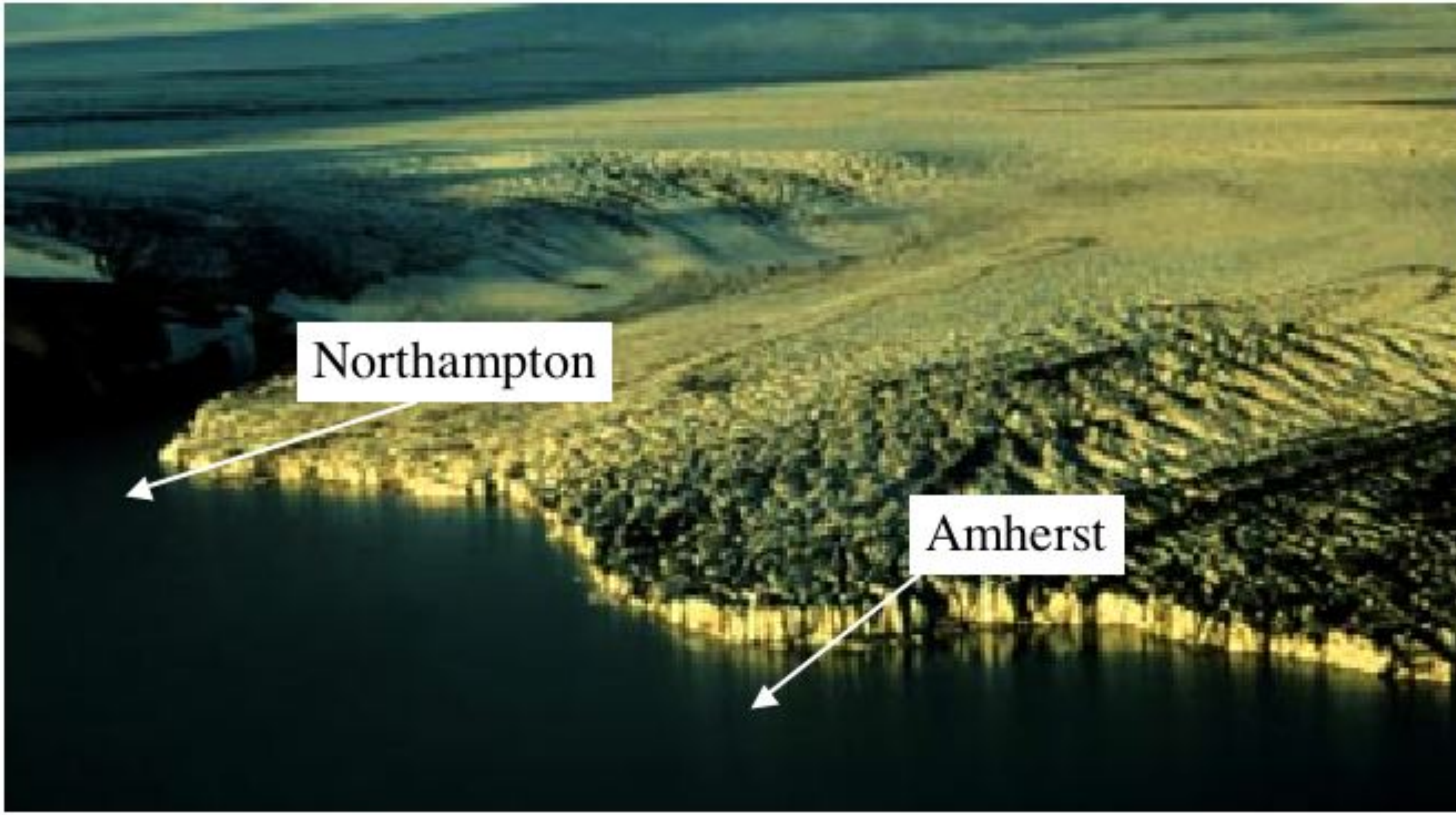
Rain → groundwater → streams can take 5-25 years to become baseflow

A Global Problem
(but solutions and consequences are local)

- Ultimately, emissions controls MUST be addressed on a global scale
- Local Adaptation and Mitigation are of critical importance to Resilience

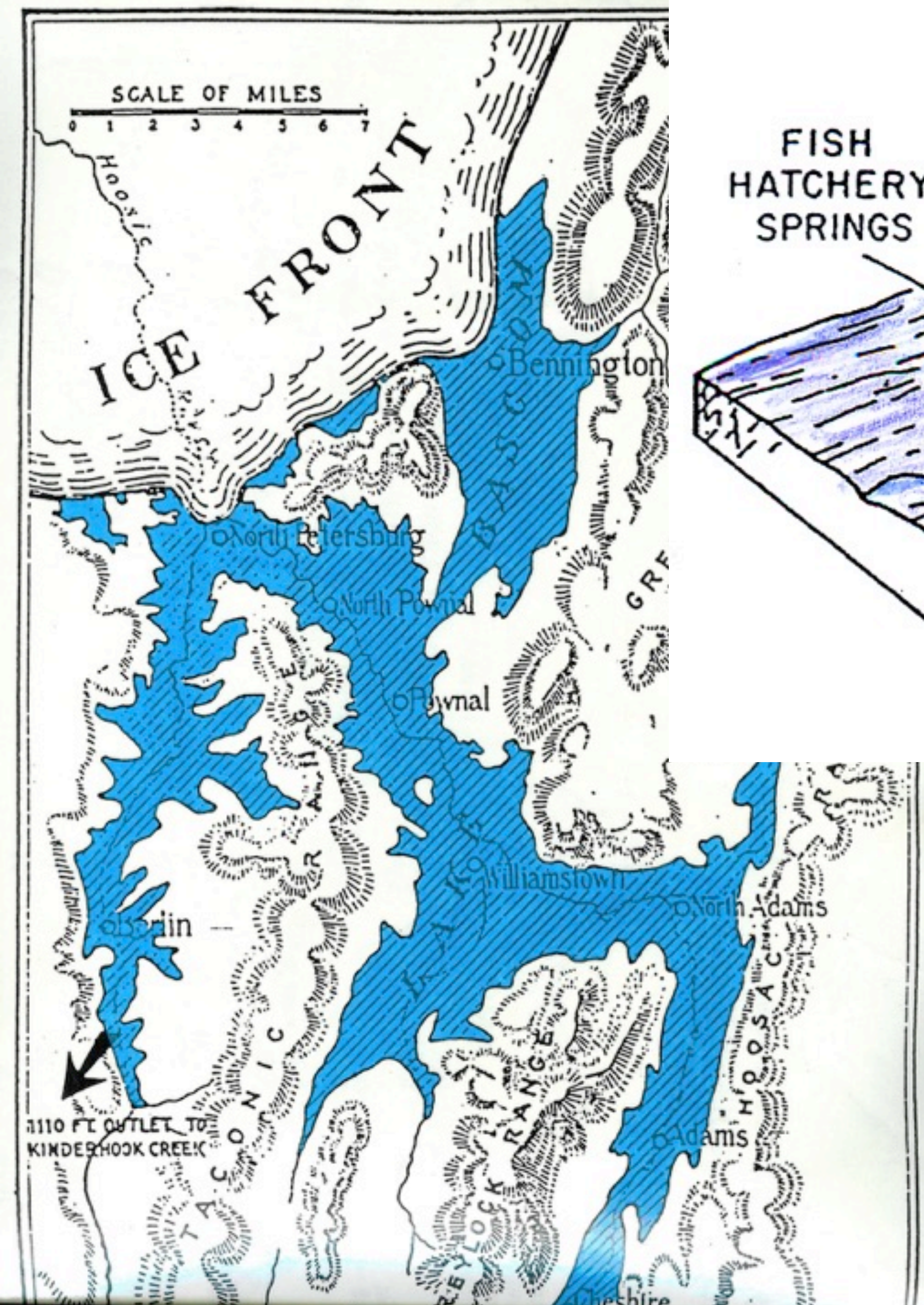
First, some Geologic Context

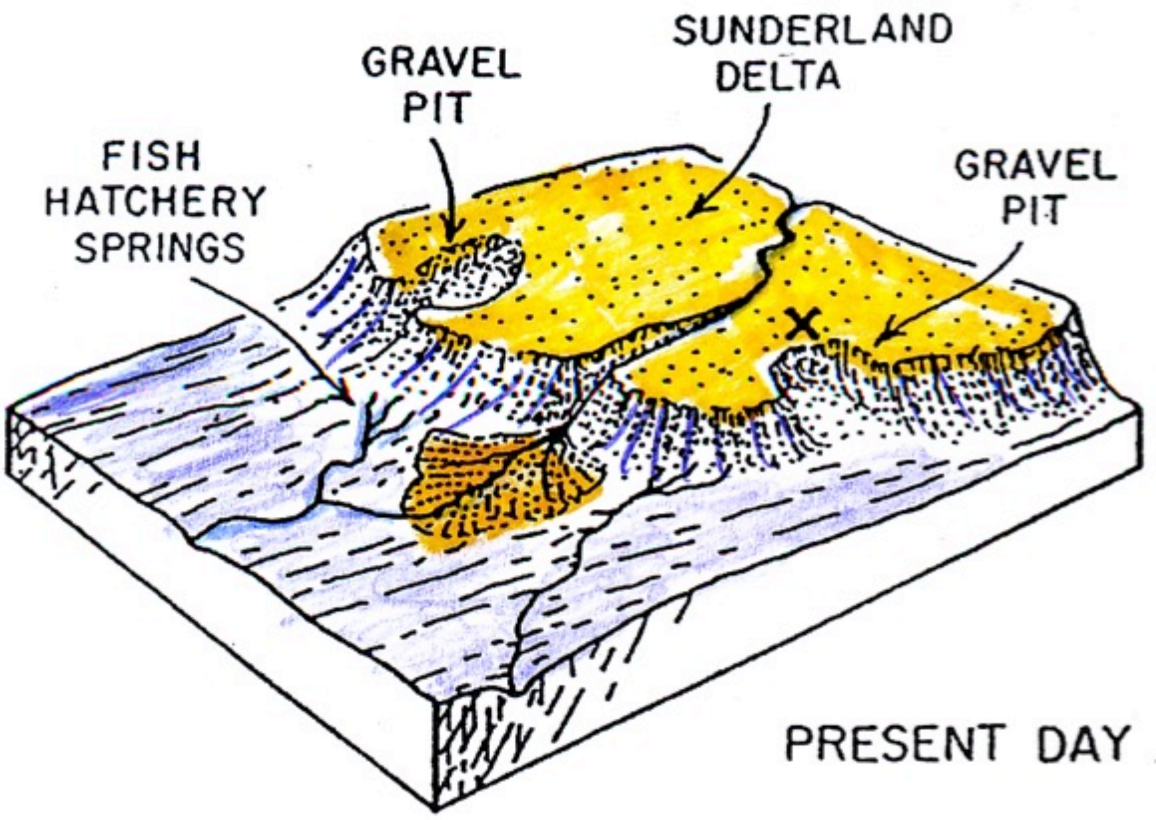




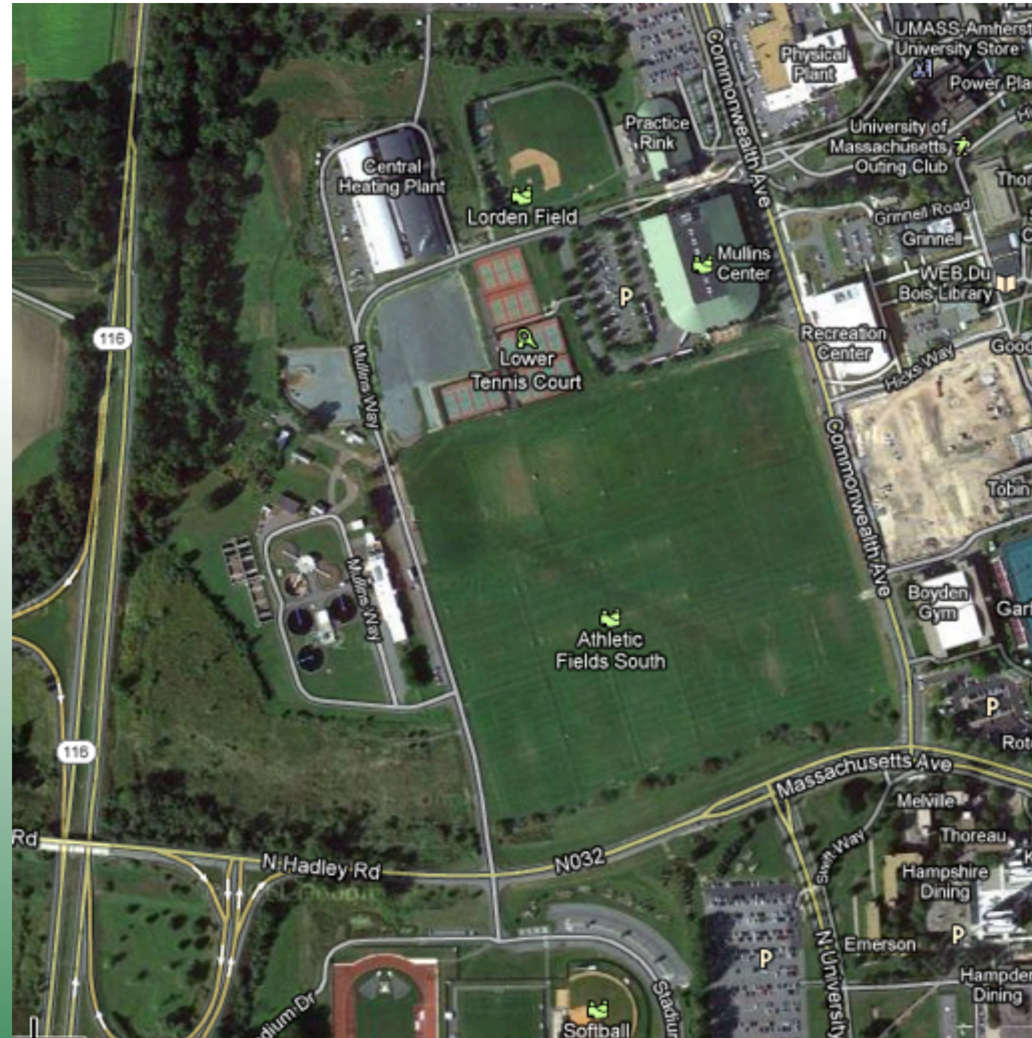
Central Massachusetts, 13-14 ka yrs BP


Glacial Geology of Massachusetts
Stratified Deposits - Coarse Grained
Stratified Deposits - Fine Grained
Floodplain Alluvium
Till and/or Till with Shallow or Exposed Bedrock
Outline of Glacial Lake
Position of Glacier Margin
Glacial Lake Bascom
Glacial Lake Hitchcock
Swift River lakes
Glacial Lake Nashua
Glacial Lake Shawsheen-Merrimack
Glacial Lake Concord
Glacial Lake Sudbury
Glacial Lake Bouve
Glacial Lake Housatonic
Glacial Lake Winimussett
Glacial Lake Assabet
Glacial Lake Whipples
Glacial Lake Charles
Glacial Cape Cod Bay lake
Glacial Lake Great Falls
Westfield arm of Glacial Lake Hitchcock
Glacial Lake Neponset
Glacial Lake Taunton
Glacial Cape Cod Bay lake


SCALE OF MILES
0 1 2 3 4 5 6 7
ICE FRONT
Hoosic
Bennington
North Petersburg
North Pownal
Pownal
Williamstown
North Adams
Berlin
Adams
Cheshire
TACONIC RANGE
HOOSAC
GRE
1110 FT. OUTLET TO
KINDERHOOK CREEK


SUNDERLAND
DELTA
GRAVEL
PIT
FISH
HATCHERY
SPRINGS
GRAVEL
PIT
PRESENT DAY

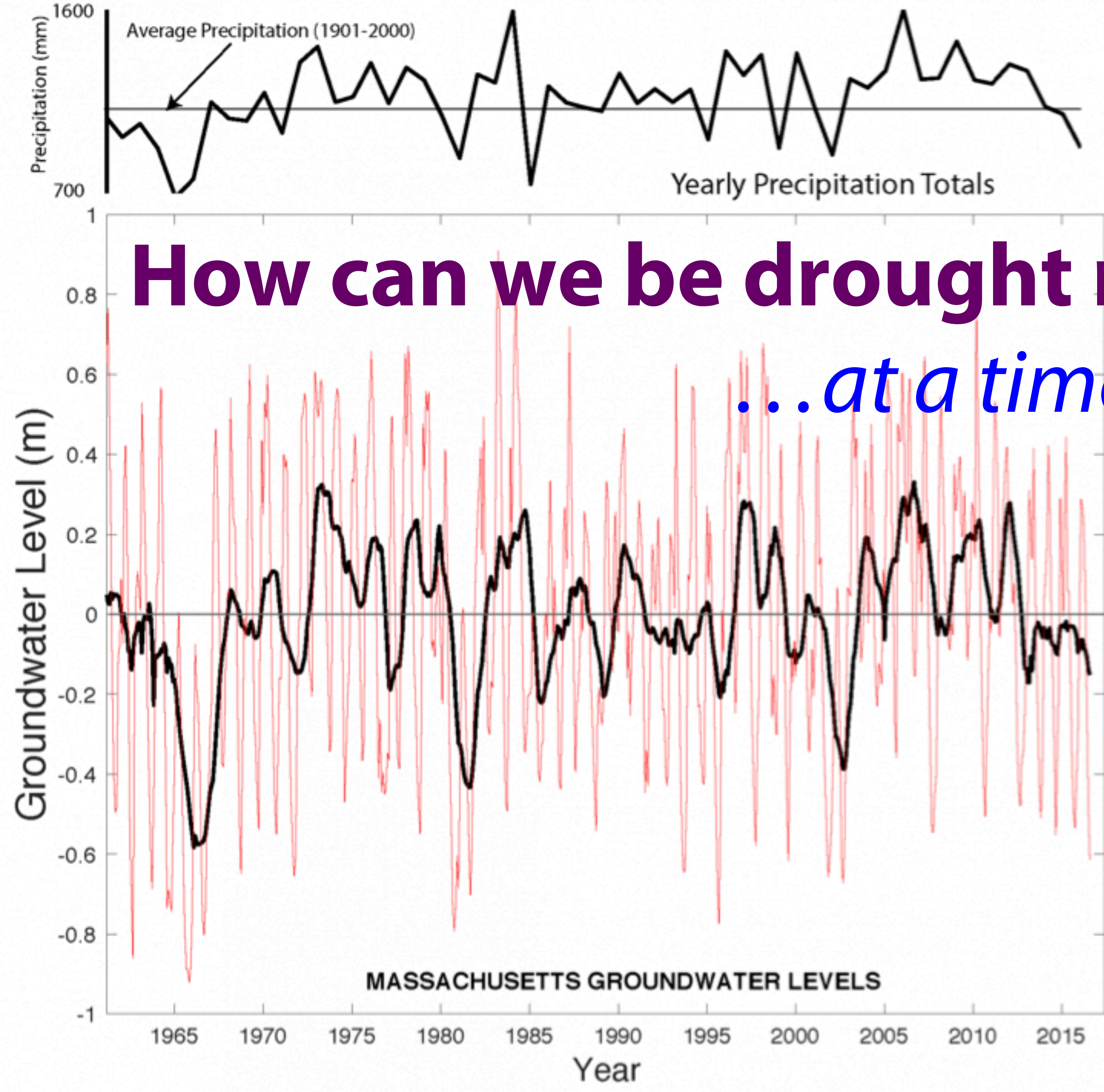
Glacial Lake Hitchcock Varve Record, 17.5-13.5 ka BP



Rittenour, Brigham-Grette and Mann, 2000, *Science*

How can we be drought resilient?

…at a time like this?



1. It's not that bad (yet)

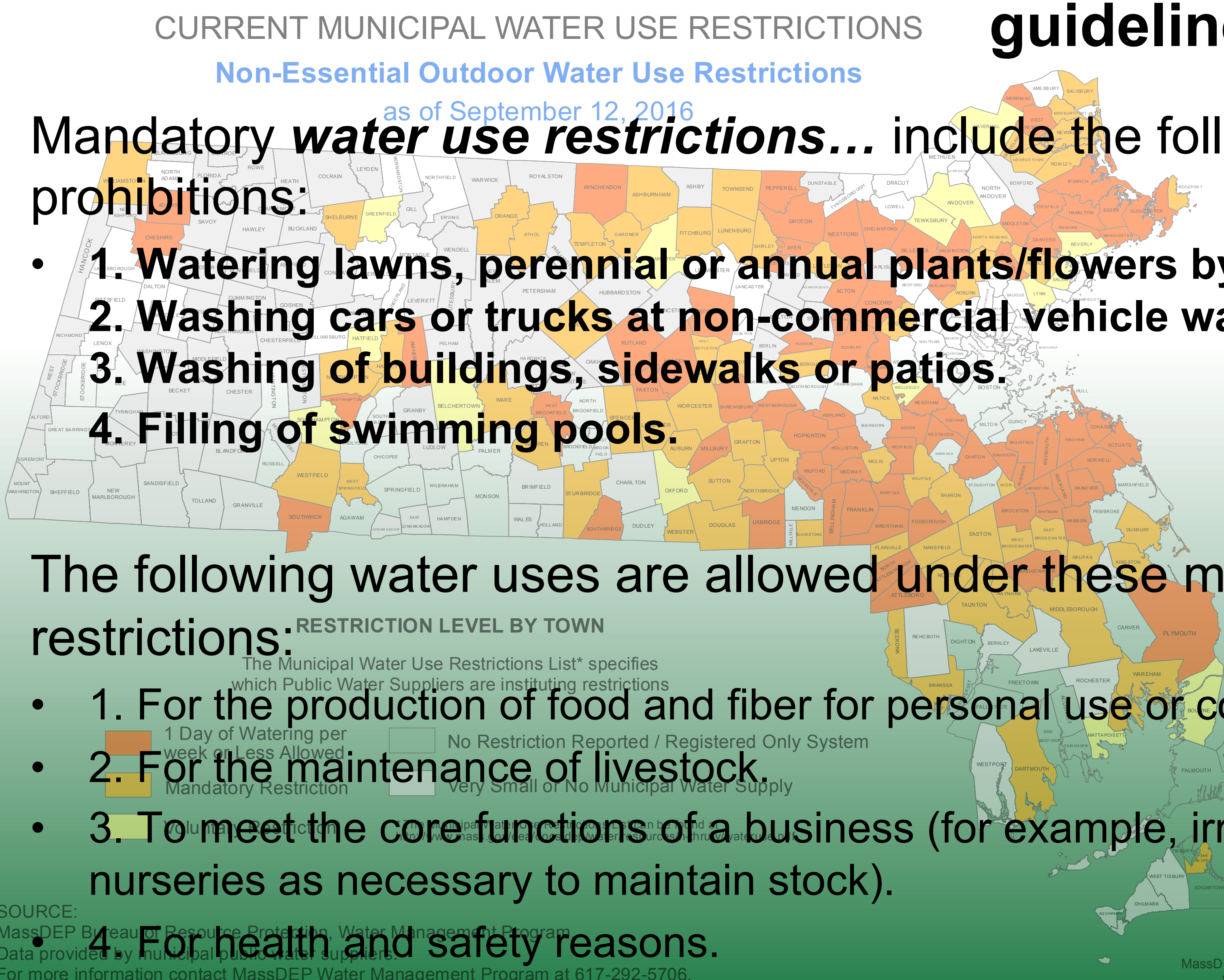
2. Follow recommended guidelines

Mandatory ***water use restrictions…*** include the following prohibitions:

- **1. Watering lawns, perennial or annual plants/flowers by any method.**
  2. Washing cars or trucks at non-commercial vehicle washes.
  3. Washing of buildings, sidewalks or patios.
  4. Filling of swimming pools.

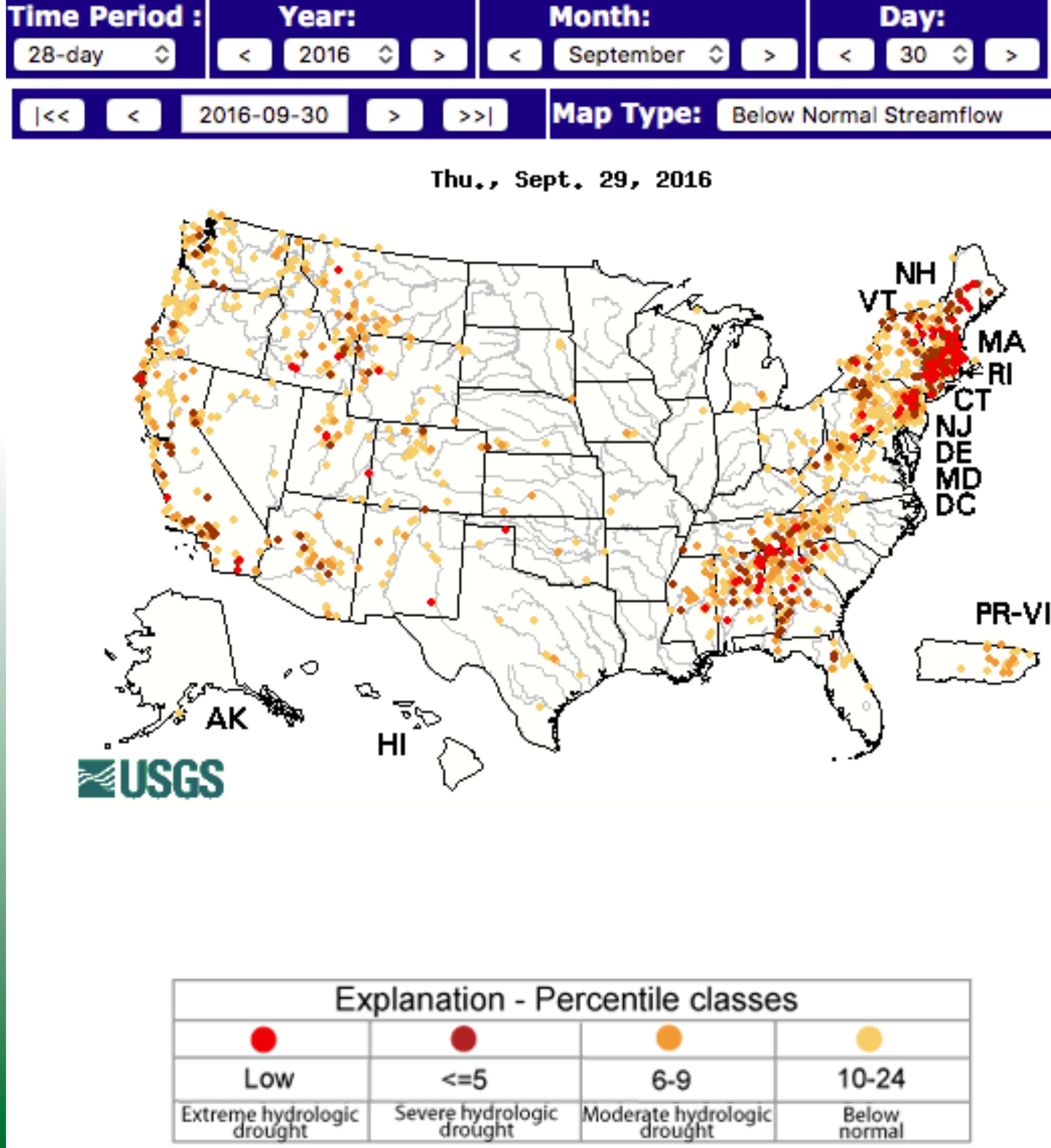
The following water uses are allowed under these mandatory restrictions:

- 1. For the production of food and fiber for personal use or commercial sale.
- 2. For the maintenance of livestock.
- 3. To meet the core functions of a business (for example, irrigation by plant nurseries as necessary to maintain stock).
- 4. For health and safety reasons.



Try permaculture techniques

- Rain barrels
- Straw mulch
- Water reuse
- No-till/low-till
- Perennials
- Diversified crops


Time Period :
28-day
Year:
2016
Month:
September
Day:
30
|<<
2016-09-30
>>|
Map Type:
Below Normal Streamflow
Thu., Sept. 29, 2016
NH
VT
MA
RI
CT
NJ
DE
MD
DC
PR-VI
AK
HI
USGS
Explanation - Percentile classes
Low
Extreme hydrologic drought
<=5
Severe hydrologic drought
6-9
Moderate hydrologic drought
10-24
Below normal

Consequences of changing precipitation:

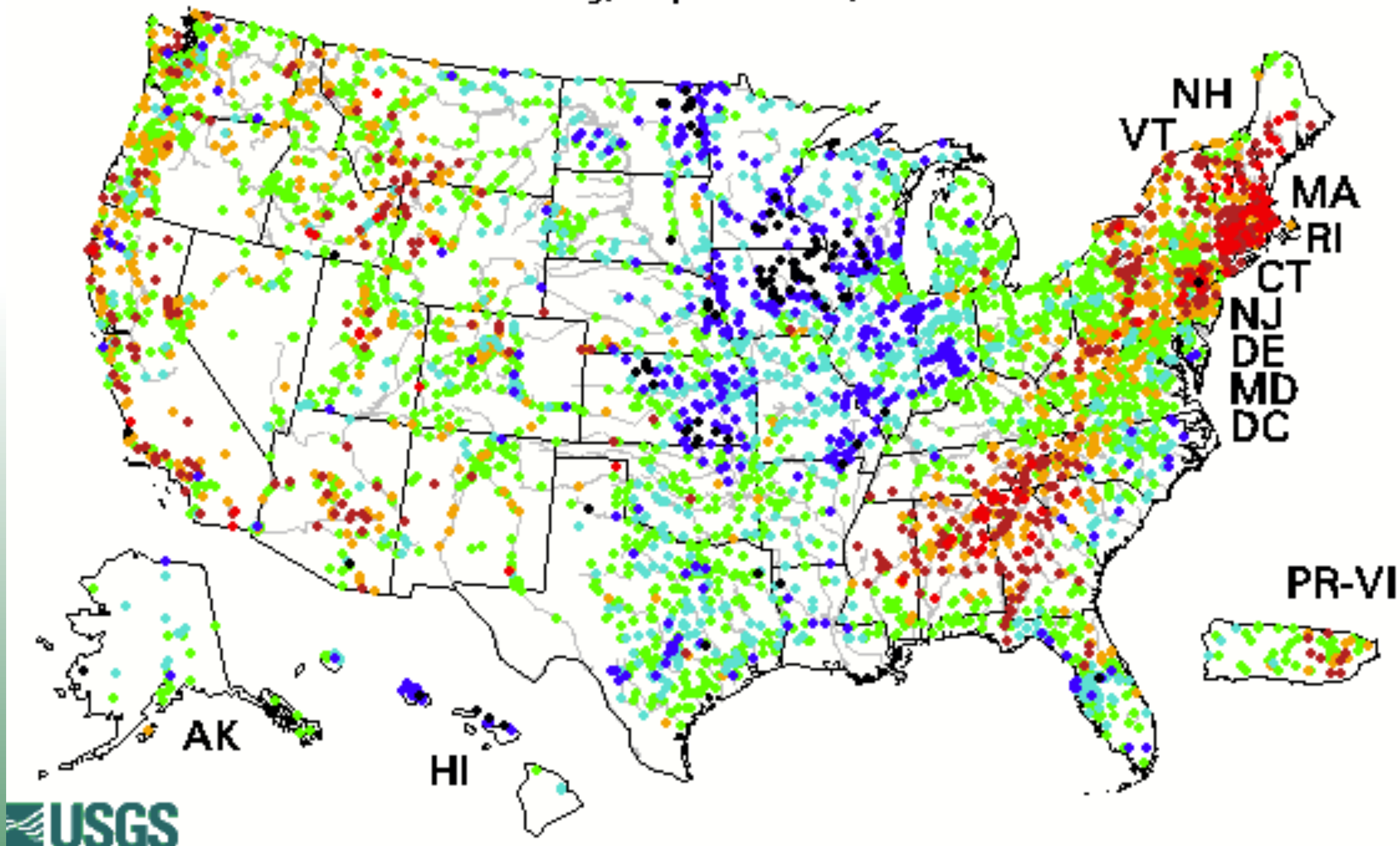
- Increased intensity of precipitation
  - Landslides
  - Erosion
  - ***Flooding***
- Increased frequency of extreme events
  - Design storms are inadequate predictions
  - Storm surge damage
- Increased likelihood of droughts
  - Water shortages for crops and municipal supply

Summary from: *Frumhoff, et al,. 2007*. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. *NECIA, UCS*.

28-day | < | 2016 | > | < | September | > | < | 30 | > | Help

|<< | < | 2016-09-30 | > | >>| **Map Type:** Streamflow Map

Thursday, September 29, 2016



Explanation - Percentile classes						
Low	<10 Much below normal	10-24 Below normal	25-75 Normal	76-90 Above normal	>90 Much above normal	High

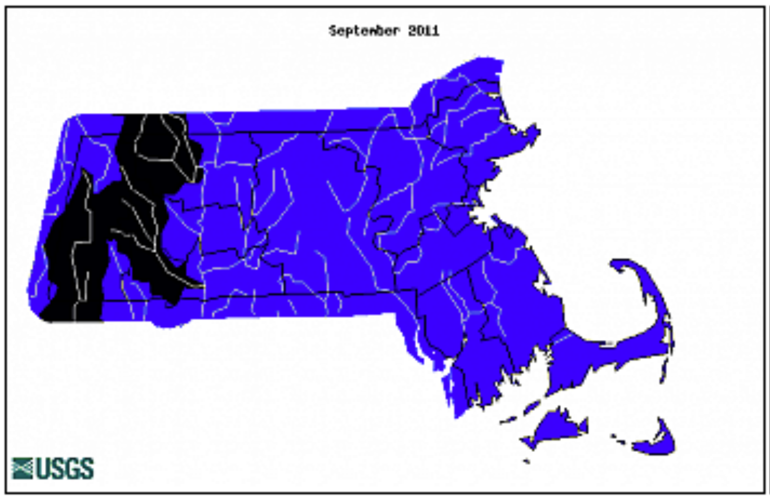
Comparison of Streamflow Maps

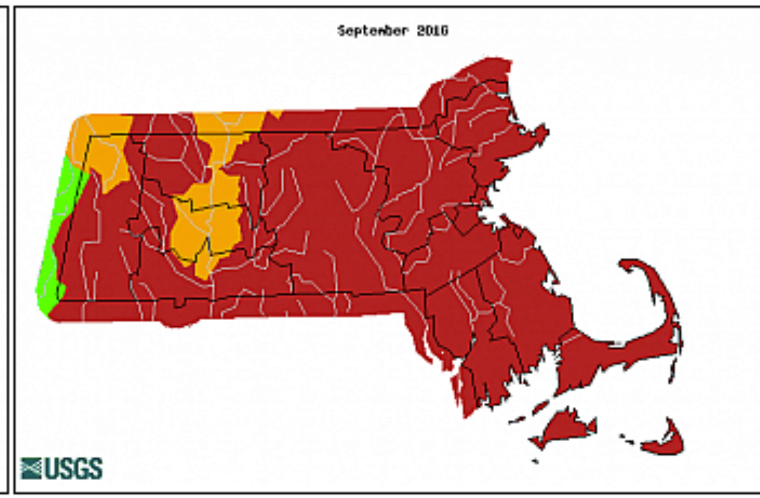
Geographic area: Massachusetts **Water resource region:** GO

Map type: Monthly Streamflow (month of year) **Sub type:** HUC Streamflow Map

Date (YYYYMM): 201109

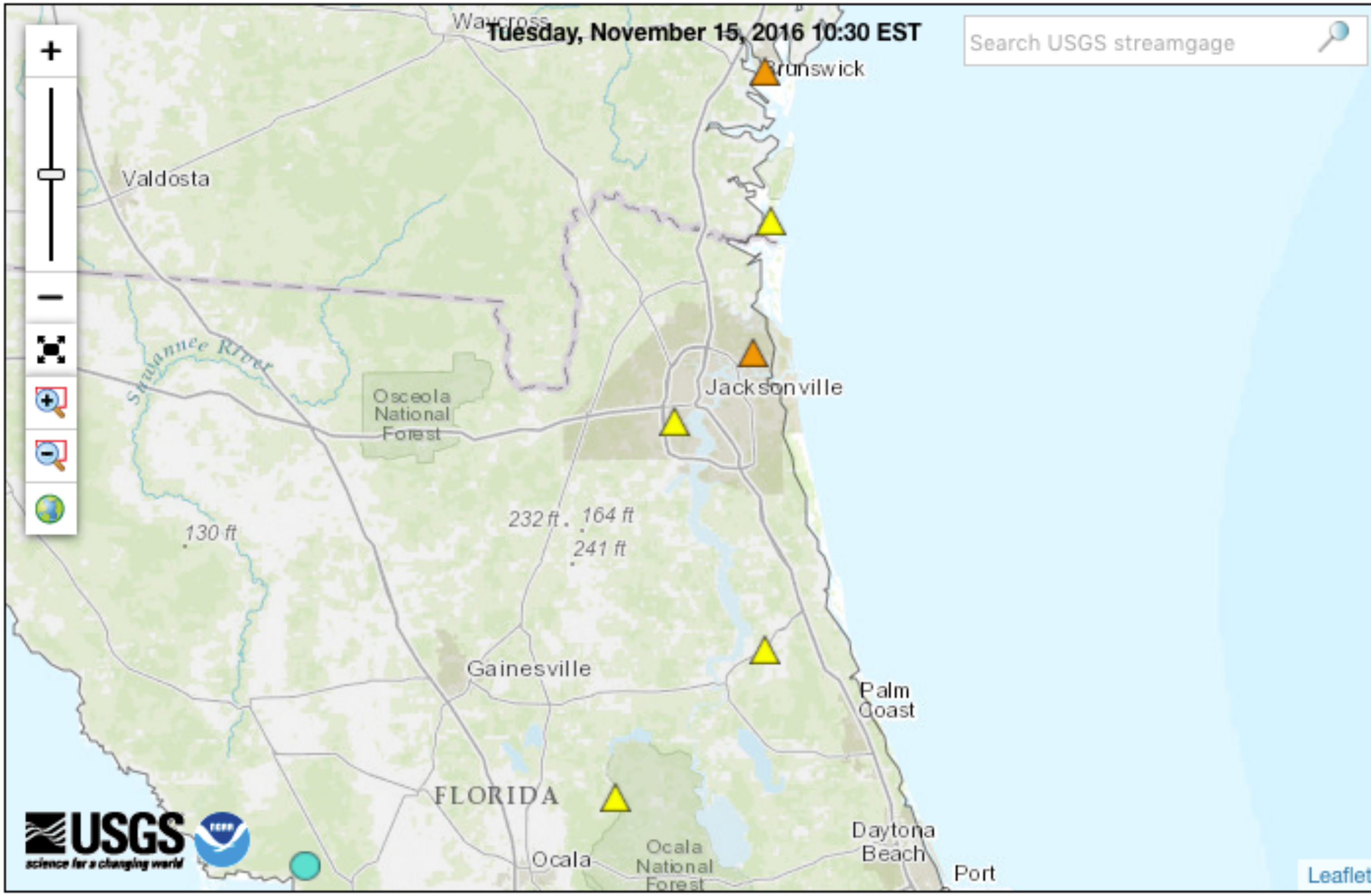
Date (YYYYMM): 201609





Explanation - Percentile classes							
Low	<10	10-24	25-75	76-90	>90	High	No Data
	Much below normal	Below normal	Normal	Above normal	Much above normal		

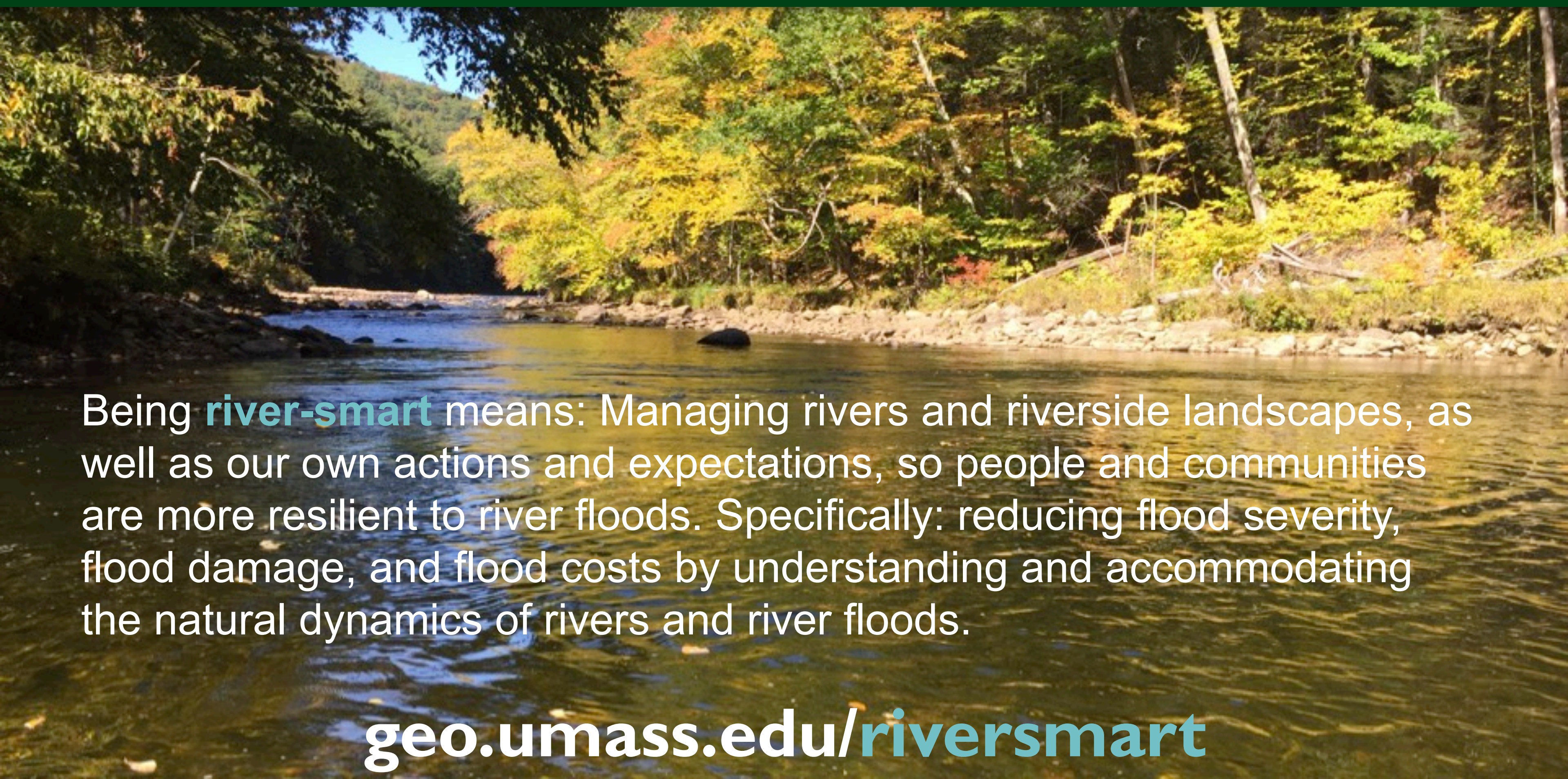
Map of flood and high flow conditions



Explanation - Percentile classes							
<95	95-98	>= 99	Above action stage	Above flood stage	Above moderate flood stage	Above major flood stage	Not ranked
△ Streamgage with flood stage ○ Streamgage without flood stage							

riversmart communities

supporting ecologically restorative flood prevention and remediation in New England



Being **river-smart** means: Managing rivers and riverside landscapes, as well as our own actions and expectations, so people and communities are more resilient to river floods. Specifically: reducing flood severity, flood damage, and flood costs by understanding and accommodating the natural dynamics of rivers and river floods.

geo.umass.edu/riversmart

Lesson: Rivers move more than water.

Water

Sediment

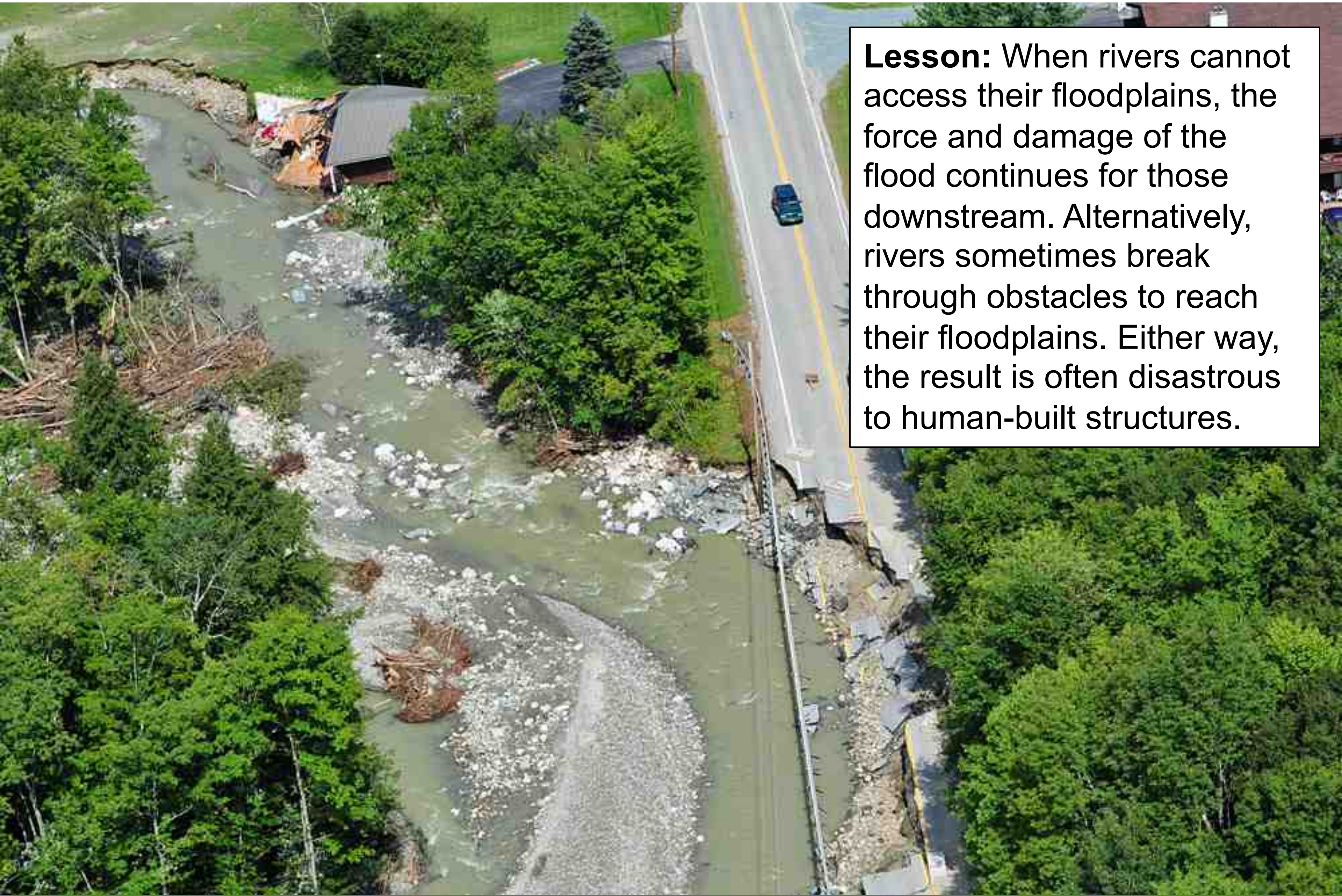
Debris

Lesson: During floods, mountain streams can rapidly erode, undercut and carry away parts of the landscapes around them.

House in the White River valley
Source: Jerry LaBlond, The Herald. Reprinted in Drysdale, M. D., S. Morris, and S. Levesque. 2012. *The Wrath of Irene: Vermont's Imperfect Storm of 2011.* Randolph, VT: The Public Press.

Lesson: Eroded material is deposited where the river reaches turn to flatter valleys below.

Photo by Chris Condit (UMass)/John Fellows



Lesson: When rivers cannot access their floodplains, the force and damage of the flood continues for those downstream. Alternatively, rivers sometimes break through obstacles to reach their floodplains. Either way, the result is often disastrous to human-built structures.

"River claims a new channel through VT RT100"

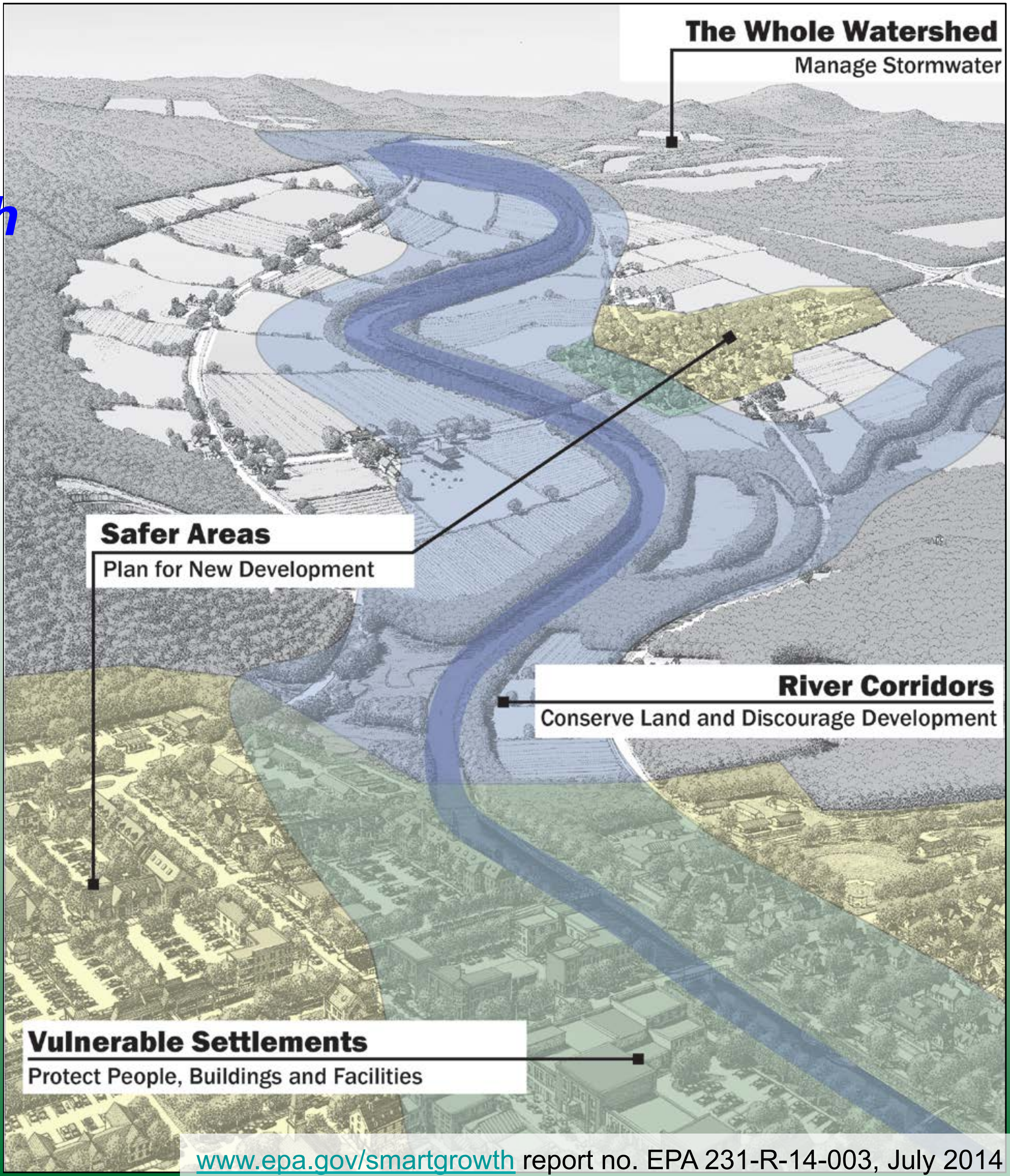
Source: From Mansfield HeliFlight, printed in Vermont Agency of Natural Resources Climate Change Team 2012: "Tropical Storm Irene by the Numbers," http://www.anr.state.vt.us/anr/climatechange/irenebythenumbers.html

The River Corridor

Giving rivers enough room to be rivers

- Resilience
- Ecosystems
- Floodplains
- Infrastructure

The river corridor is the area where channel-driven fluvial processes, including the river's natural movement of water, sediment, debris and other materials, affect or are likely to affect the landscape, based on current, historic, and projected conditions.



www.epa.gov/smartgrowth report no. EPA 231-R-14-003, July 2014