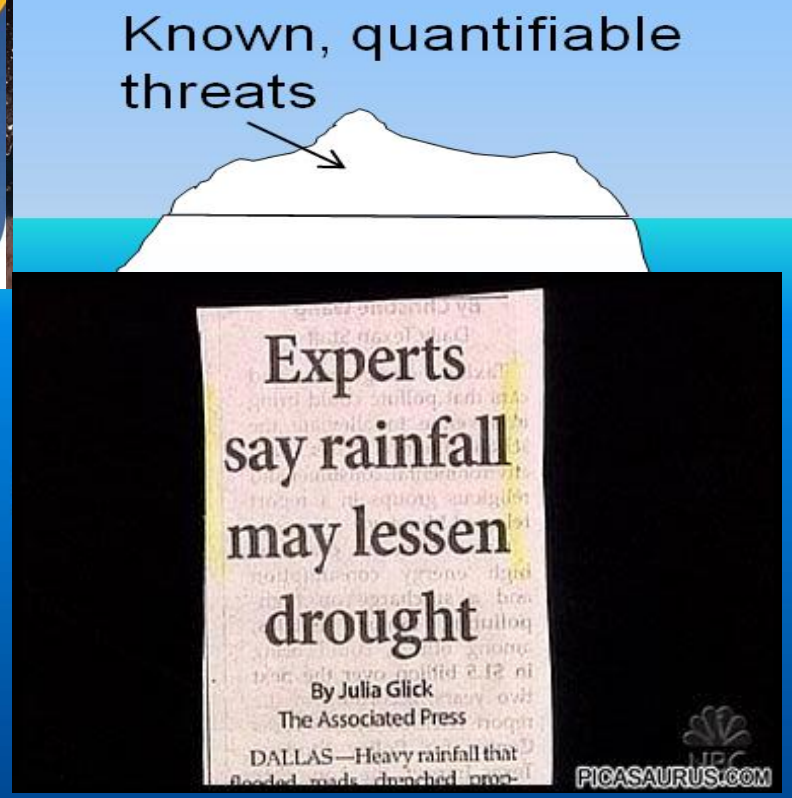
Going to Extremes: Managing through a changing climate



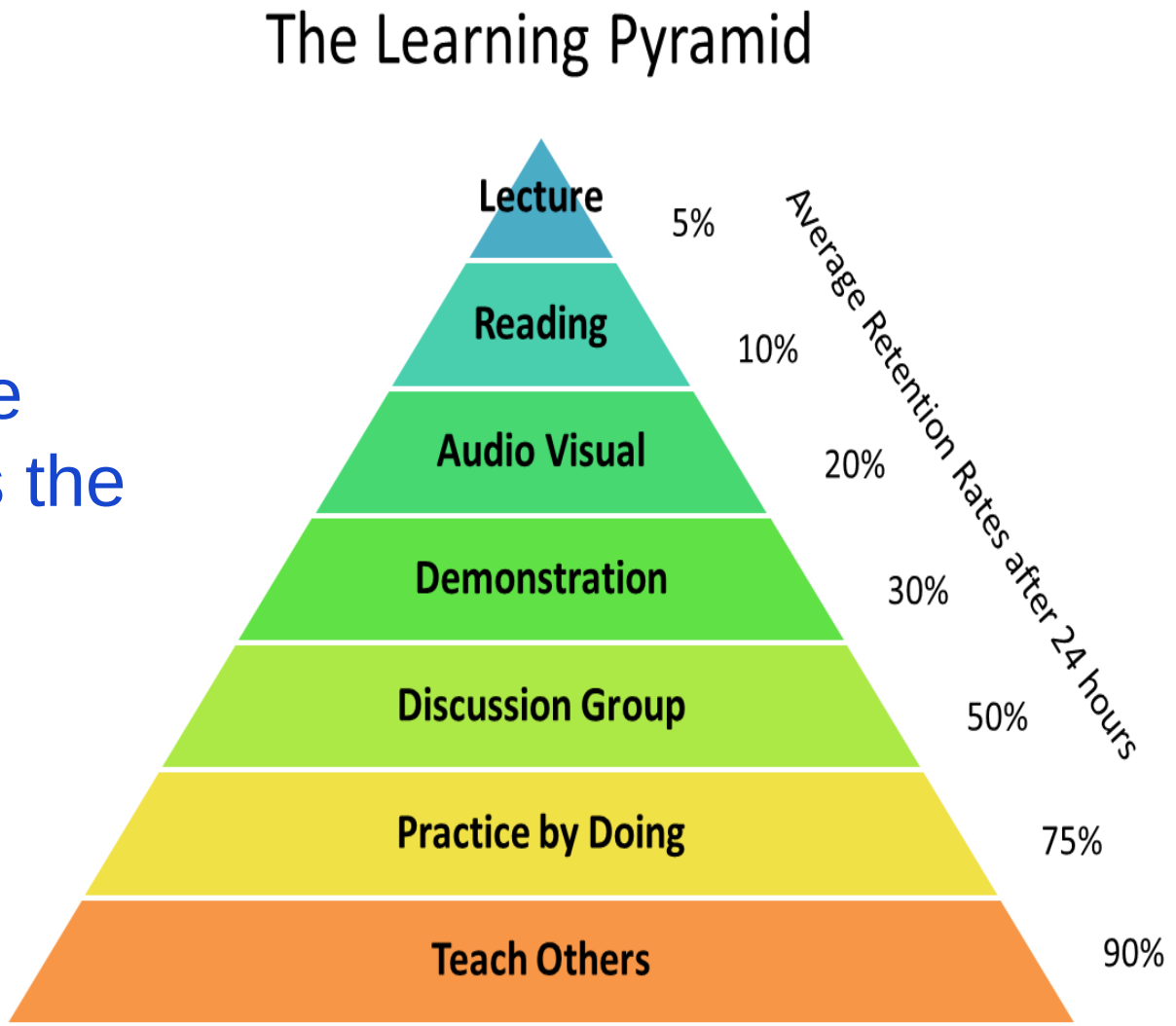
Roger S. Pulwarty[1],
Mark Svoboda[2], Doug Kluck[1], D. Todey[3], R. Webb[1], Molly Wolozyn[1], Colin Wellenkamp[4]
[1]NOAA, [2]University of Nebraska, [3]USDA ,[4] Mississippi River Cities and Towns Initiative (MRCTI)

And a lot of other people

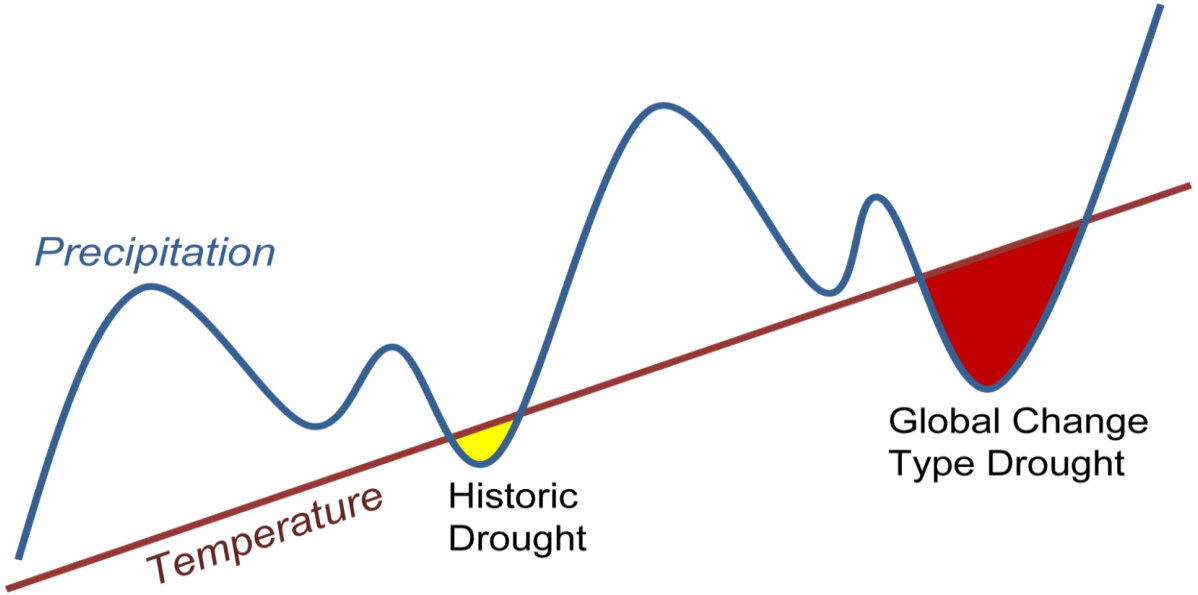
First Hurdle: How do we learn?

Human beings learn in a variety of ways.

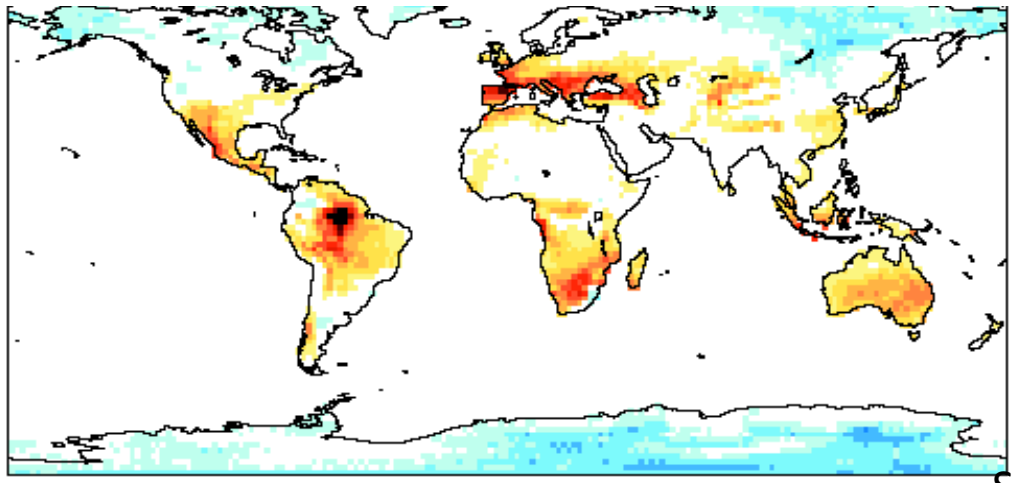
Educational research has shown that one of the least effective methods is the traditional lecture



Source: National Training Laboratories, Bethel Maine

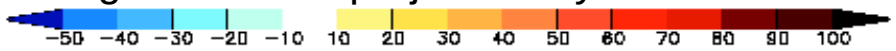


Year

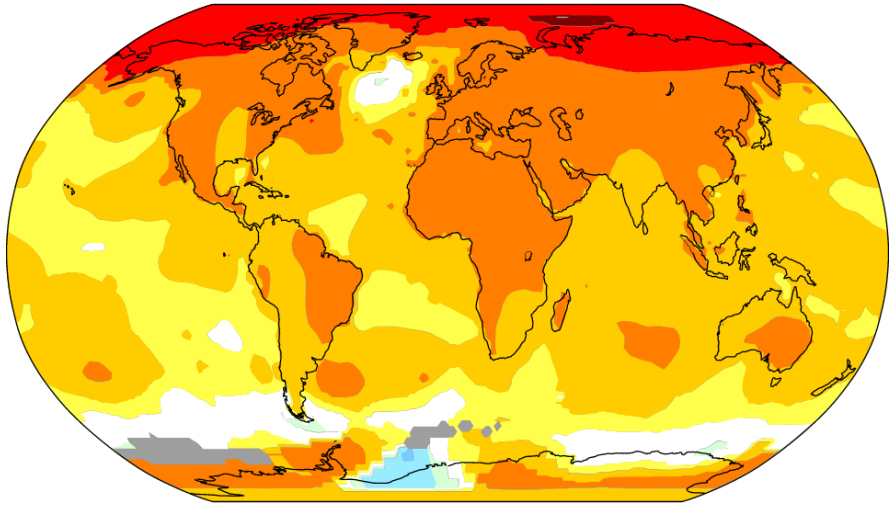


Model agreement on projected dry and wet conditions

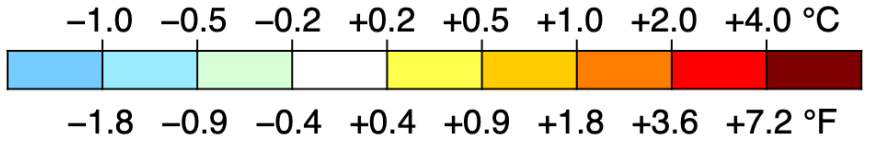
Sanderson



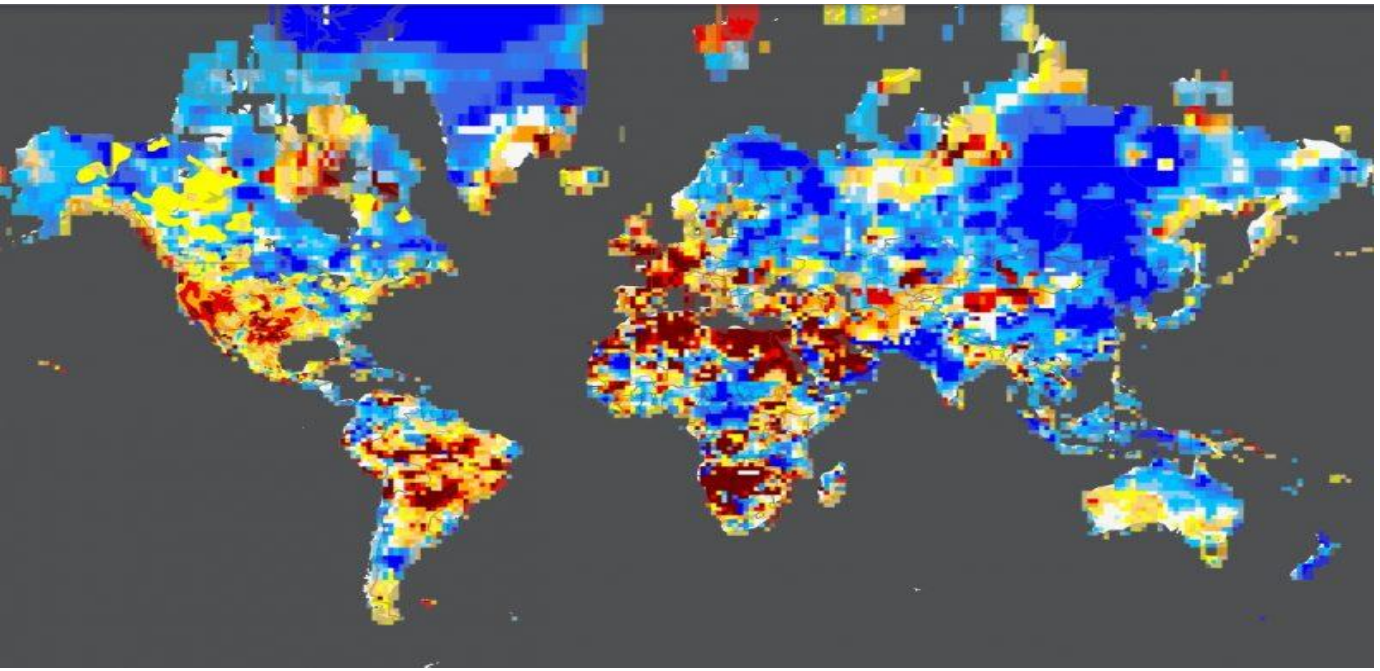
Temperature change in the last 50 years



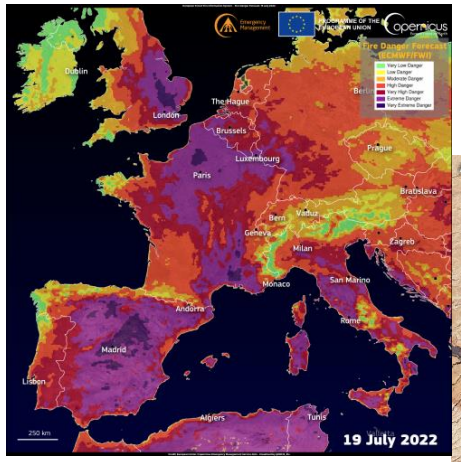
2011–2021 average vs 1956–1976 baseline

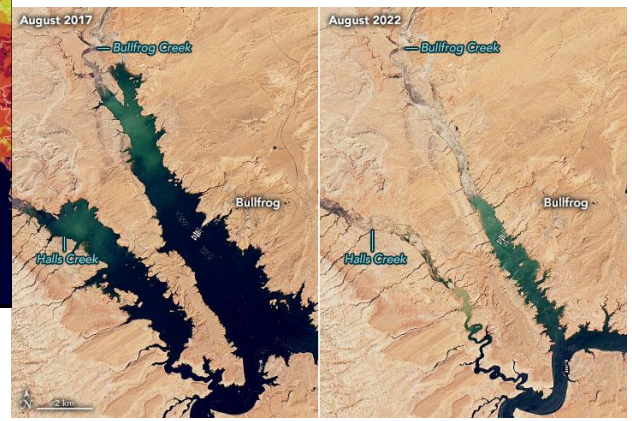


Many potential futures
Are our assumptions supported by the climate record?



Drought in 2022 (to date)





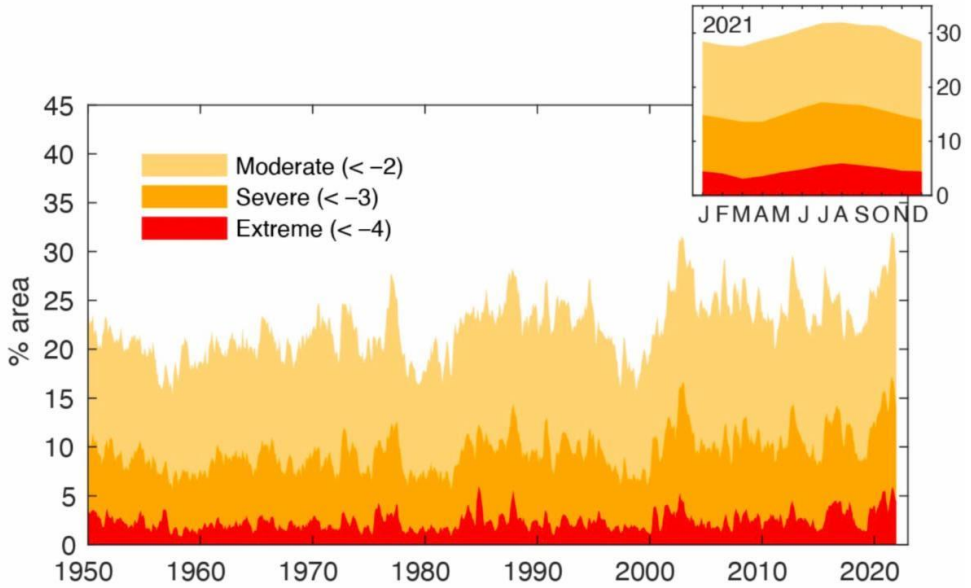
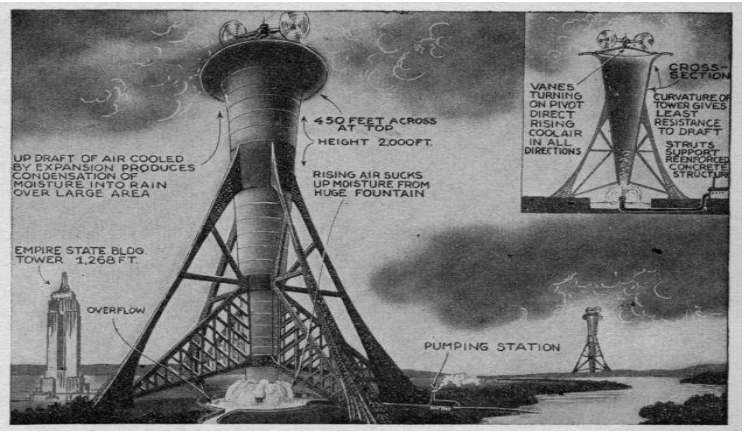
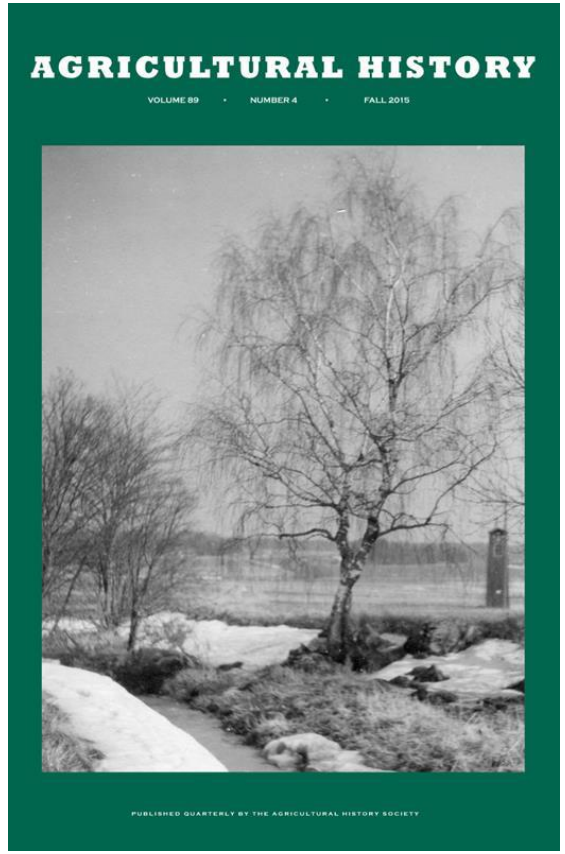


Figure. Percentage of global land area (excluding ice sheets and deserts) with scPDSI levels of less than −2, −3, and −4, indicating moderate, severe, and extreme drought, respectively, for each month of 1950–2021. Source: State of the Climate in 2021. *Bull. Amer. Meteor. Soc.*

"On the Edge of the Possible: Artificial Rainmaking and the Extension of Hope on the Great Plains,"
J. Courtwright U. Iowa Agricultural History

Inter-State Artificial Rain Company (1891)
Swisher Rain Company (1892)
Goodland Artificial Rain Company (1892)





“Hope, like moisture, was in constant demand”

The Great American Desert….becomes the High Plains

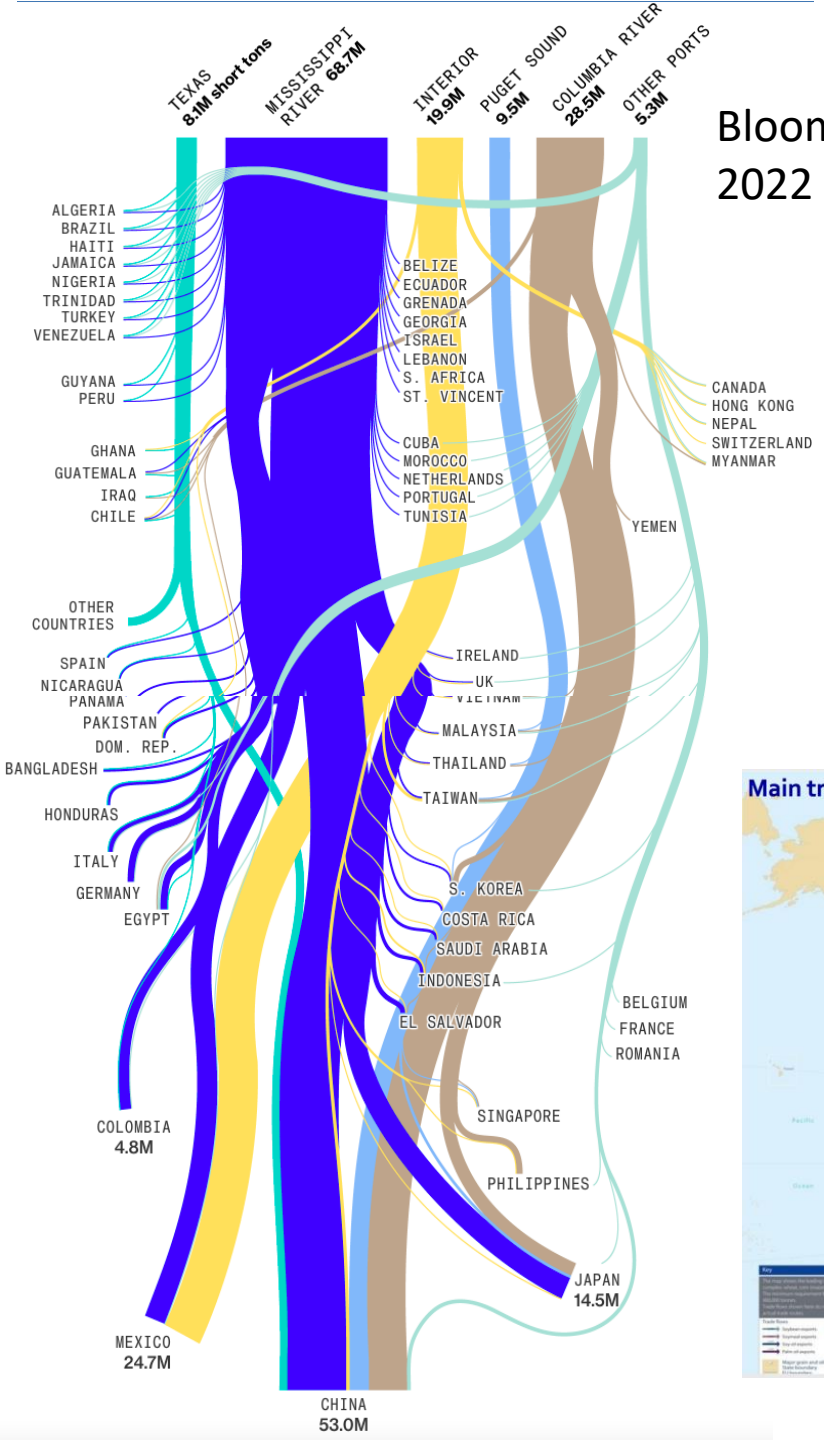
Edwin James (Stephen Long's geographer):

A place "…**almost wholly unfit for cultivation**, and of course, uninhabitable by a people depending upon agriculture for their subsistence" (Long and James 1823: 236).

- Became:

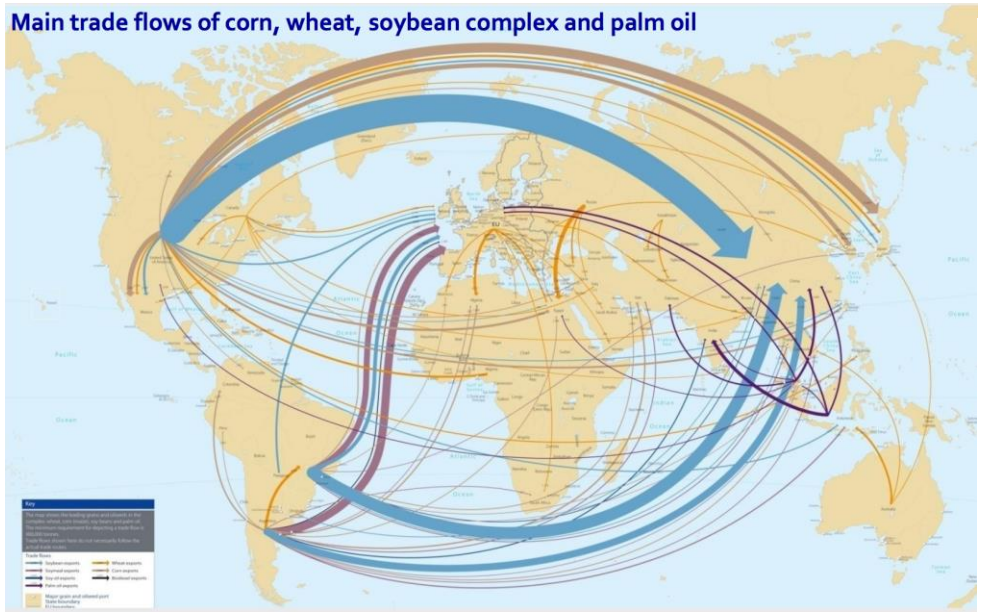
"The Breadbasket of the World"…

Matt Sanderson, KSU 2018



Bloomberg
2022

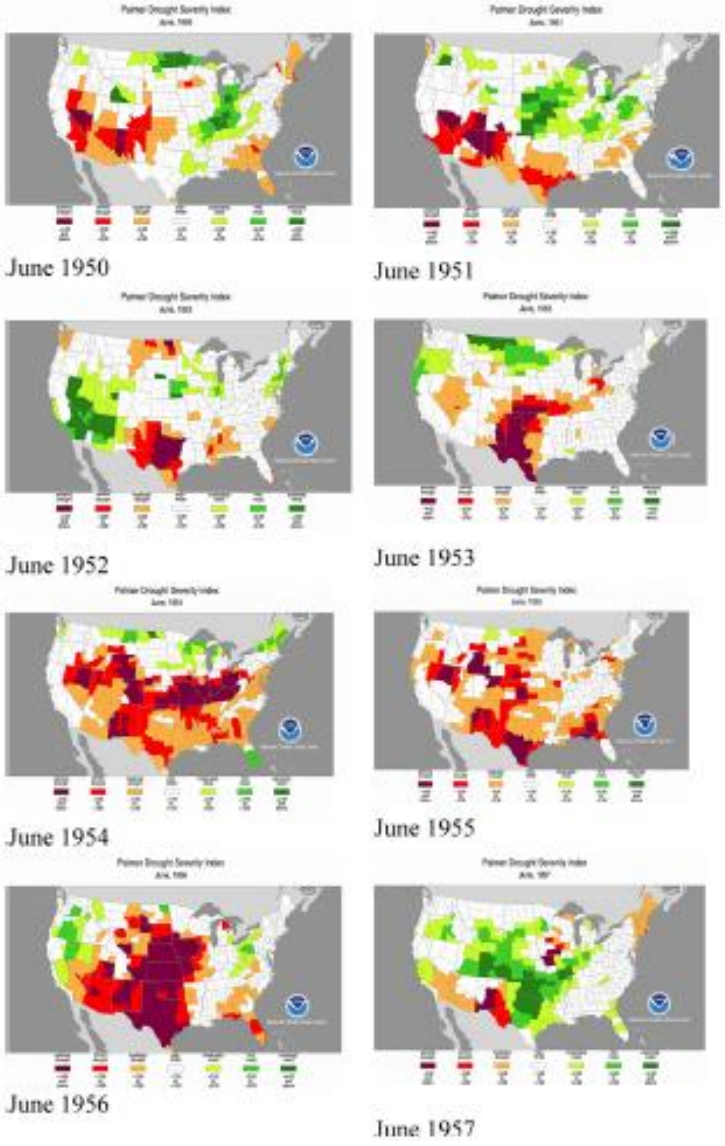
The Mississippi River was more than 8 feet below normal near Memphis in early November. Sunday, Nov. 6, 2022.



Optimized for

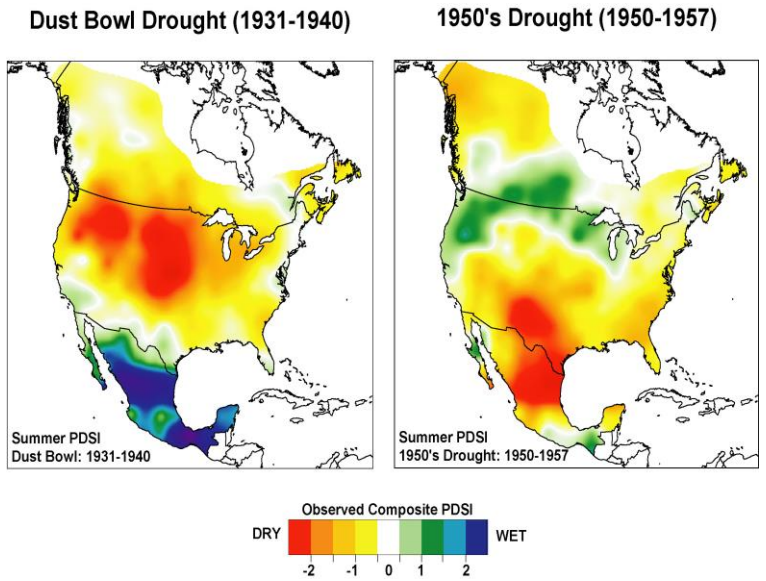
- **Global networks and trade regimes,**
- **efficiency, peace time and a relatively stable environment**

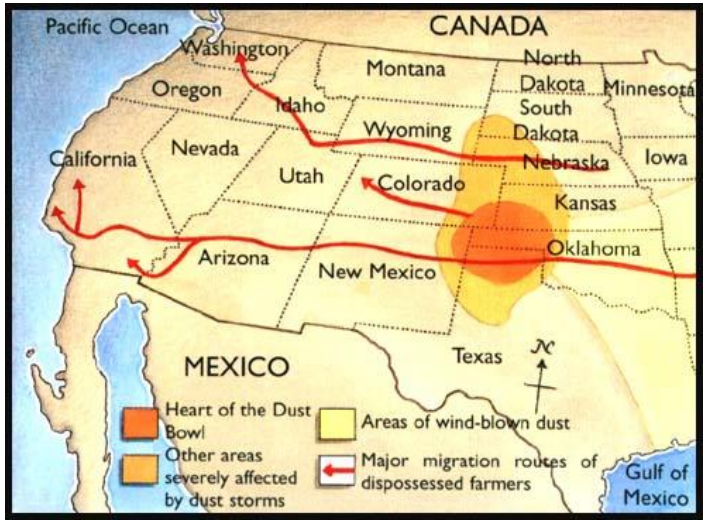
- Fragile



US Drought: The 1950s

Dust Bowl migration routes





To what extent are earlier adaptation strategies still viable?

Contents lists available at ScienceDirect

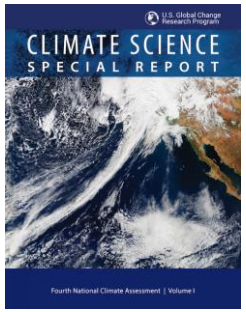
Weather and Climate Extremes

journal homepage: www.elsevier.com/locate/wace

Bite without bark: How the socioeconomic context of the 1950s U.S. drought minimized responses to a multiyear extreme climate event

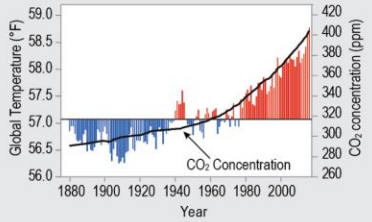
John D. Wiener[a], Roger S. Pulwarty[b,*], David Ware[c]

What is changing and (why) does it matter?

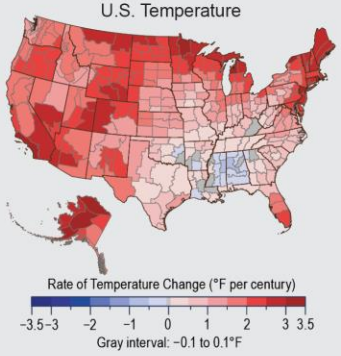


WEATHER AND CLIMATE

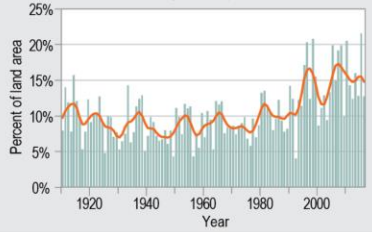
(a) Global Temperature and Carbon Dioxide



(b) U.S. Temperature

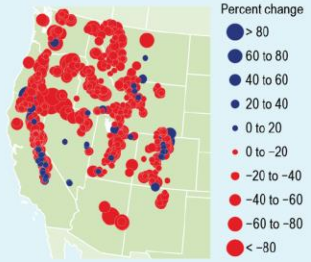


(c) U.S. Heavy Precipitation

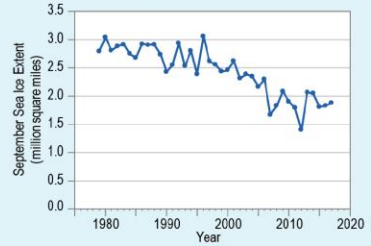


SNOW AND ICE

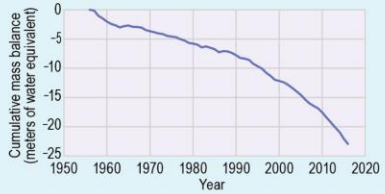
(d) Western U.S. Snowpack



(e) Arctic Sea Ice Extent

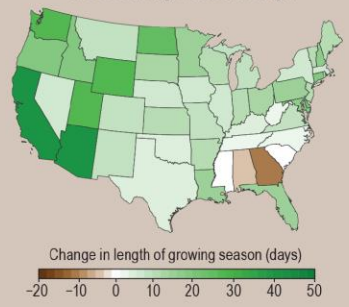


(f) Global Glacier Mass Balance

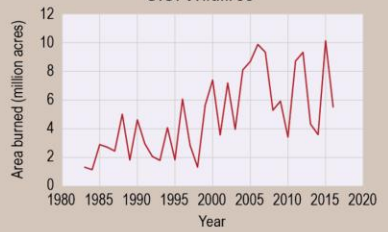


LAND AND WATER

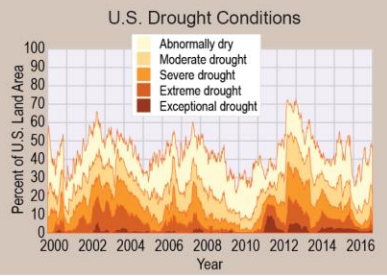
(g) U.S. Growing Season Length



(h) U.S. Wildfires

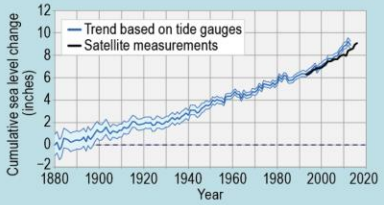


(i) U.S. Drought Conditions

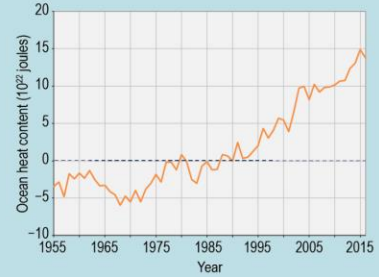


OCEANS AND COASTS

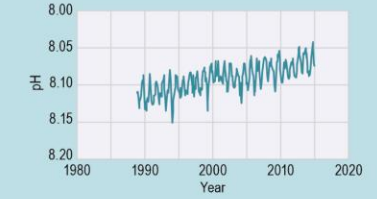
(j) Global Sea Level

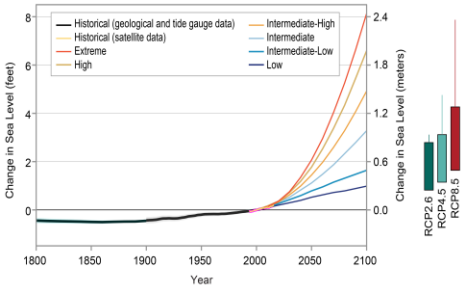


(k) Global Ocean Heat Content



(l) Hawai'i Ocean Acidity





Impacts of a Changing climate

Weather and Climate Extremes Variability& Change

?

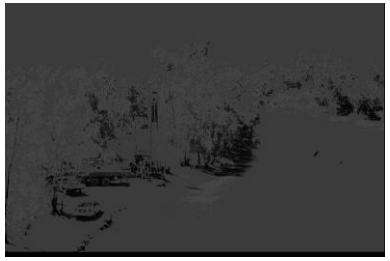
?

?

?

?

Higher evaporation. More farm dams as surface water availability reduces



Increased demand for groundwater as surface water availability reduces

Greater irrigation efficiency as surface water availability reduces

Increased evapo-transpiration due to higher temps

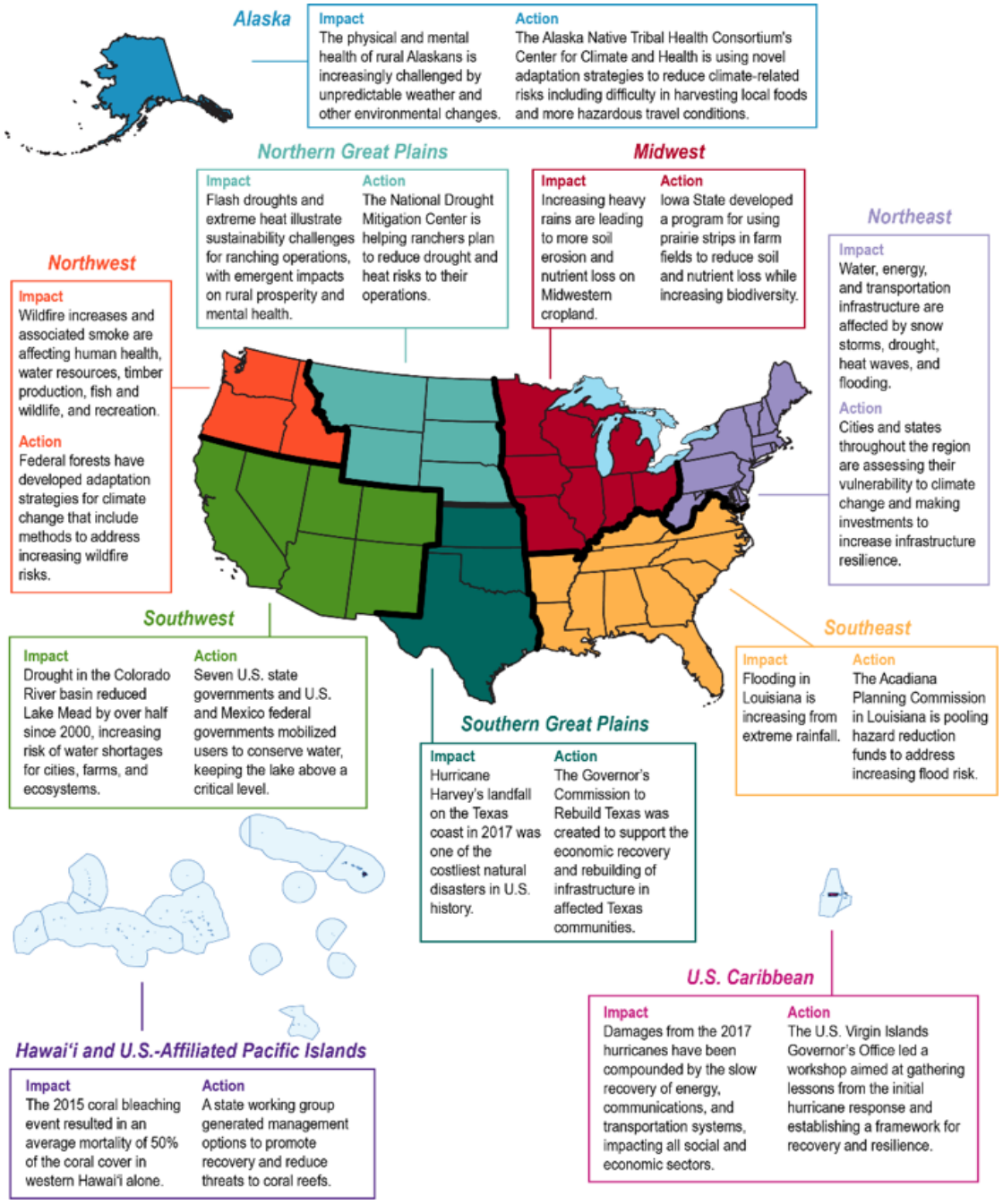
Higher frequency and intensity of wildfires due to higher temps and droughts

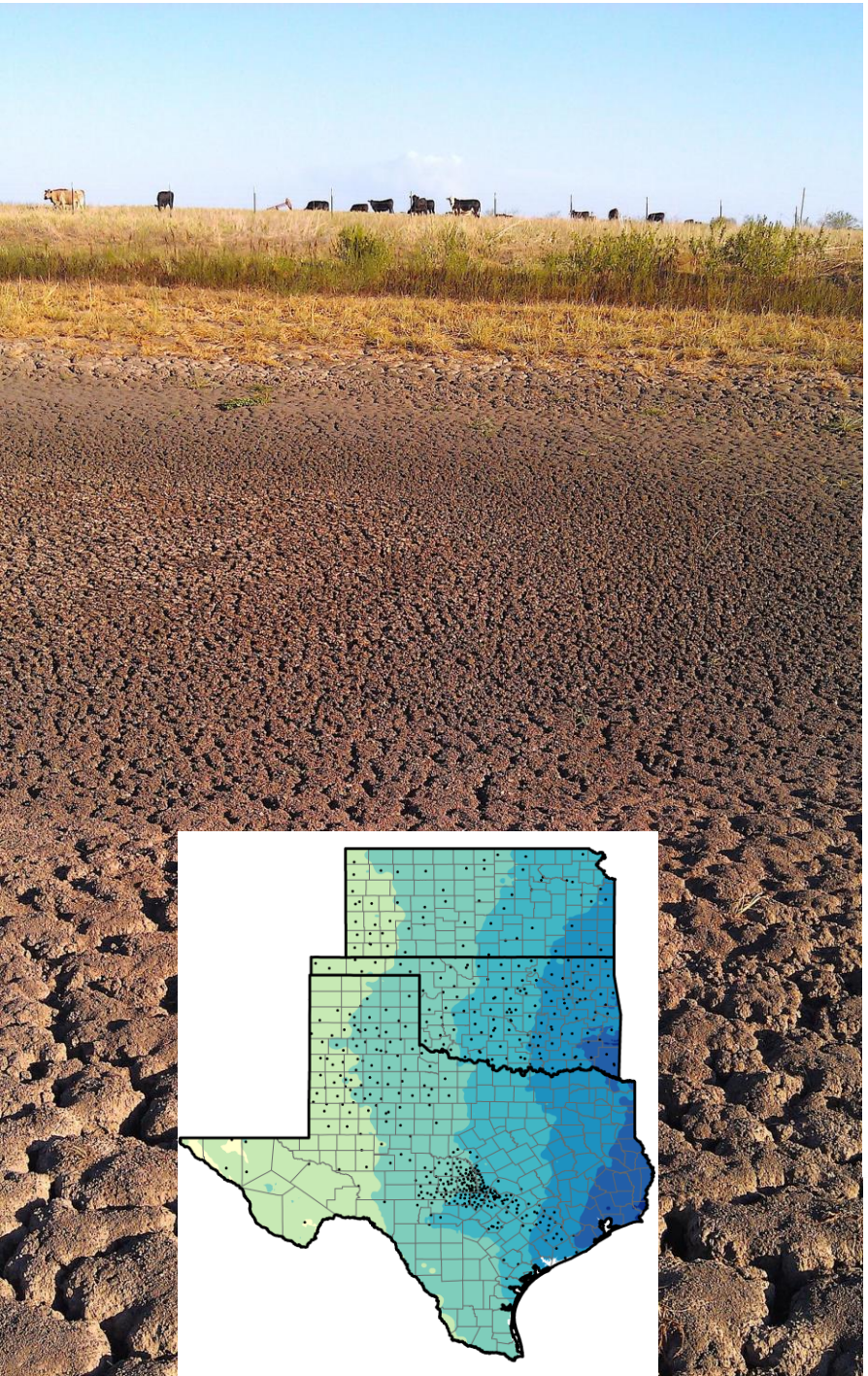
America Adapts!

Climate-related impacts and response actions that are helping the region address related risks and costs.

Examples are illustrative i.e. not indicative of which impact is most significant in each region or which response action might be most effective.

Implementation is increasing but is not yet commonplace.





Late 21st Century

Lower Scenario
(RCP4.5)

Higher Scenario
(RCP8.5)

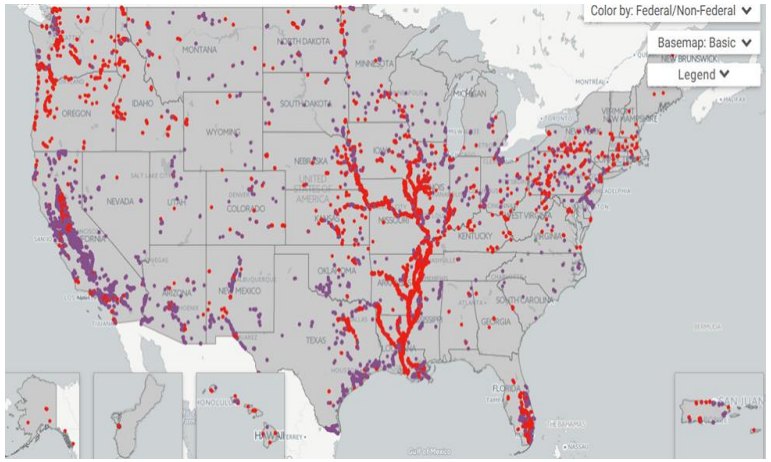
Change in Number of Days

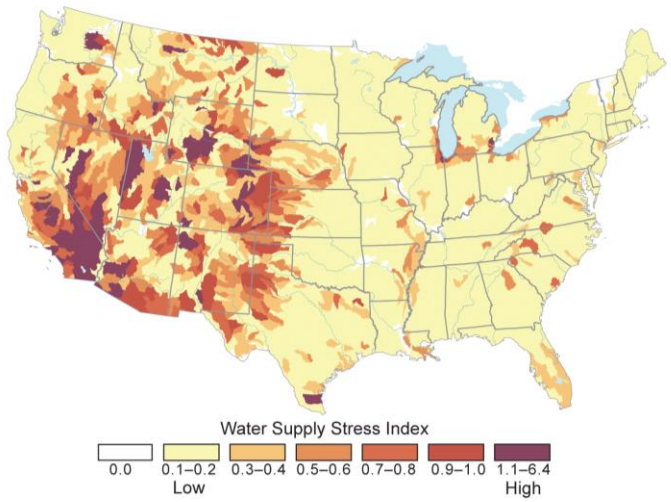
20 30 40 50 60 70 80 90 100

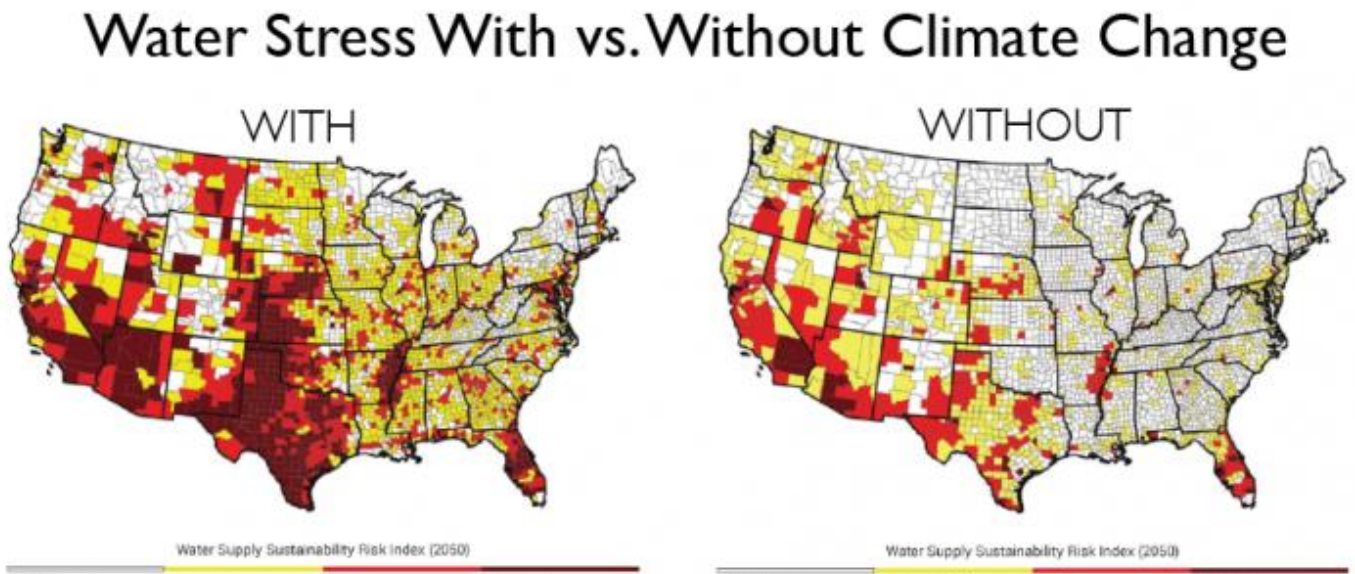
Water Resources

NCA4 2018
IPCC 2014
IPCC 2022

- Changes in Water Quantity and Quality
- Deteriorating Water Infrastructure at Risk
- Water Management Uncertainty in a Changing climate



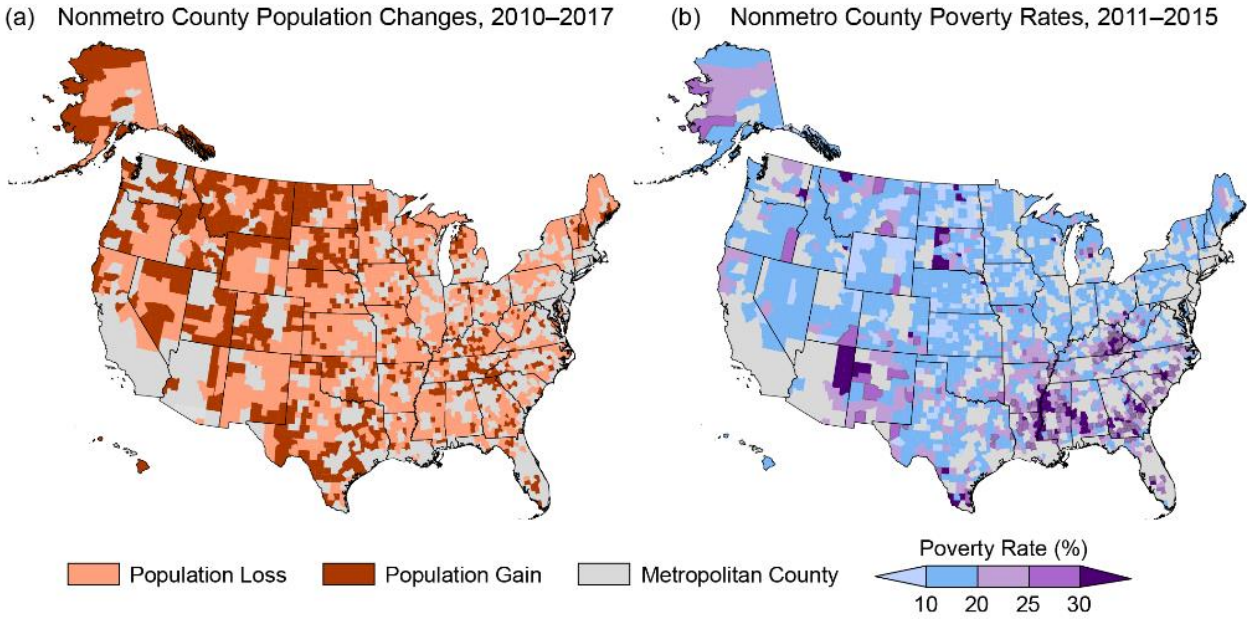


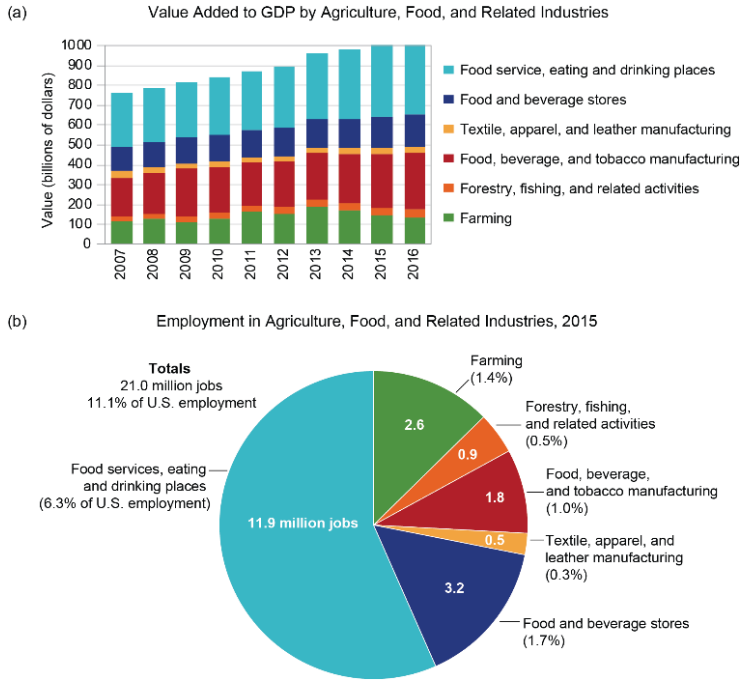


Agriculture and Rural Communities

NCA4 2018
IPCC 2014
IPCC 2022

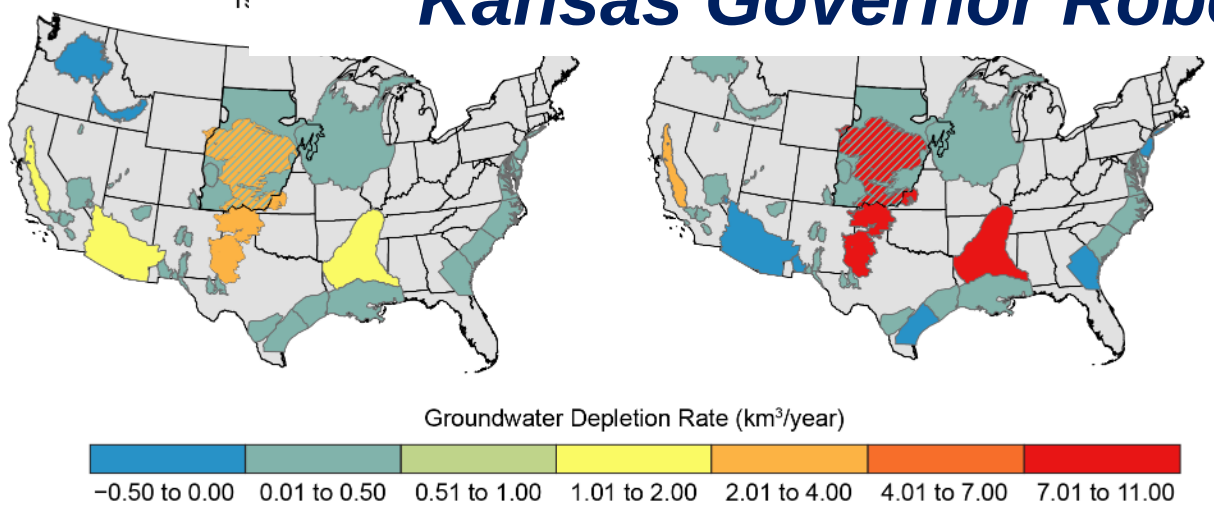
- Reduced Agricultural Productivity
  - Degradation of Soil and Water Resources
    - Health Challenges to Rural Populations and Livestock
      - Vulnerability and Adaptive Capacity of Rural Communities



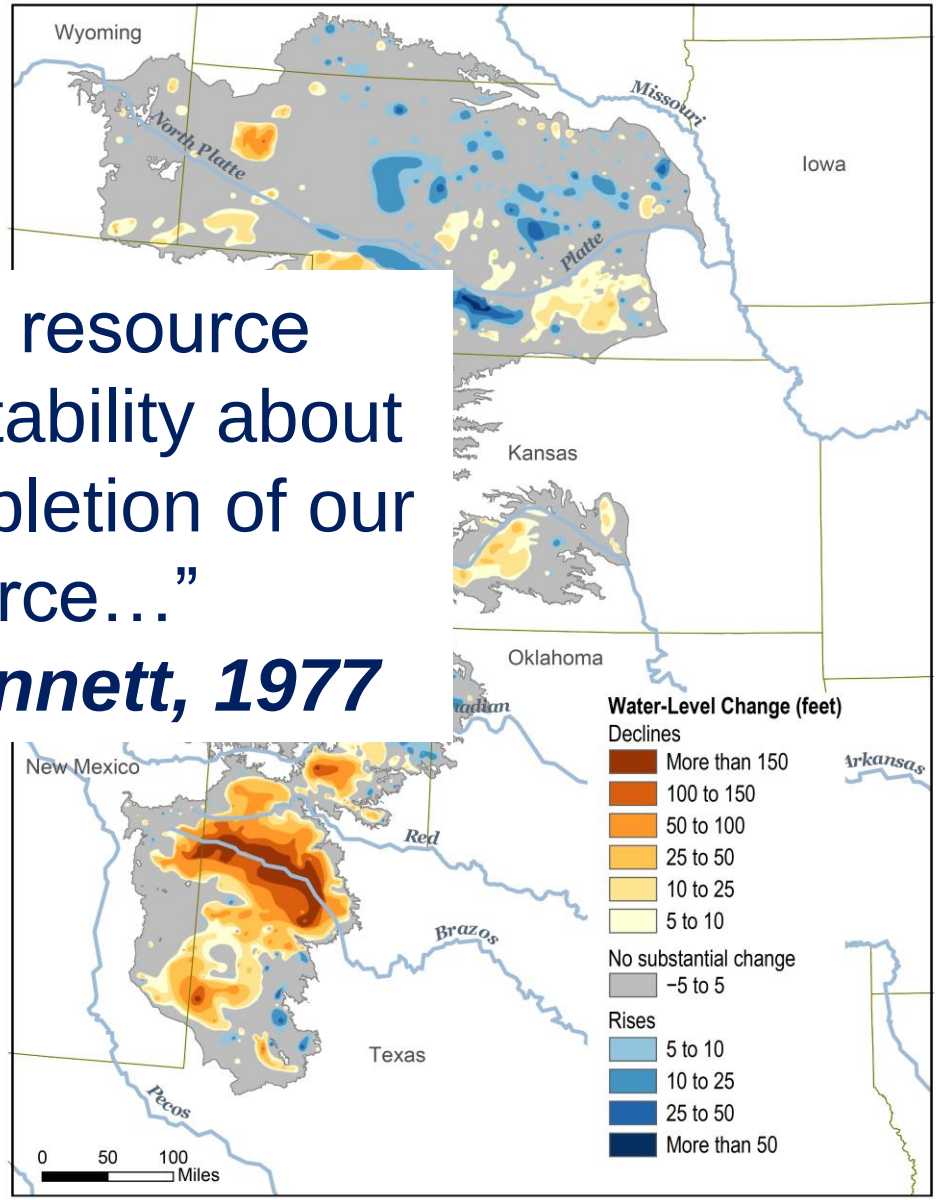


"…certain aspects of our water resource problems have a degree of predictability about them. Most notable is the rapid depletion of our valuable groundwater resource…"

Kansas Governor Robert Bennett, 1977



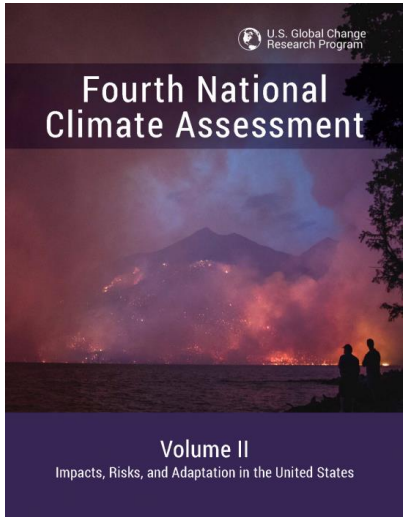
Groundwater depletion



See Steward et al 2013 for projections to 2110

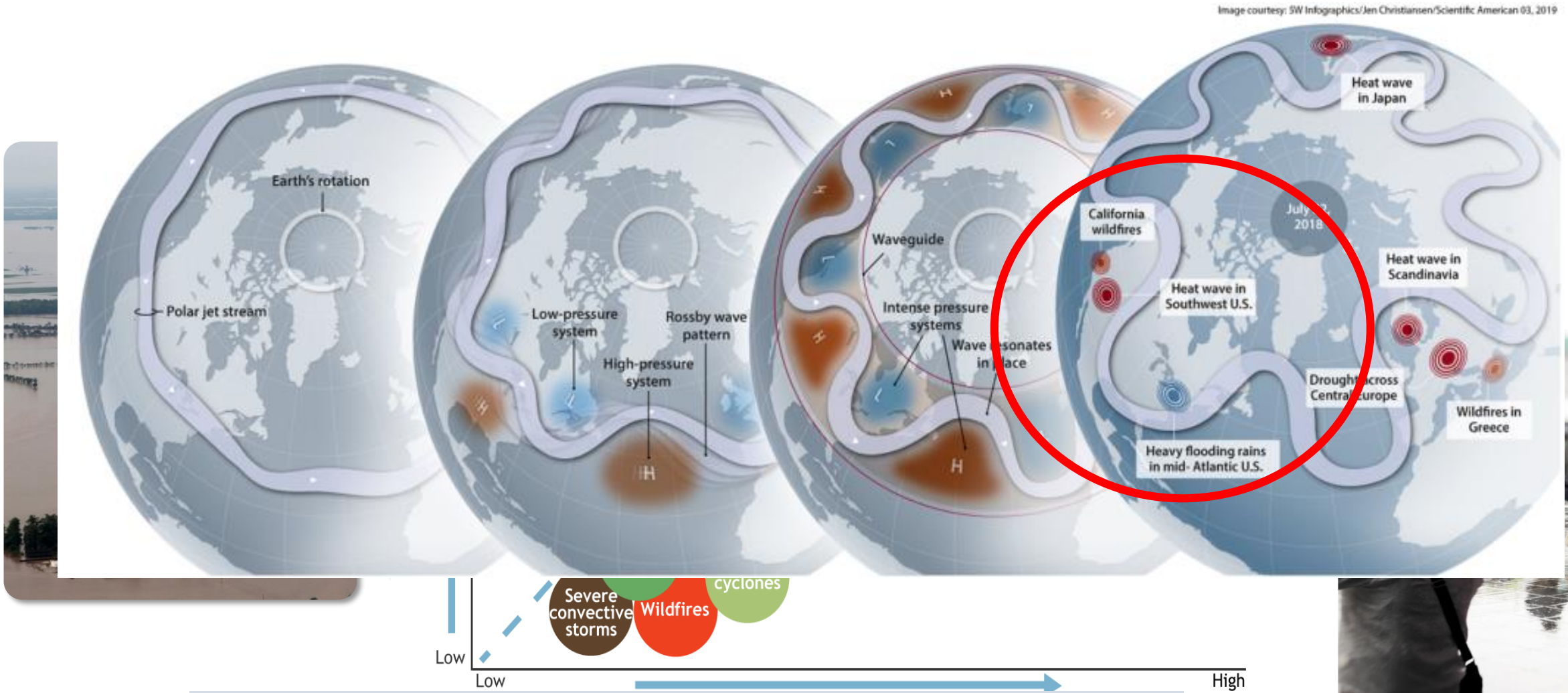
National Climate Assessment Volume II in 5 Bullets

- Earth's **climate is now changing faster** than at any point in modern civilization.
- These changes are **primarily but not only the result of human activities**, the evidence of which is overwhelming and continues to strengthen
- The **impacts of climate change are already being felt** across the country, and climate-related threats to Americans' physical, social, and economic well-being are rising



- **Americans are responding** in ways that can bolster resilience and improve livelihoods
- However, **neither global efforts to mitigate** the causes of climate change **nor regional efforts to adapt** to the impacts **currently approach the scales needed to avoid substantial damages** to the U.S. economy, environment, and human health and well-being over the coming decades

The changing nature of climate extremes



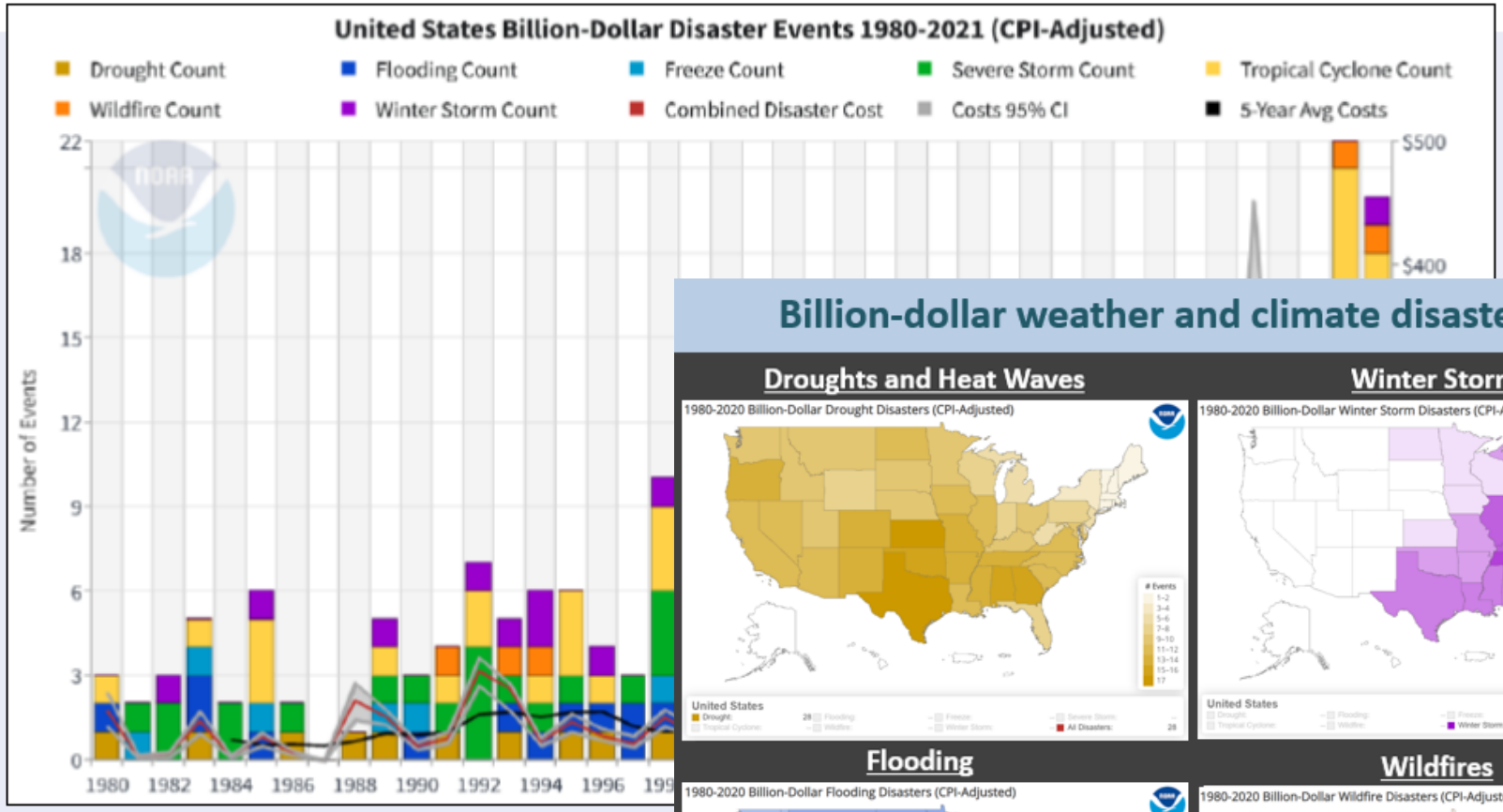
Climate circulation dynamics impact convection, drought, wildfires, flood risk locations

NAS 2016

U.S. Billion-dollar event frequency, annual cost, 5-year cost average (1980–2021)

NOAA/ NCEI

1980-2021



Western wildfires, severe storms, inland flooding and h

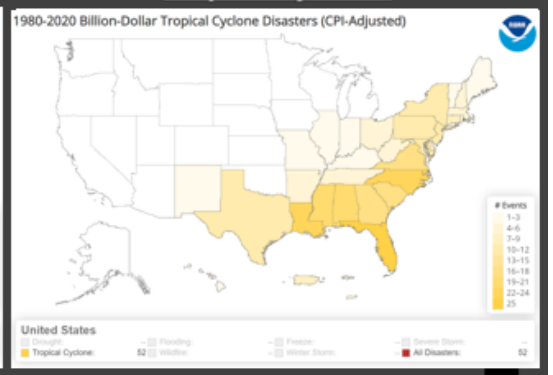
5-year annual cost average >$148.4 billion - a reco

Billion-dollar weather and climate disasters frequency mapping: 1980-2020

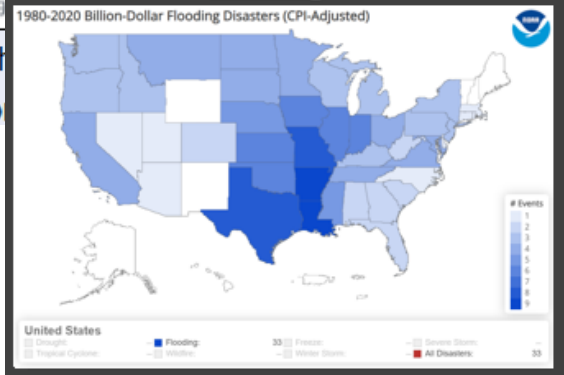
Droughts and Heat Waves

Winter Storms

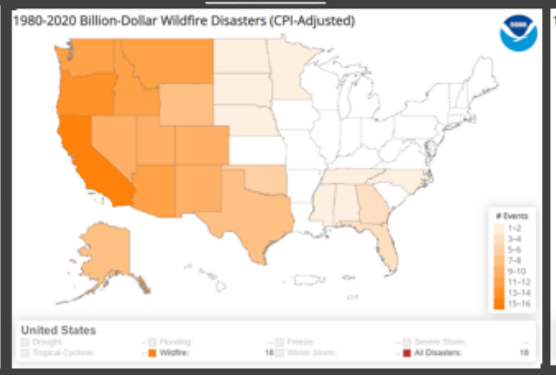
Tropical Cyclones



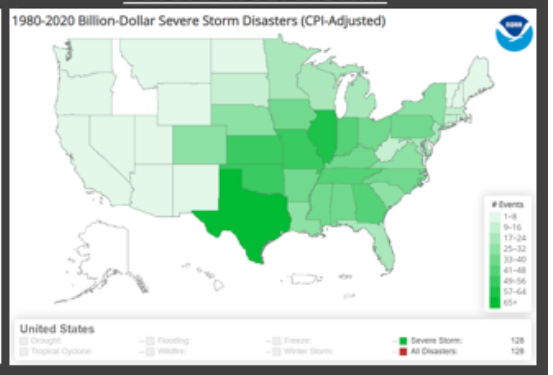
Flooding



Wildfires



Severe Local Storms



*__285__ weather and climate disasters reached or exceeded $1 billion during this period (CPI-adjusted); cost > **$1.875 trillion in damages**

Please note that the map reflects a summation of billion-dollar events for each state affected (i.e., it does not mean that each state shown suffered at least $1 billion in losses for each event).

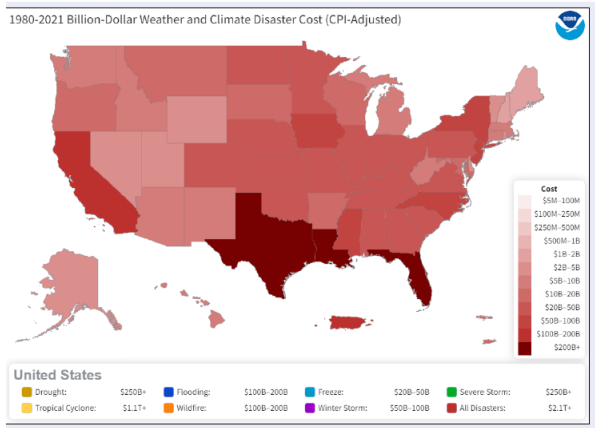
Risk = Expected Annual Loss x Social Vulnerability ÷ Community Resilience

where Expected Annual Loss (EAL) =

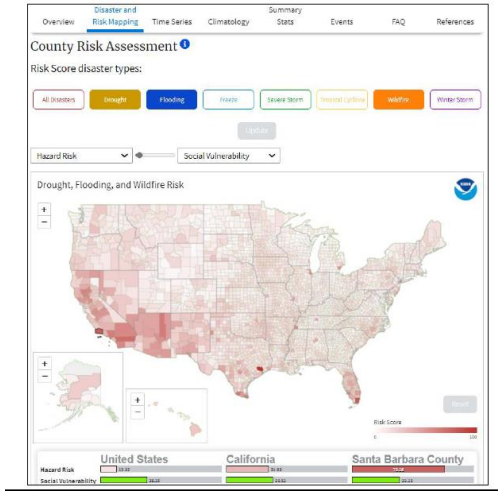
Annual Frequency		Exposure		Historic Loss Ratio
Rate of occurrence	X	• Property Value • People • Agriculture	X	Percentage of property/people/crop losses
How likely is hazard to occur?		How many people & how much property are potentially at risk?		What percent of property/people have historically been lost from hazard in a given area?

FEMA

From 1980–2021, the U.S. **South, Central** and **Southeast** regions experienced a higher cost from billion-dollar disaster events. CA, NY, NJ, PR and V.I. as well.



- Reflects the **severity** and **vulnerability** of weather & climate events impacting different regions
- The **top 3 most impacted states:**
  Texas ($343 billion)
  Louisiana ($270 billion)
  Florida ($248 billion)
- The relative costs are more acute in Louisiana, as its population and economic size is much smaller than Texas or Florida.
- Louisiana also has a high frequency of disaster events, which can leads to compounding, cascading socioeconomic impacts.

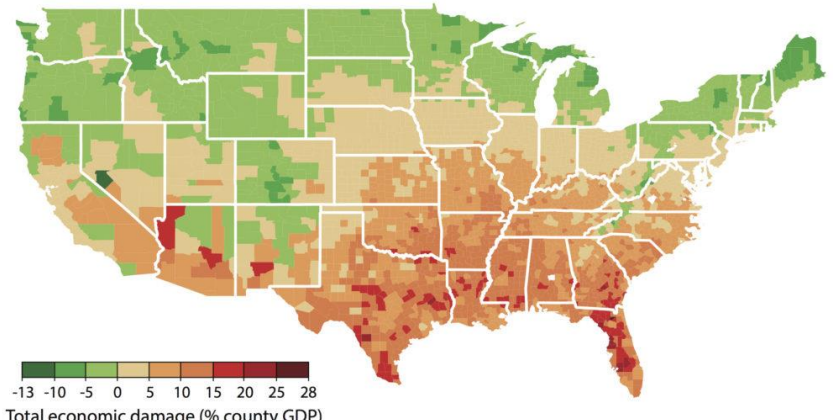


Compound hazard county risk (Drought, Wildfire and Flooding)

Each region faces **unique hazard combinations, which are useful in a new era of more likely cascading hazard impacts** (i.e., drought-enhanced wildfires produce mountain-side burn scars, which often enhance debris flows from flooding.

As noted in National Climate Assessment (2017) **"the physical and socioeconomic impacts of compound extreme events (such as simultaneous heat and drought, wildfires associated with hot and dry conditions, or flooding associated with high precipitation on top of snow or waterlogged ground) can be greater than the sum of the parts."**

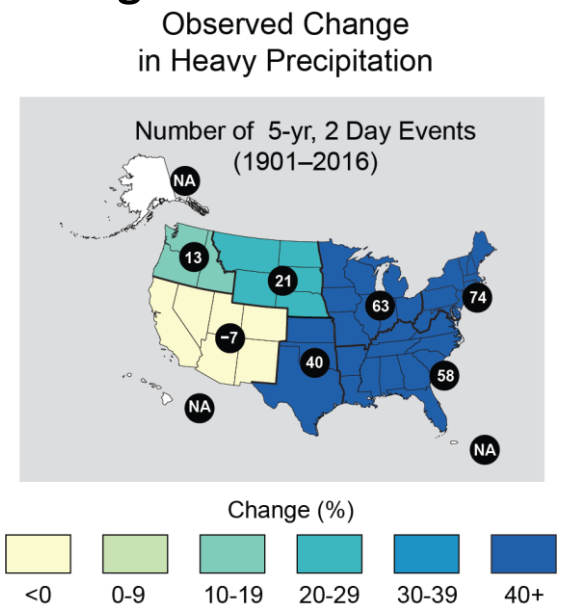
23

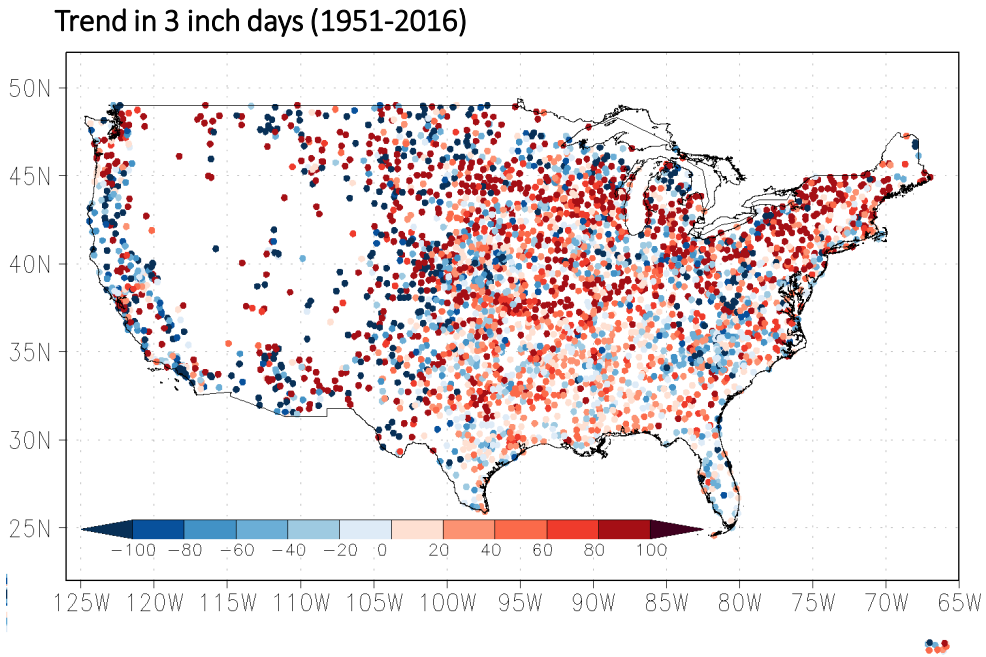


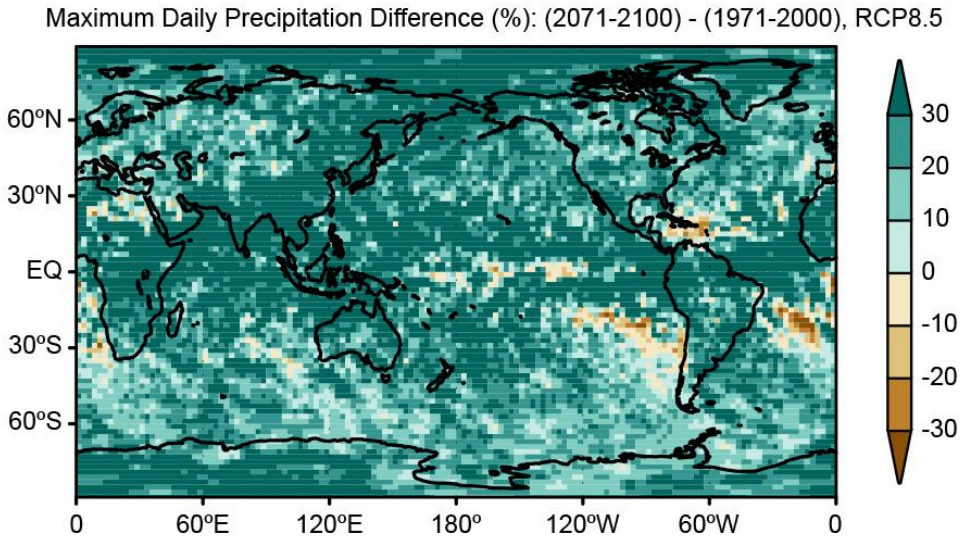
Projected economic impact from climate change (Relative to county GDP) in 2080-2099 under business-as-usual scenario)

Extreme Precipitation and Climate Change: Observations and Projections

Model extreme precipitation increases by 10-30+% by end of 21st Century under a high emissions scenario



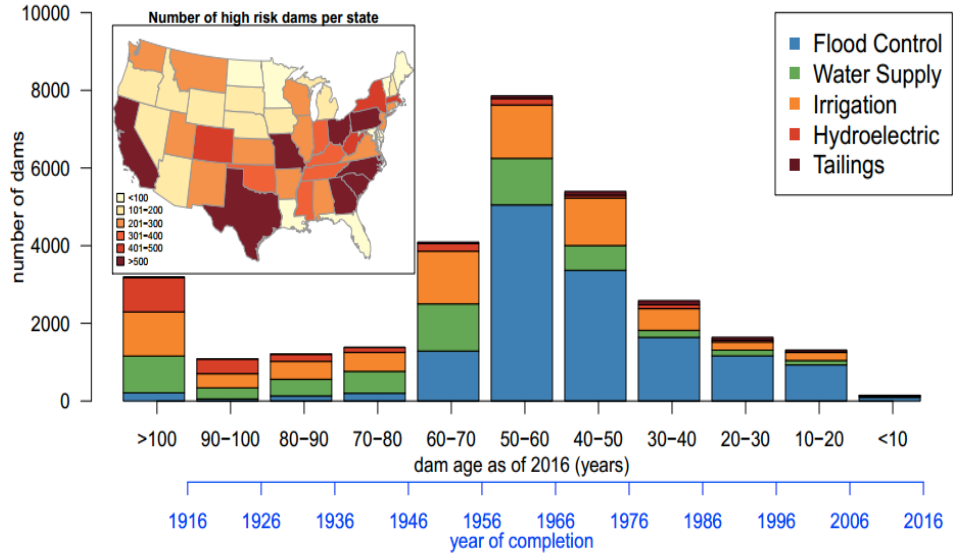




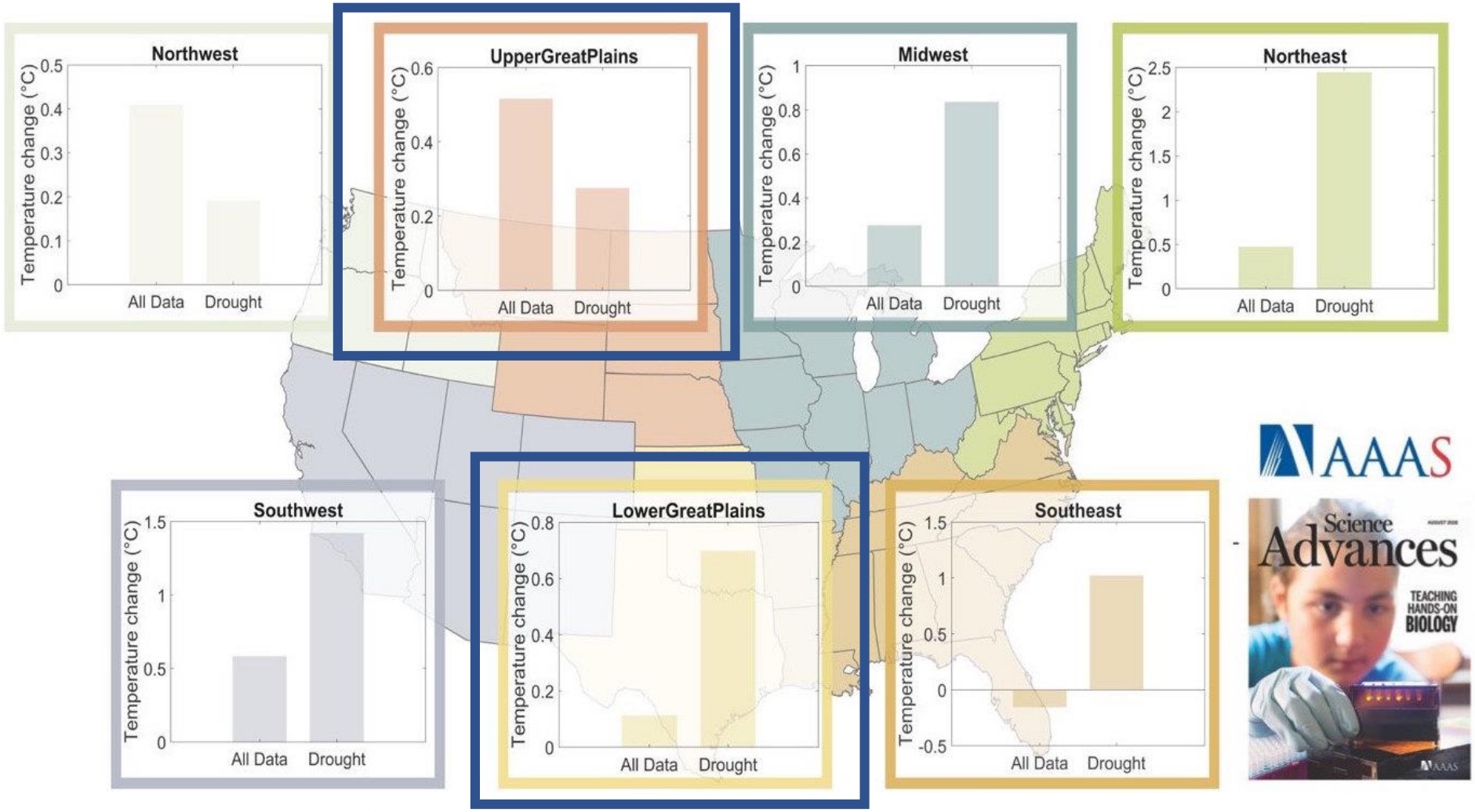
(Kunkel et al 2020

Easterling et al 2017)

Atlas -14 provides **precipitation frequency estimates** guidelines

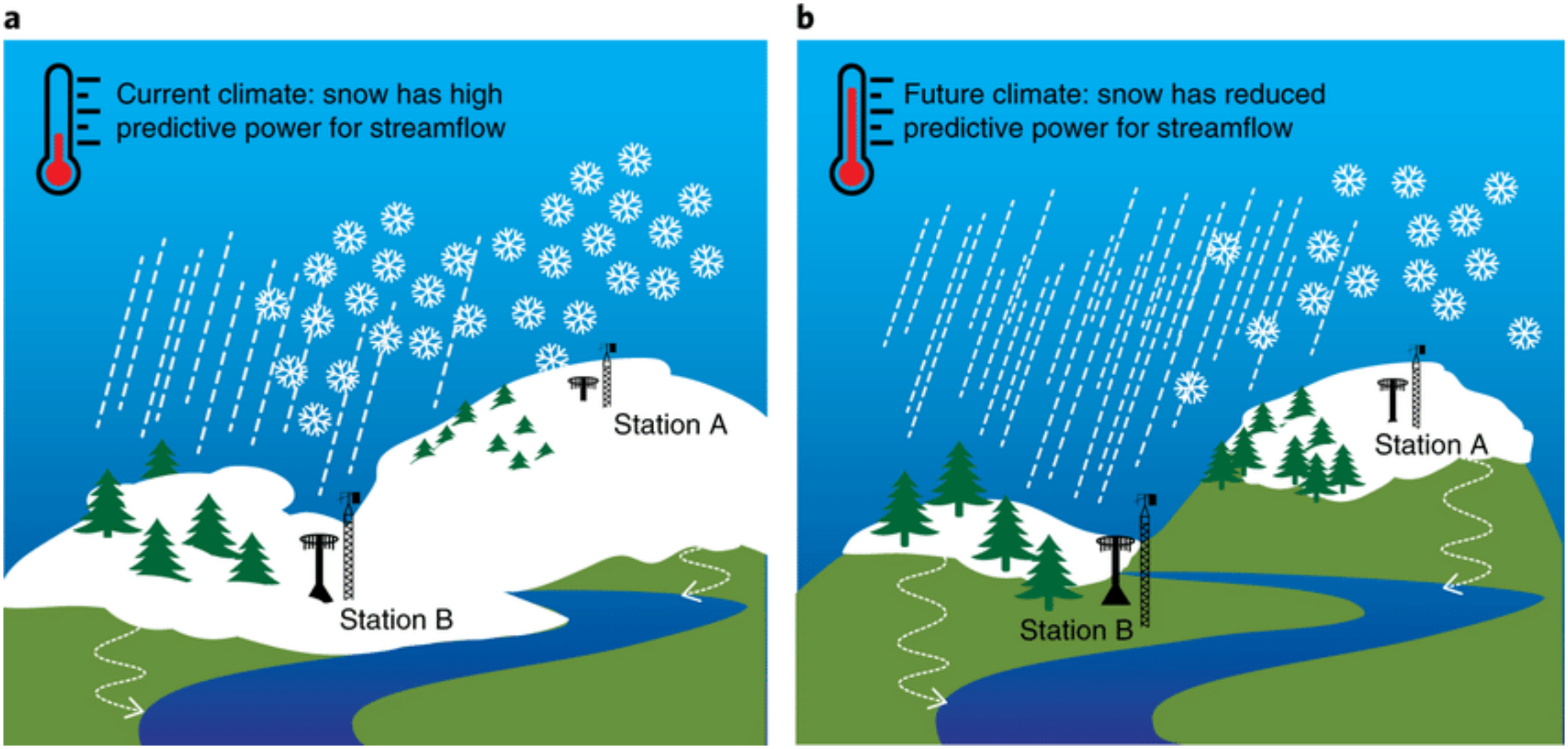


-Compounding events: Droughts have warmed faster than the average climate



Temperature shifts corresponding to the average climate and drought conditions based on ground-based observations [1965-2014 relative to 1902-1951]

Chiang F., AghaKouchak, A, et al., 2018, Science Advances, 4 (8), eaat2380.
http://advances.sciencemag.org/content/4/8/eaat2380



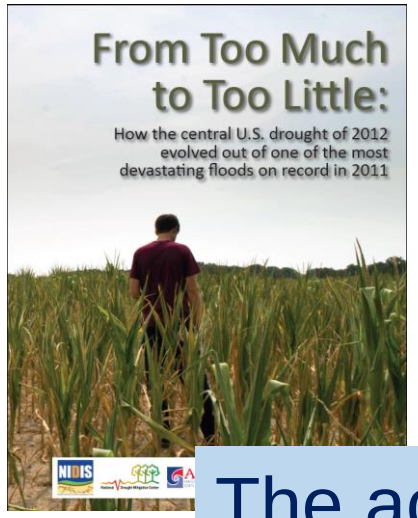
A **snow drought** is a period of abnormally little snowpack for the time of year

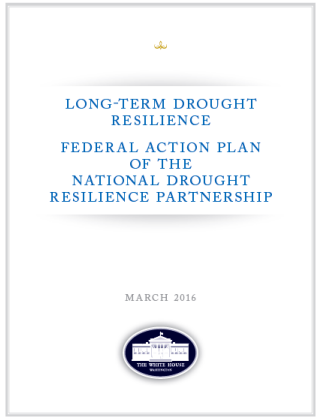
A Complex System

- Local governments
- State governments
- Federal agencies
- Business and industry
- Universities
- Regional entities
- Non-profit organizations
- International connections

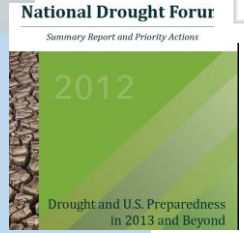
The Missouri -Mississippi River System at (1.25 m sq. miles, 3.22 m km^2) fourth largest river system and the most economically valuable corridor in the world .

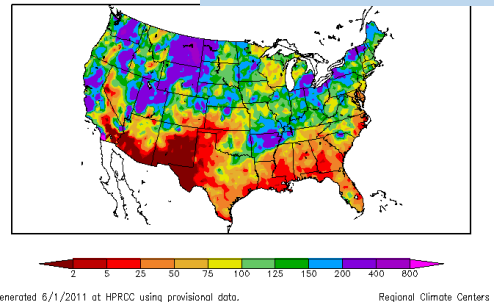
Highest volume for the transportation of goods in the US.. Over 460 million short tons (420 million metric tons) and 3.25 million short tons of shipments respectively each year, with 92% of the nation's agricultural exports and 78% of the world's feed grains and soy beans.



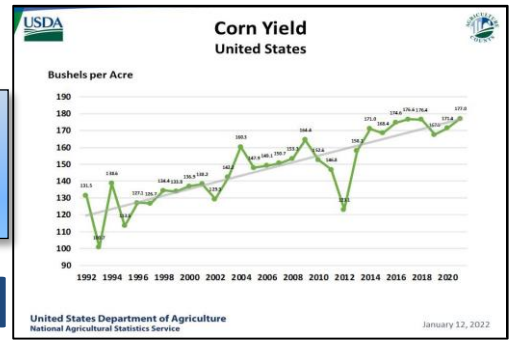


The actions derived included the development of the interagency National Drought Resilience Partnership

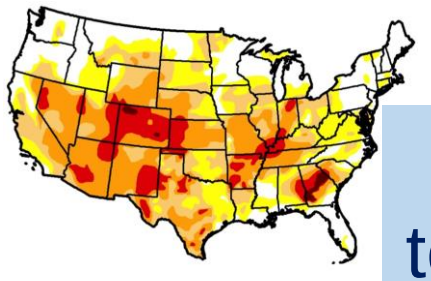




2010-12: First time U.S. corn yield fell three years in a row since 1928-30 (USDA)

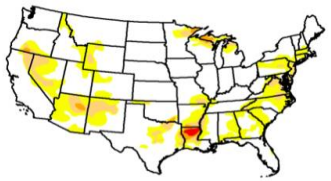


"Climate Extreme Drought To Extreme Flood Whiplash Hits The Midwest"

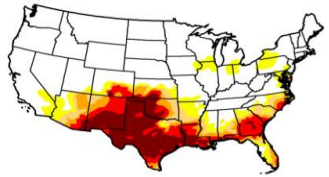


The Basin appears to be becoming even more variable in terms of runoff. Annual runoff variability has nearly doubled in the last 20 years (Livneh 2016)

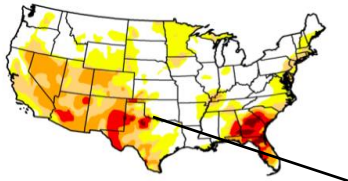
(McNutt et al; in Wilhite and Pulwarty 2017)



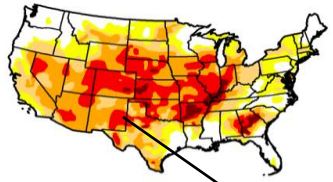
July 2010
8% moderate
to exceptional



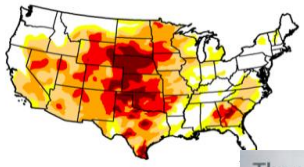
July 2011
28% moderate
to exceptional



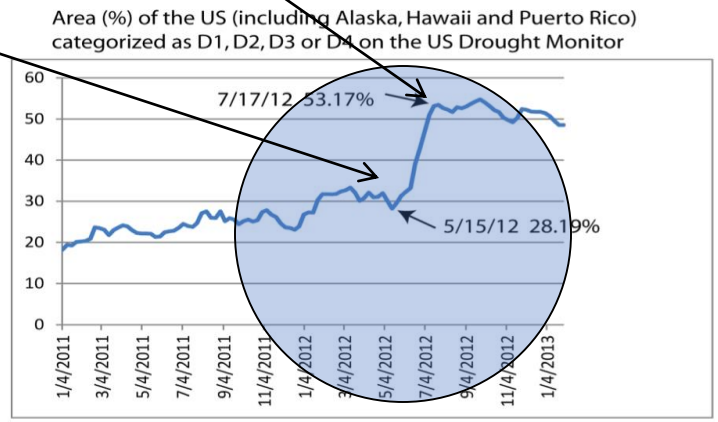
May 2012
35% moderate
to exceptional



July 2012
64% moderate
to exceptional



January 2013
58% moderate to
exceptional



- **A complete explanation of these droughts must invoke not just the ocean forcing but also the particular sequence of internal atmospheric variability - weather - during the event.**

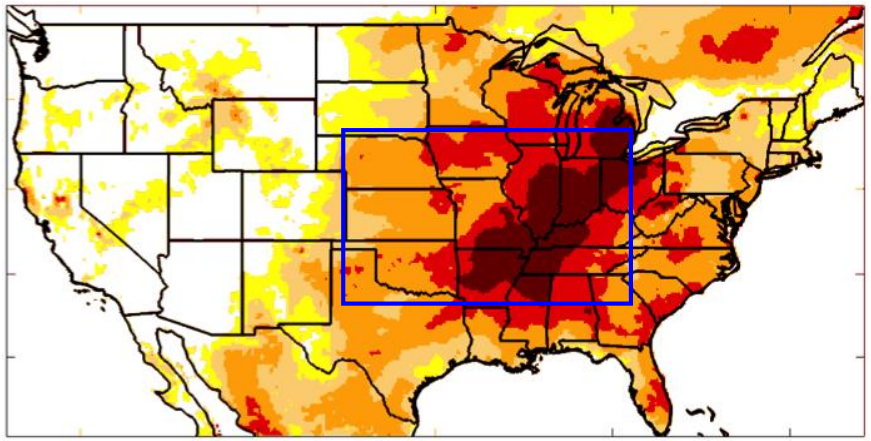
2012 Evaporative Demand Drought Index

May to August 2012: Areal extent of U.S. drought jumped 30 to 60%

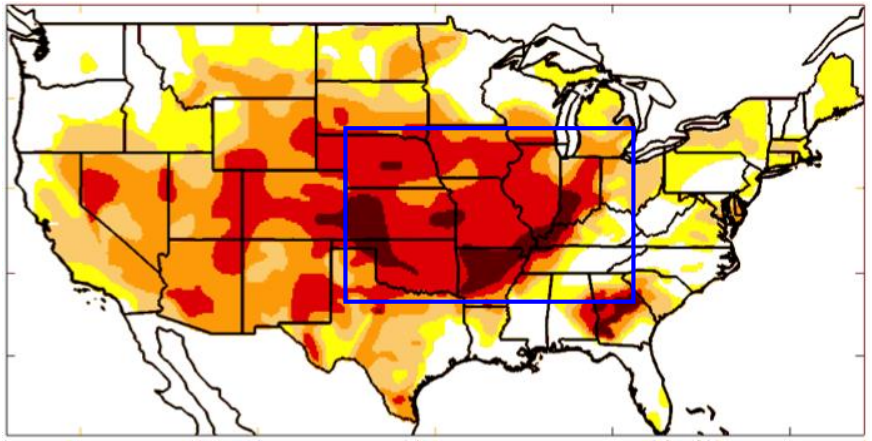
May 31 August 7

$$EDDI_j = \frac{\sum_{t=i}^{j}\left(ET_{0_t} - \overline{ET_{0_t}}\right)}{\sigma_{\overline{ET_{0_t}}}}$$

2-week *EDDI*



USDM

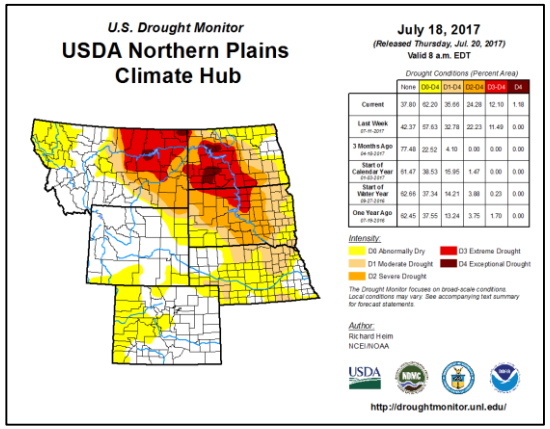


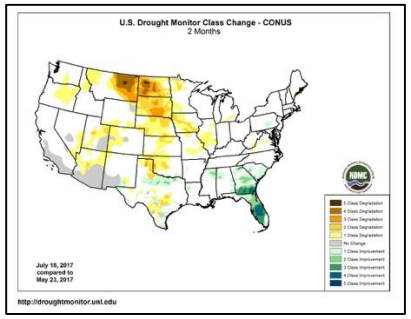
note little drought in western US

much of region; 2 months after *EDDI*

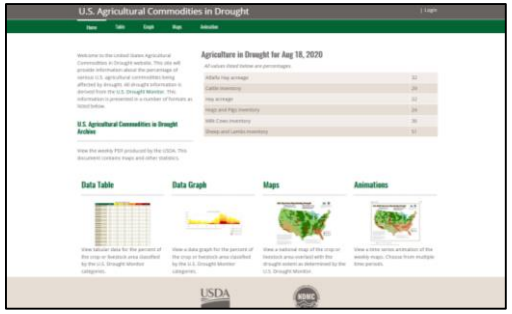
- **Due to land-atmosphere feedbacks, evaporative demand (E_0) reflects surface moisture conditions, *often before ET does*,**
  - **responds positively to both flash droughts and sustained droughts.**

Upper MidWest ”Rapid-onset” Drought 2017





The 8-week change map between the July 18, 2017 and May 23, 2017. Large parts of the Northern Plains saw a 4-5 class deterioration over this two month period.



Agricultural Commodities in Drought: https://agindrought.unl.edu

Cumulative risk: Antecedent conditions

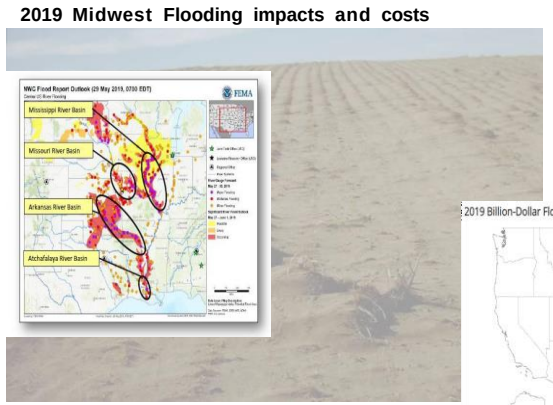
In May 2017, the region was mostly drought-free, and at least average summer precipitation was forecasted.

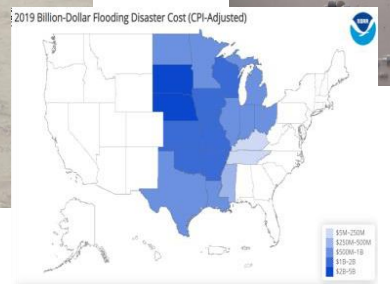
By July 2017, North Dakota, South Dakota, eastern Montana, and the Canadian prairies were experiencing severe to extreme drought, resulting in fires that burned 4.8 million acres across both countries and U.S. agricultural losses in excess of $2.6 billion dollars

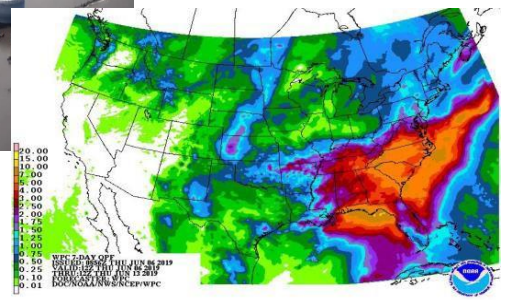
(Hoell et al 2020)

2019 Central U.S. Floods

Cumulative risk: Antecedent conditions







The wettest spring and summer on record for much of the United States occurred in 2019.

- 14 million acres of insured farmland went unplanted in the MidWest/Hgh Plains- largest since USDA's 'prevented-plant' acreage record keeping began in 2007,
- Reduced corn and soybeans – 13% and 6% of total acreage, respectively.
- 5 million acres were planted in unfavorable conditions. In the words of one expert "it turned out to be a really bad bet."

What is the message……..

……..in the context of a changing climate?

- …s to date, predicting future hydro-climate variab… …ll remain a major challenge

- Nature is complex an… …modeling its nonlinear behavior remians challengi… …of high resolution information “generated” by model…

- ***Long-term and sustained observation programs are … especially for model verification***

Factoring in resiliency in water resources systems design and planning is still the safest approach

Moving from diagnostics to implementation

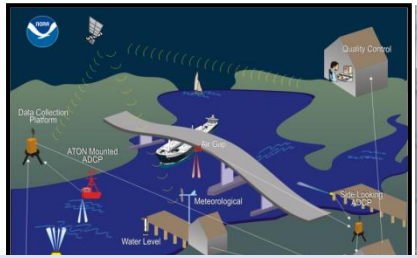
Economies

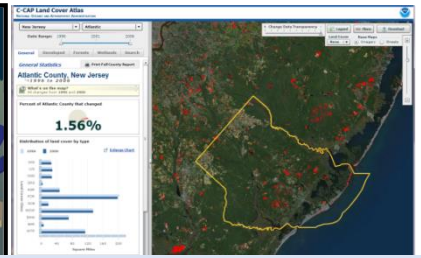
Ensuring Resilient Economies

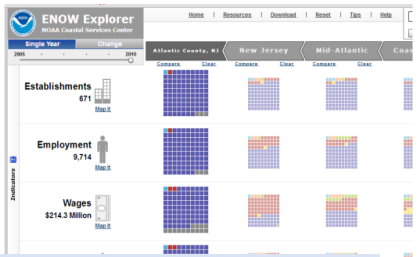
Communities

Supporting Well-being and dignity



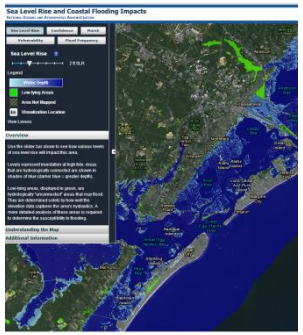






Develop scientific and technological applications and services to reduce social, environmental, and economic risks and realize co-benefits/savings

Promoting Environmental Resilience



Putting the pieces together

Monitoring/
Forecasting

Innovation

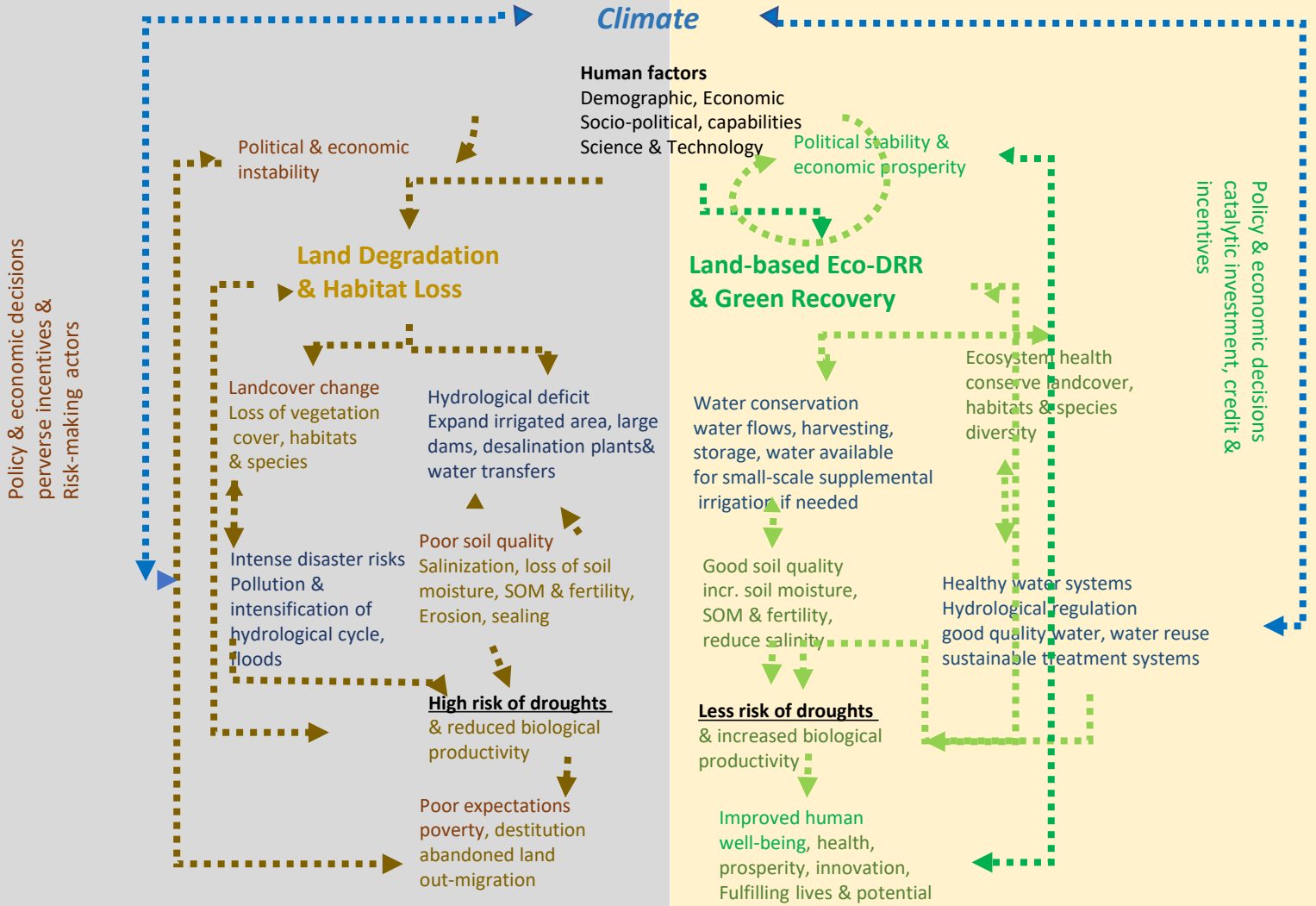
Evaluation

Learning

Shift from responding solely on an event by event to addressing the propagation and accumulation of risk and cascading impacts.

NEGATIVE DYNAMICS - INCREASING RISKS

POSITIVE DYNAMICS - INCREASING RESILIENCE



Chinese proverb "If we are not careful we will end up where we are going"

If it’s so easy why is it so hard to do?

”Closing” water systems, climate and scarcity

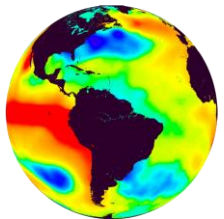
- As yet-Little comprehensive understanding of the long-term and widespread consequences of past adaptations

- Complications of changes in the spatial and temporal distribution of rainfall, soil moisture, runoff, frequency and magnitudes of droughts and floods are gradually being included in response planning

- Systems design, operational inflexibility, and legal and institutional constraints still reduce the adaptability of water systems to respond to climatic changes

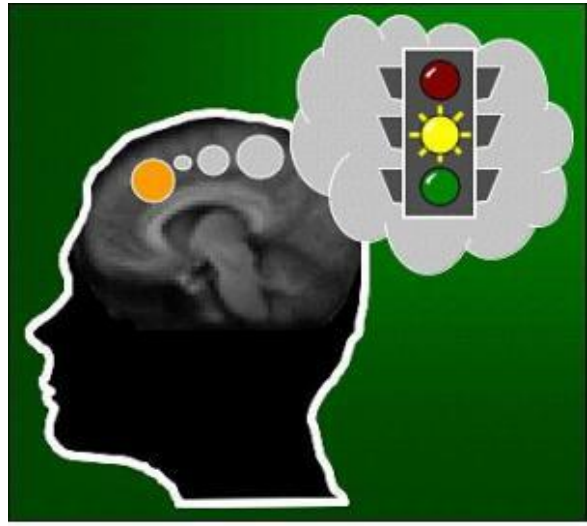
- Compounded by lack of agreement on event definitions, such as what constitutes an “extraordinary” (i.e., severe and persistent) drought in different place

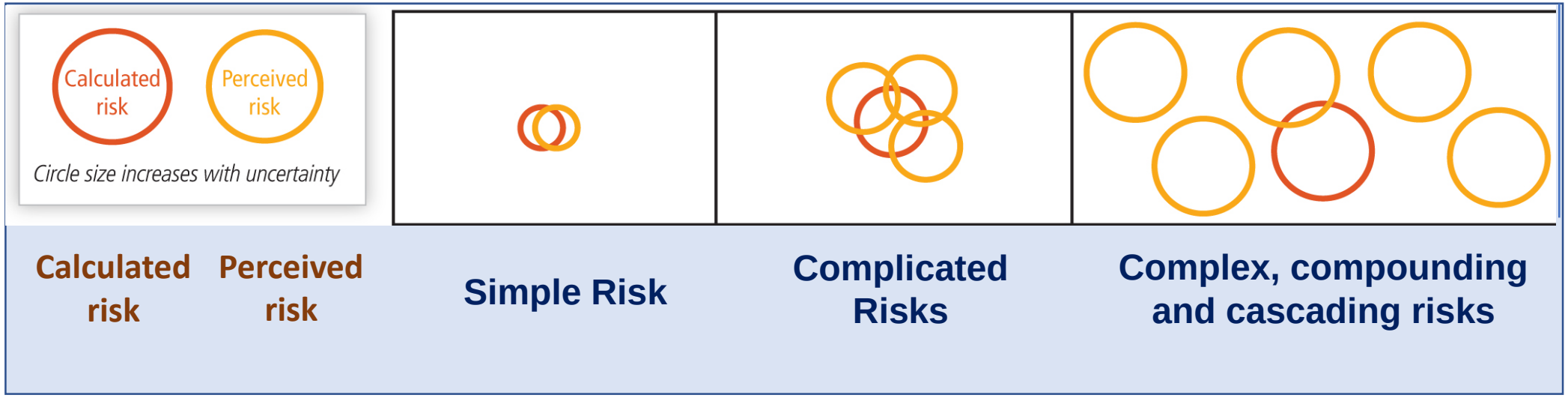
  Equitable and reasonable use of water involves definitions of broad concepts such as “no harm,” and “optimal utilization”

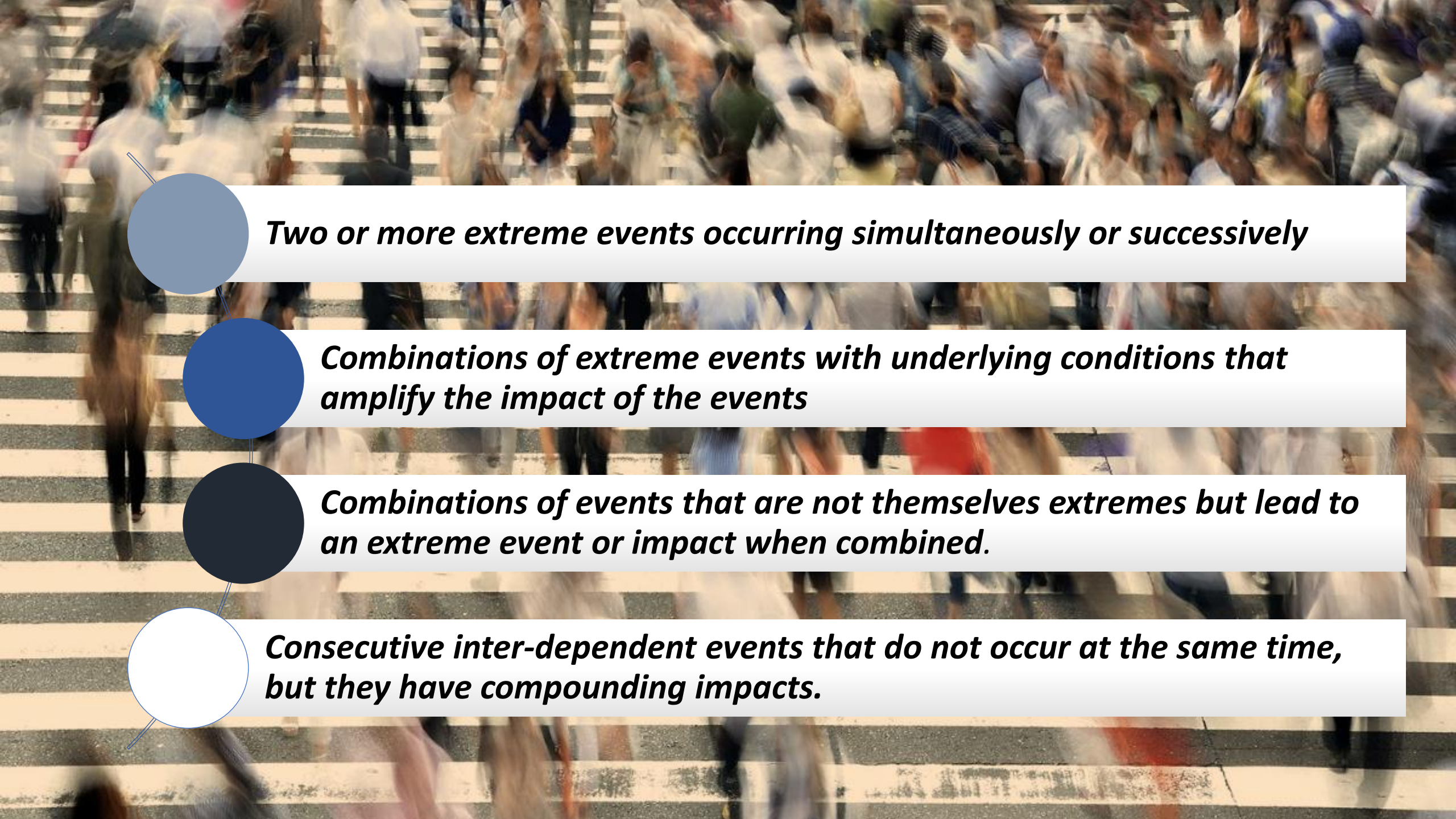


DESIGNING FOR CLIMATE CONFIDENCE:

Managing “through” a changing climate







- ***Two or more extreme events occurring simultaneously or successively***
- ***Combinations of extreme events with underlying conditions that amplify the impact of the events***
- ***Combinations of events that are not themselves extremes but lead to an extreme event or impact when combined.***
- ***Consecutive inter-dependent events that do not occur at the same time, but they have compounding impacts.***

Toward sustainable development of water resources

1. **Measurement**

2. **Valuation**

3. **Informing decision-making**

4. **Coordination and risk management**

Ensure that policies and management decisions are actually delivered through an adaptive set of institutions, incentives, and instruments.

Garrick et al and others

IDENTIFYING AND MANAGING CLIMATE RISKS

THE CLIMATE CHANGE DECISION TREE

- A scientifically defensible, flexible, cost-efficient tool on climate risks
- A bottom-up approach taking into account local realities and climate sensitivity

CLIMATE RISK MANAGEMENT PLAN & CLIMATE RISK REPORT
Measures needed to ensure the project's robustness are documented

PHASE 4 CLIMATE RISK MANAGEMENT

Can the project cope with potential climate changes in the system ('robustness')?

YES

NO → If project robustness is not achievable, the project is adjusted and put through phase 3 again, or a redesigned project starts at phase 1.

Exhaustive climate risks analysis: Combining historic data, global climate model projections, a hydrologic-economic water system model, etc.

PHASE 3 CLIMATE STRESS TEST

What is the plausible climate risk?

HIGH

LOW → Climate Risk Report

A rapid project scoping exercise, using a (simplified) water resources system model, compares climate impacts with others such as existing variability, population growth, etc.

PHASE 2 DESKTOP ANALYSIS

Is climate a dominant factor?

YES

NO → Climate Risk Statement

Climate sensitivity screening for all Bank projects: Is climate a factor to take into account?

PHASE 1 PROJECT SCREENING

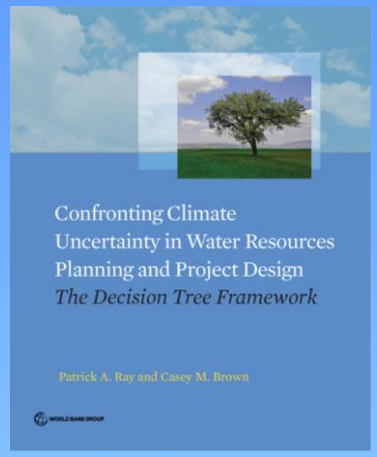
Is the proposed project climate sensitive?

YES

NO → Climate Screening Worksheet

WORLD BANK GROUP Water
worldbank.org/water

WATER PARTNERSHIP PROGRAM
water.worldbank.org/wpp

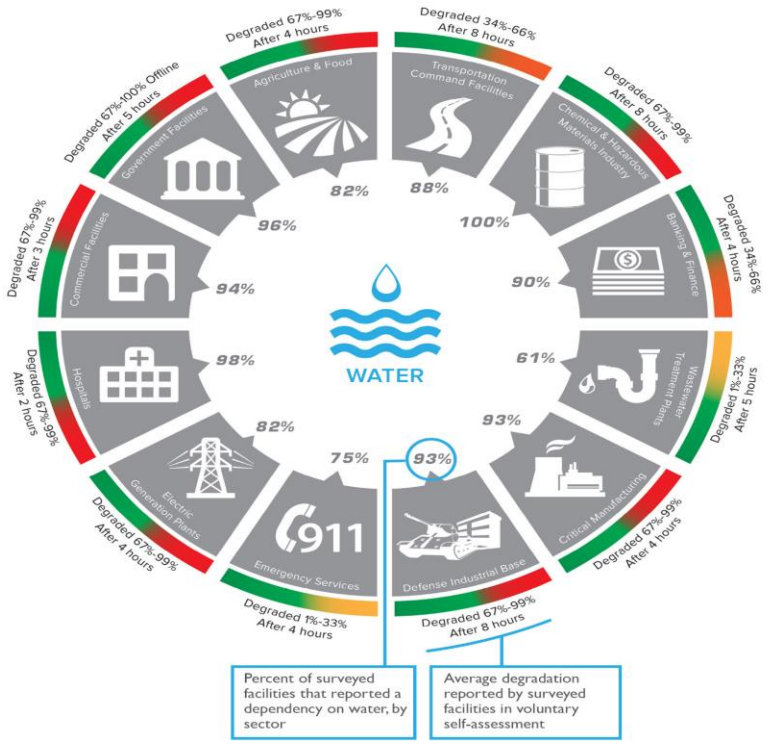


Brown
Linkov
Pulwary
and others

Use paleo-data, events of record and Stress-testing approaches, as well as projections

Co-benefits to Water Sector Resilience related to addressing drought

Critical Infrastructure dependence on water and potential function degradation following loss of water services



CRITICAL INFRASTRUCTURE SECTOR IMPACTS DUE TO DROUGHT HAZARD

National Protection and Programs Directorate Infrastructure Development and Recovery (IDR) | February 2018

Homeland Security

SCOPE

Critical Infrastructure Sector Impacts Due to Drought Hazard

Existing resources from NIDIS, EPA, USDS, DOI, DHS, FEMA,, HHS-CDC, and other sources were complied to creates a risk analysis of drought hazard impacts to ten critical infrastructure sectors

Drought Hazards: RAW WATER AVAILABILITY; RAW WATER DEGRADATION; LAND SUBSIDENCE EXACERBATION; WILD FIRES; FLOODING

Critical Infrastructure Sectors + Subsectors: CRITICAL MANUFACTURING; DAMS (AS A DEPENDENT OF WATER + WASTEWATER); ENERGY ELECTRICITY; ENERGY SECTOR PETROLEUM, NATURAL GAS + COAL; FOOD + AGRICULTURE; HEALTHCARE + PUBLIC HEALTH; TRANSPORTATION SYSTEMS

KEY FINDINGS

Direct Impacts to Critical Infrastructure from Drought Hazards

DROUGHT HAZARDS, DIRECT IMPACTS

SERVICE PROVIDER CRITICAL INFRASTRUCTURE SECTOR	Raw Water Availability	Raw Water Quality Degradation	Dust Storms	Flooding	Land Subsidence Exacerbation	Wild Fires
Critical Manufacturing	●	●		●*	●*	●
Dams						
Energy - Electricity	●	●	●	●		●
Energy - Petroleum, Natural Gas + Coal	●	●		●		●
Food + Agriculture	●	●		●	●*	●
Healthcare + Public Health		●		●*		●
Transportation Systems	●	●		●	●	●
Water + Wastewater Systems - Raw Water		●	●	●	●	●
Water + Wastewater Systems - Treated Water	●	●	●	●	●	●
Water + Wastewater Systems - Wastewater		●	●	●	●	●

* Dependency understood but not identified specifically by reference

DROUGHT AND INFRASTRUCTURE

A Planning Guide

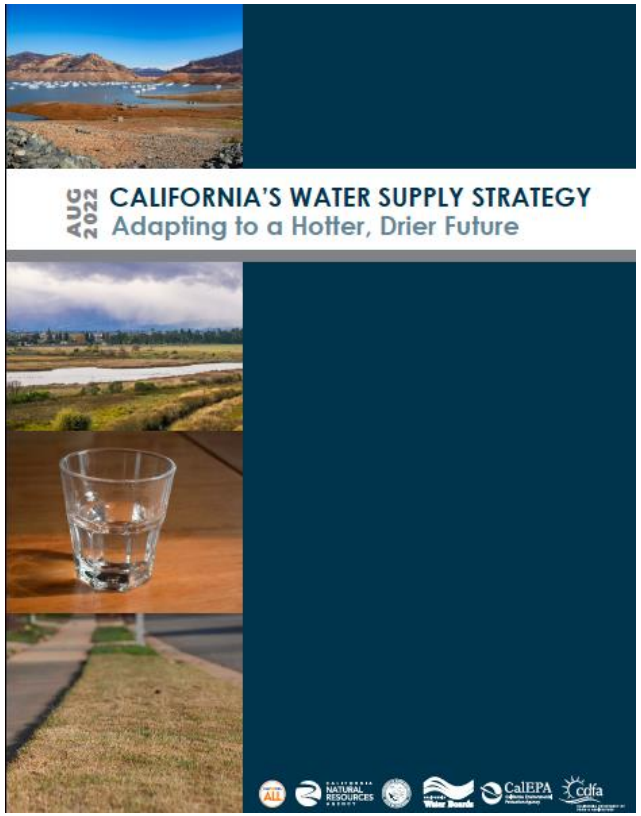
OCTOBER 2021

Cybersecurity and Infrastructure Security Agency with the National Drought Resilience Partnership

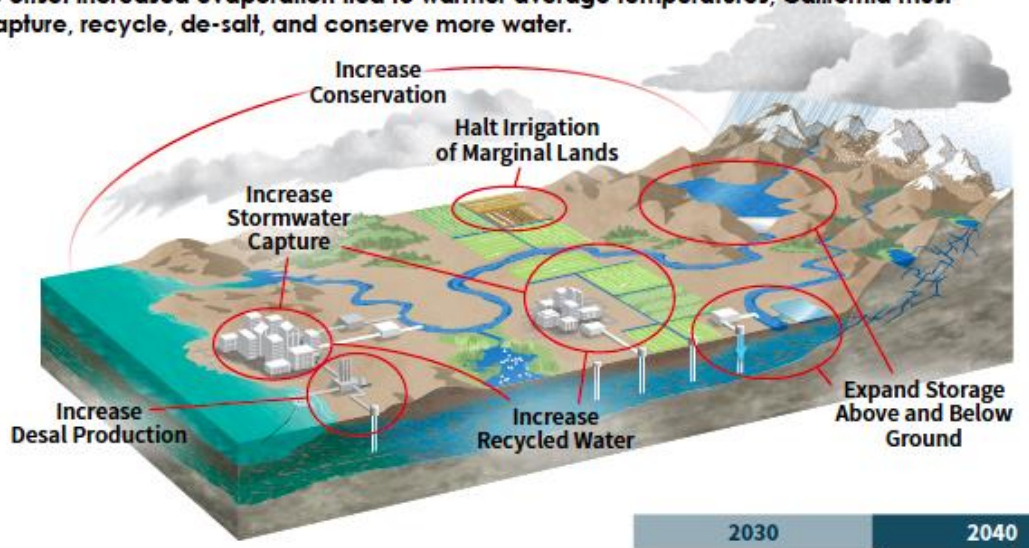
(U.S. Department of Agriculture, Environmental Protection Agency, National Oceanic and Atmospheric Administration, and Federal Emergency Management Agency)

This example is g… nent.

https://www.dhs.gov/

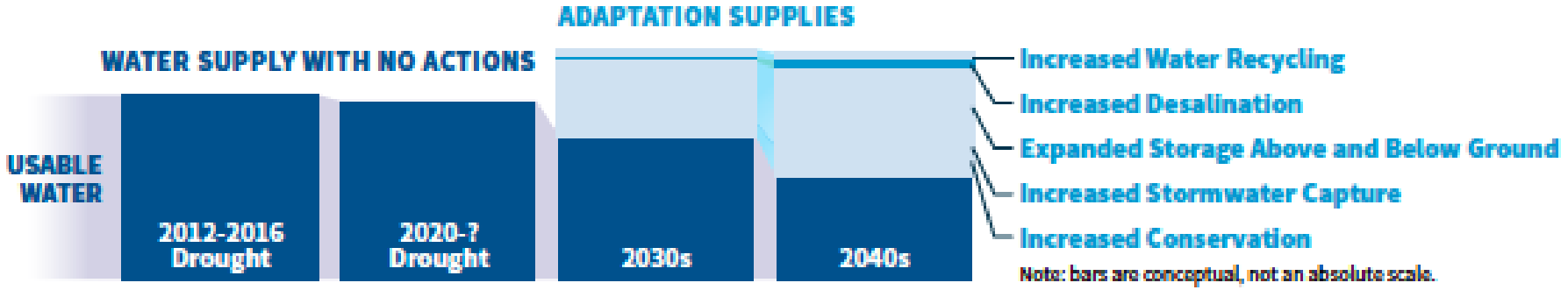


To offset increased evaporation tied to warmer average temperatures, California must capture, recycle, de-salt, and conserve more water.



	2030		2040	
Increase Recycled Water	.8 MAF	About 5 MAF	1.8 MAF	About 7 MAF
Increase Desal Production	28,000 AF		84,000 AF	
Increase Stormwater Capture	.25 MAF		.5 MAF	
Increase Conservation	.5 MAF		.5 MAF	
SUBTOTAL FOR RECYCLED, DESAL, STORMWATER AND CONSERVATION	1.6 MAF		2.9 MAF	
Expand Storage Above and Below Ground*	3.7 MAF		4 MAF	
Total	4.8 MAF		6.9 MAF	

*Additional storage capacity does not equate to a similar volume of new water supply. MAF – million acre-feet.

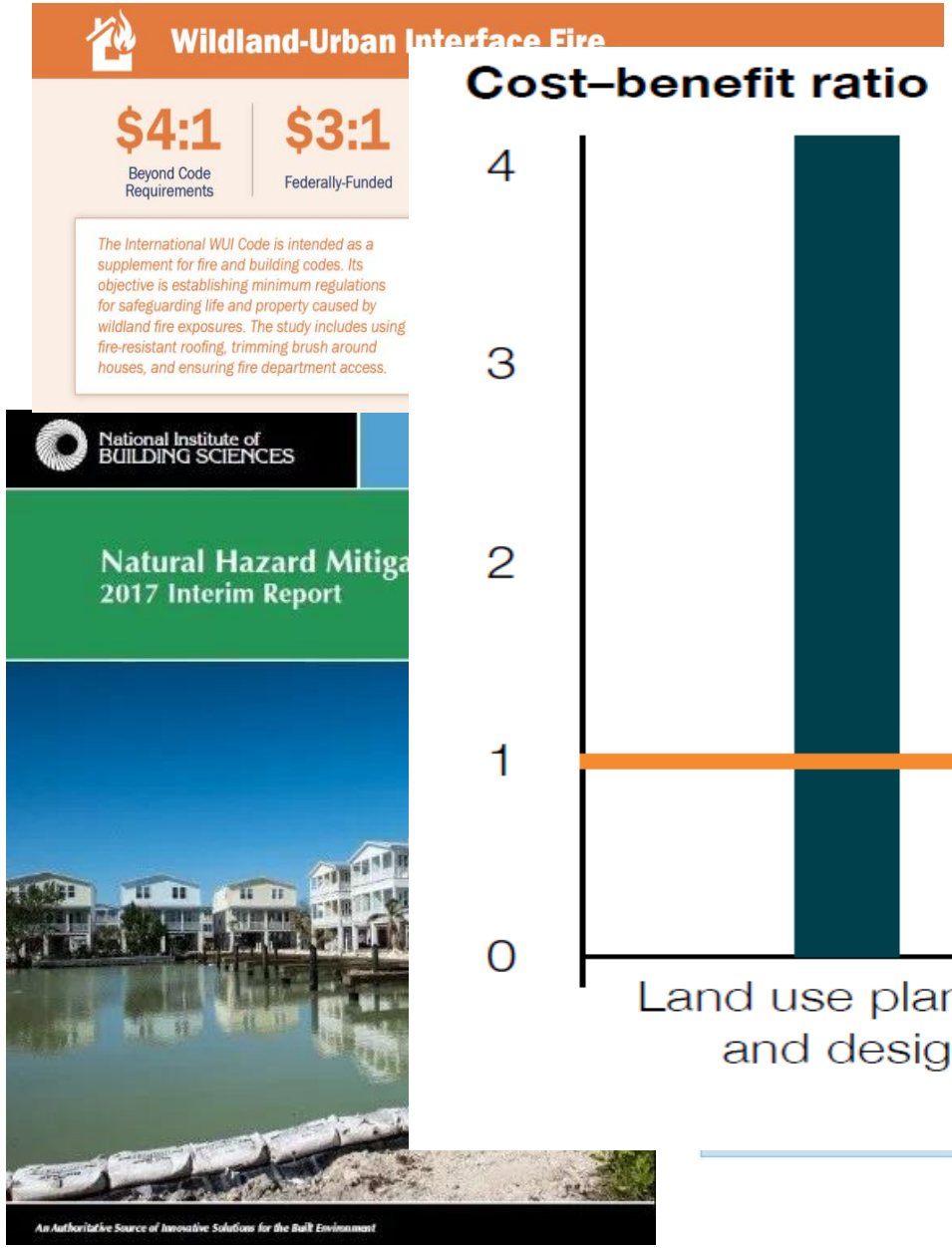


If we only knew the costs and benefits …….

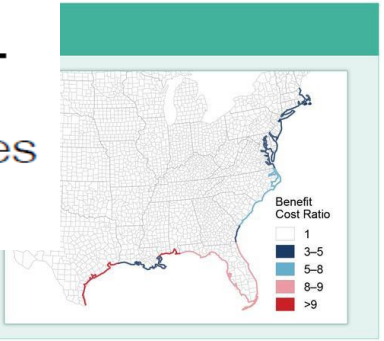
The Financial Times (29 August 2016) noted (in their words) that “people are afraid that doing something about “climate” will make them poorer/less well off” in the near-term

“ALSO, THE BRIDGE IS OUT AHEAD”

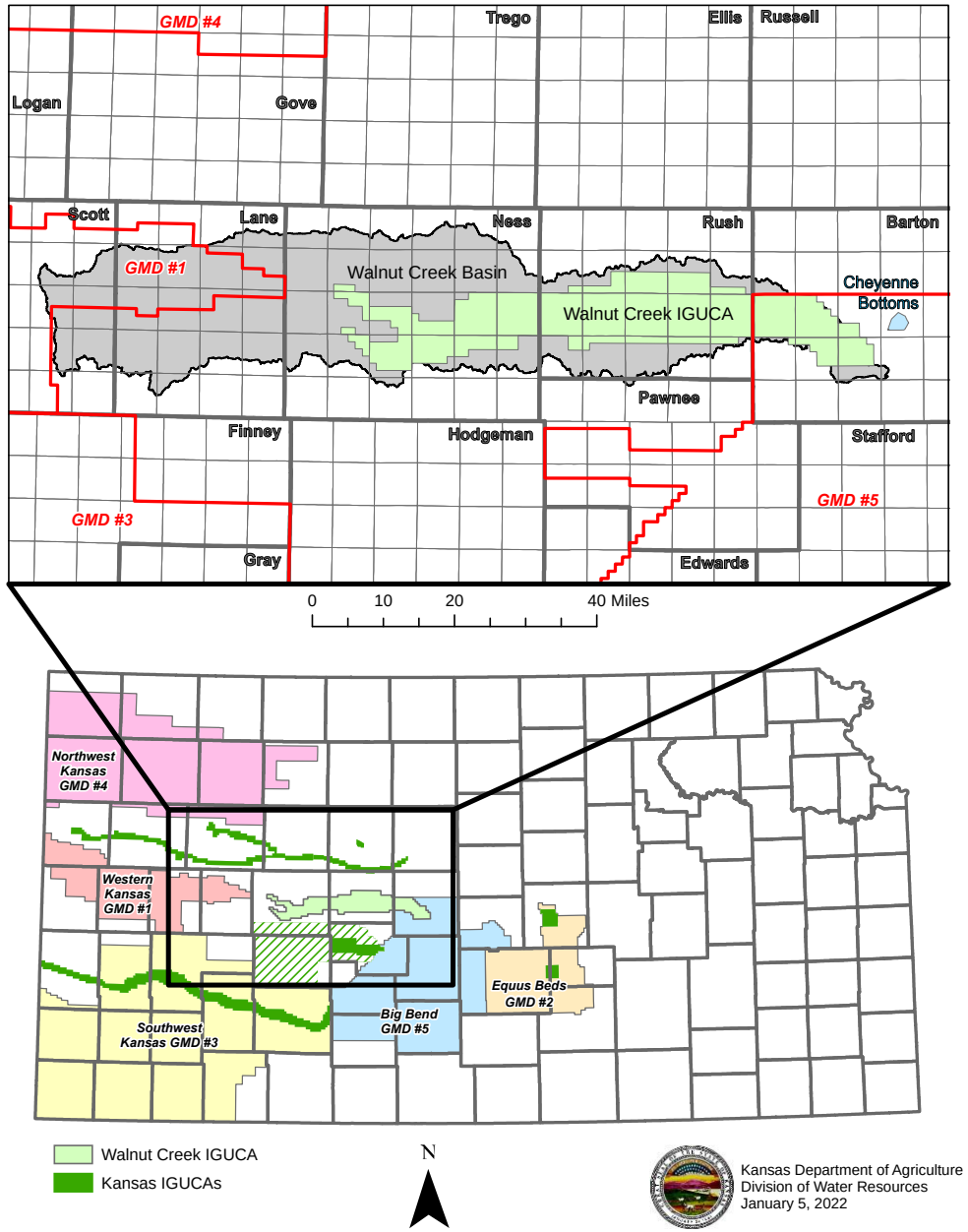
Natural Hazard Mitigation Saves: 2017 *An Independent Study to Assess the Future Savings from Mitigation Activities*.



Configurations of land-use offers the largest return on investment



Walnut Creek IGUCA



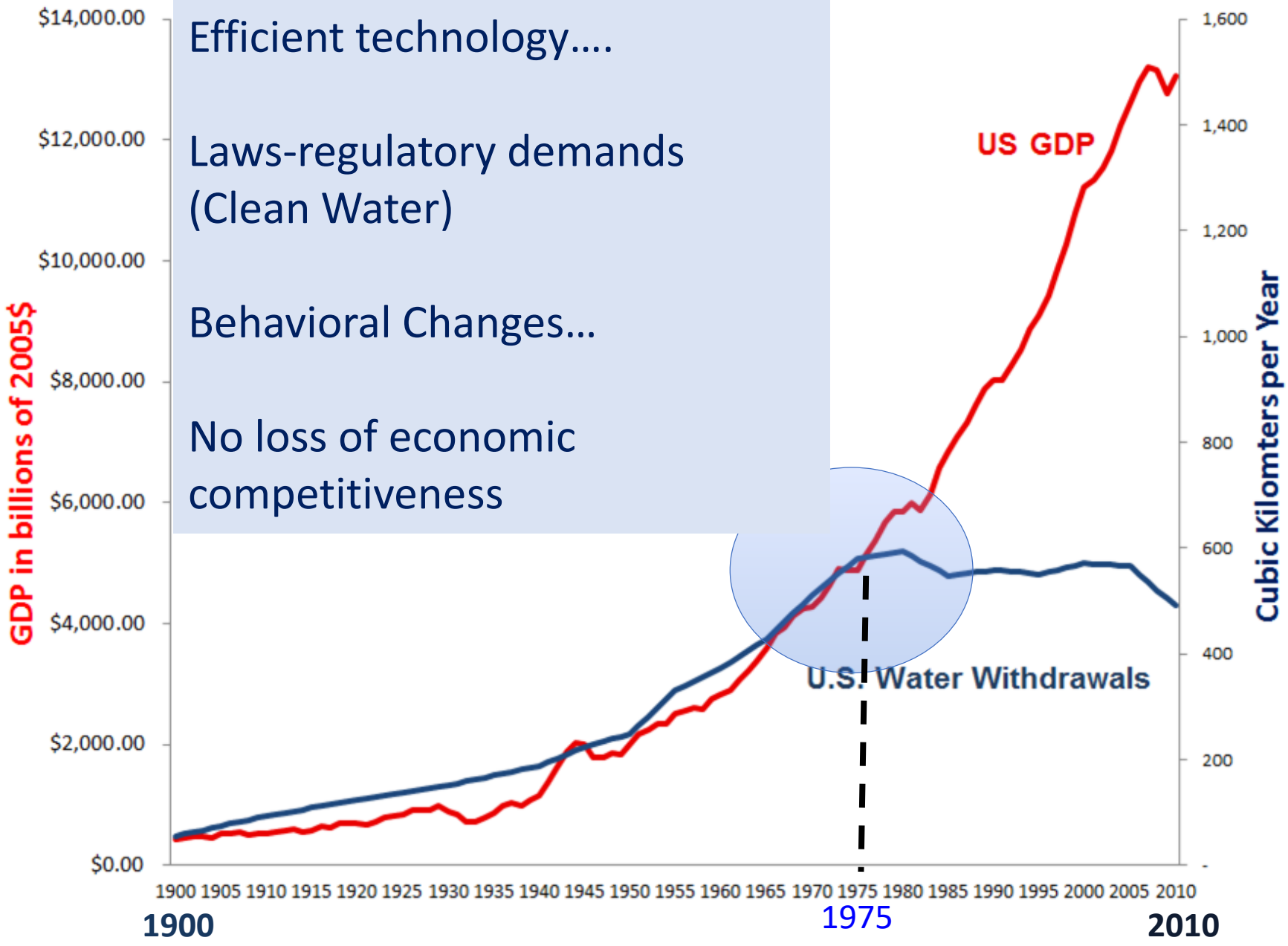
Walnut Creek Intensive Groundwater Use Control Area

Efficient technology….

Laws-regulatory demands (Clean Water)

Behavioral Changes…

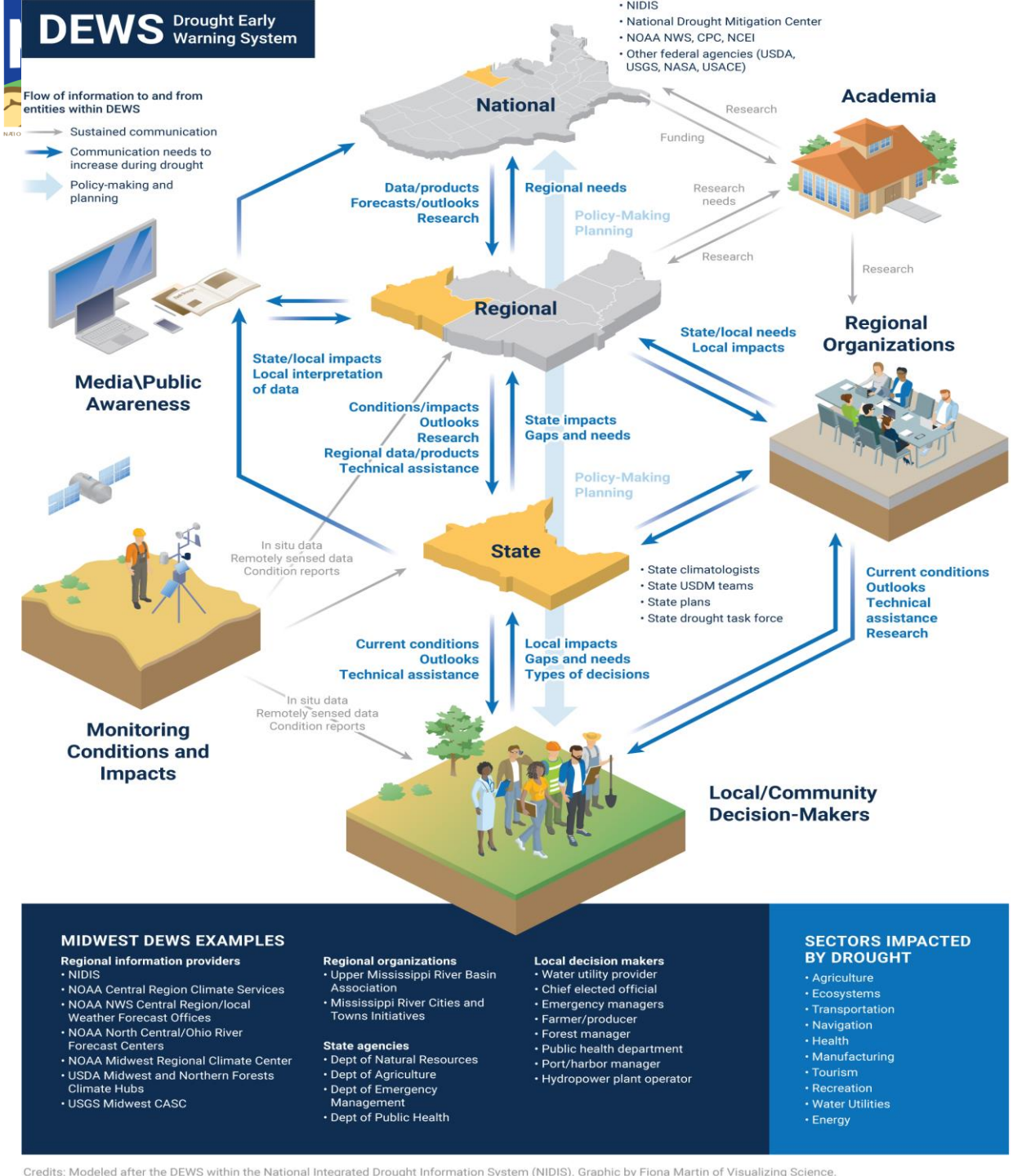
No loss of economic competitiveness



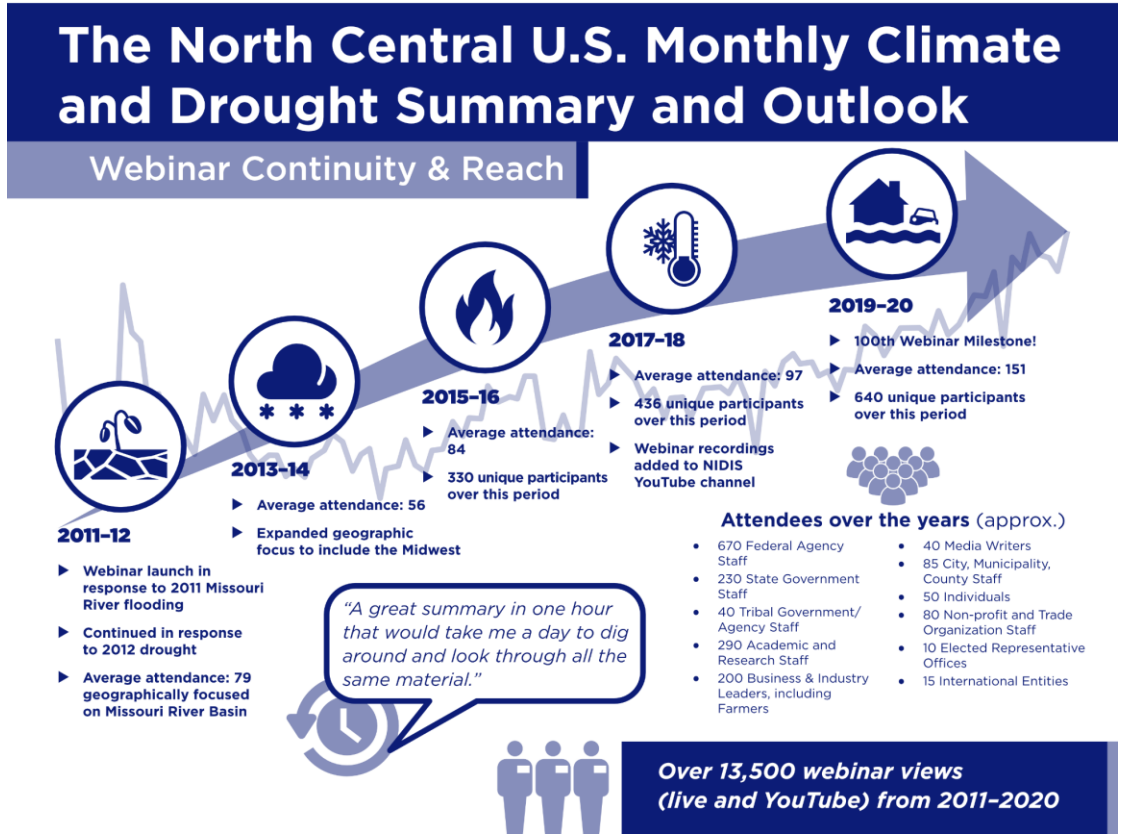
(Rogers 2003; Gleick,2014, NCA4)

Ongoing Challenge:

Supporting local and state-level professionals to sustain collaborative networks between research and practice



Credits: Modeled after the DEWS within the National Integrated Drought Information System (NIDIS). Graphic by Fiona Martin of Visualizing Science.



Doug Kluck NOAA Regional Climate Services
Molly Wolozyn National Integrated Drought Information System
Dennis Todey USDA Climate Hubs
Mark Svoboda National Drought Mitigation Center Univ. Nebraska, Lincoln

Others

Resulting actions from towns and cities (MRCTI 2020, 2021)

- Cities were able to make informed decisions regarding continued flood-flight activities
- Cities were able to more confidently begin longer term mitigation and recovery planning such as insurance arrangements;
- Cities began to coalesce around mixed infrastructure solution, including drawing lessons from each other, incorporating more natural assets at a scale more extensive than previously ;
- New partnerships at greater scale over more service areas stretching across multiple states were sought

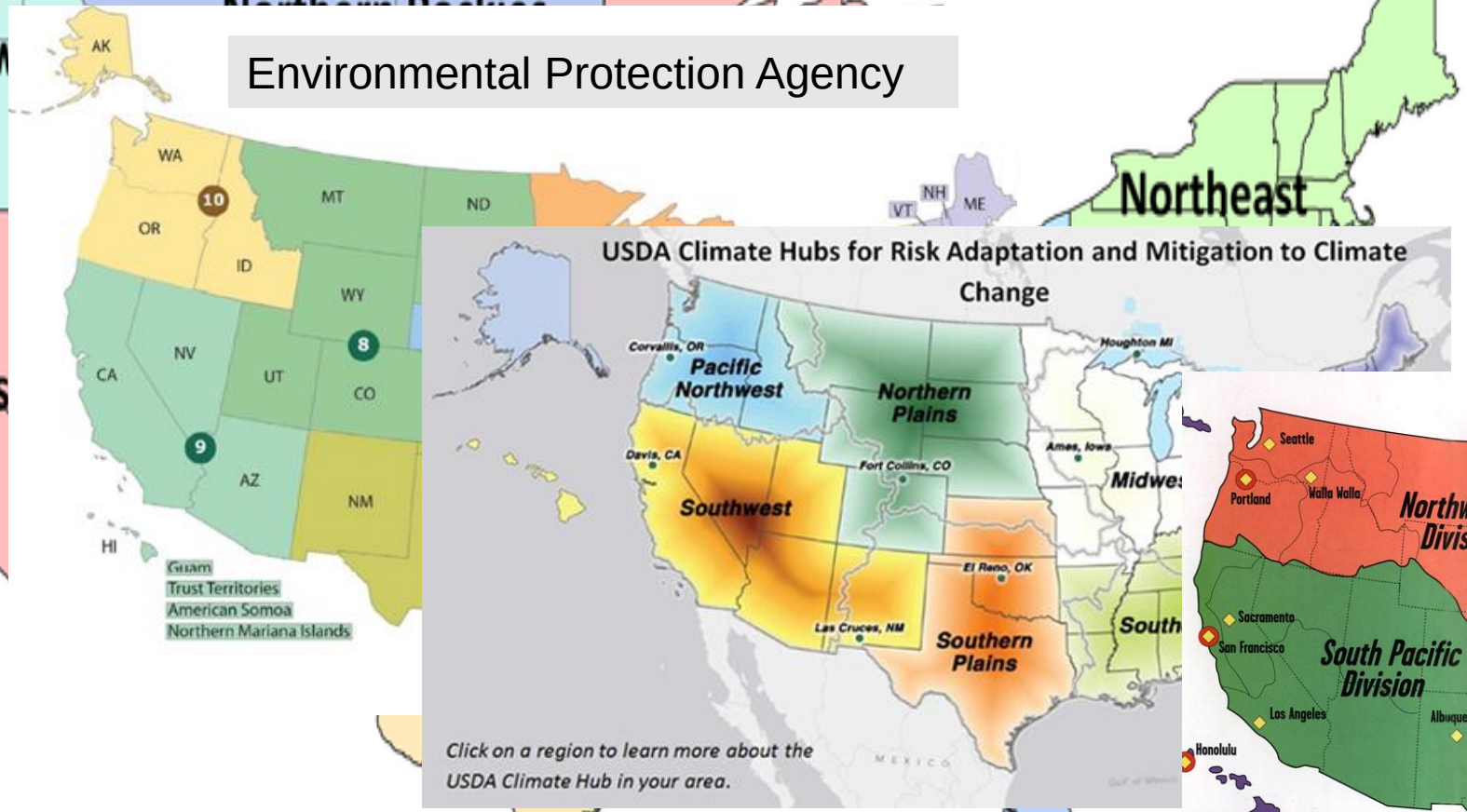
MRCTI DISASTER RESILIENCE AND ADAPTATION PROGRAM

85% reported increasing their ability to incorporate climate outlooks and information into decisionmaking

Key Federal Partnerships

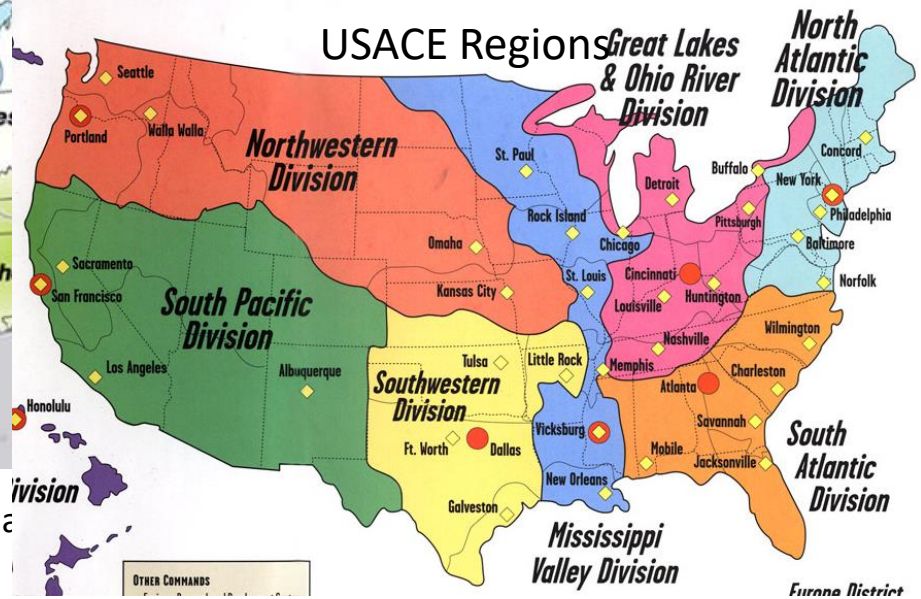
US Climate Regions

https://www.usgs.gov/ecosystems/climate-adaptation-science-centers



Environmental Protection Agency

USACE Regions

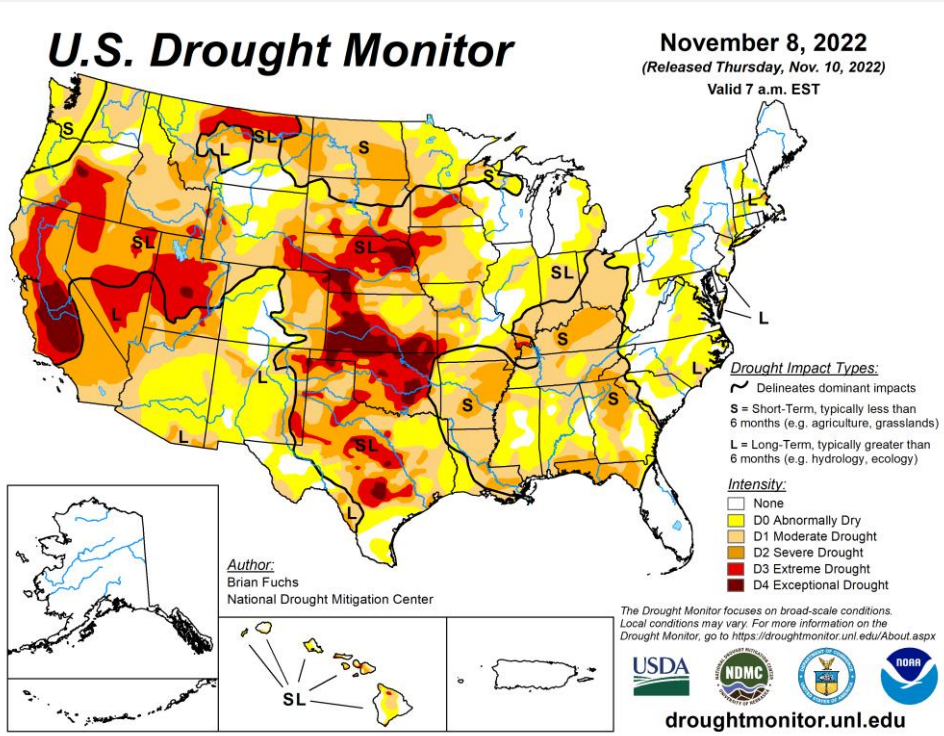


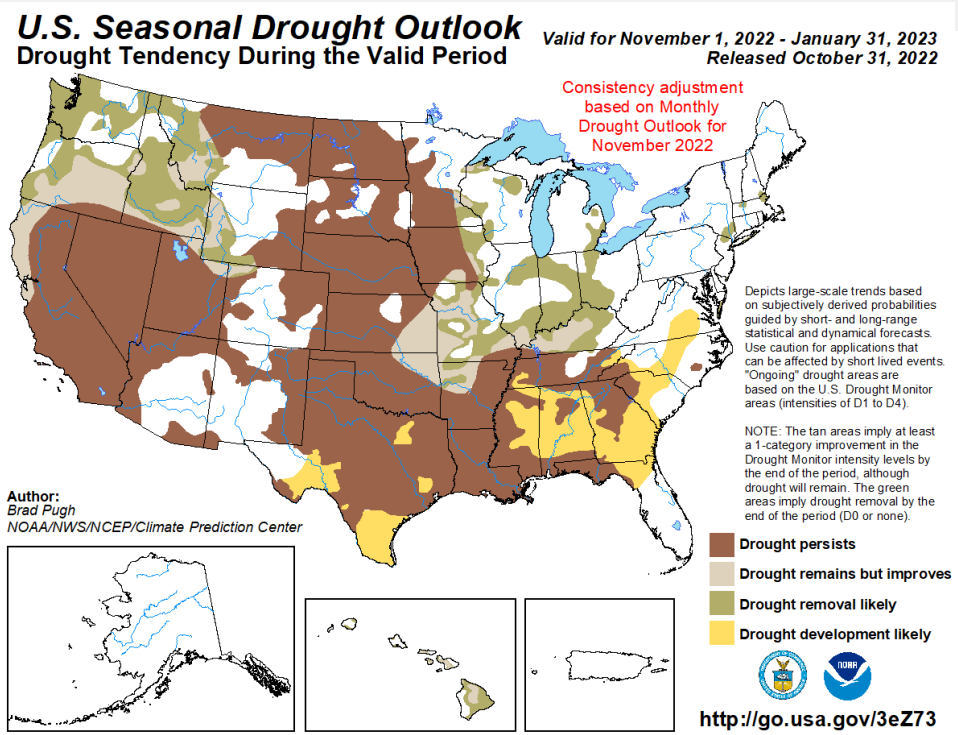
https://www.clima

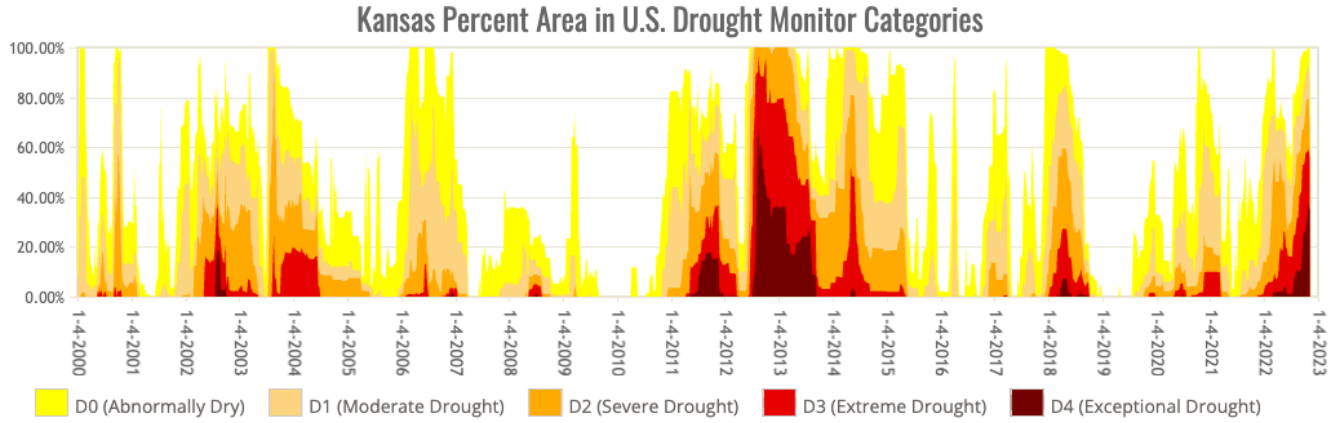
Coordination

NCEI

A brief look ahead….. and back



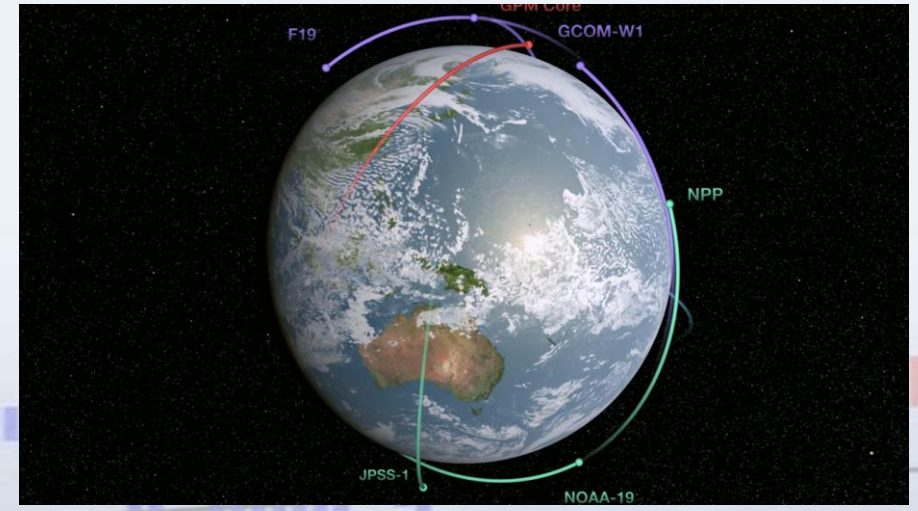












Thank you!

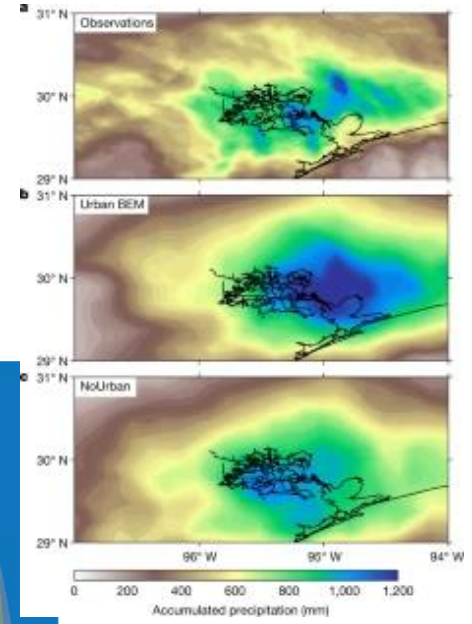
roger.pulwarty@noaa.gov

Col. Robert O. Iott

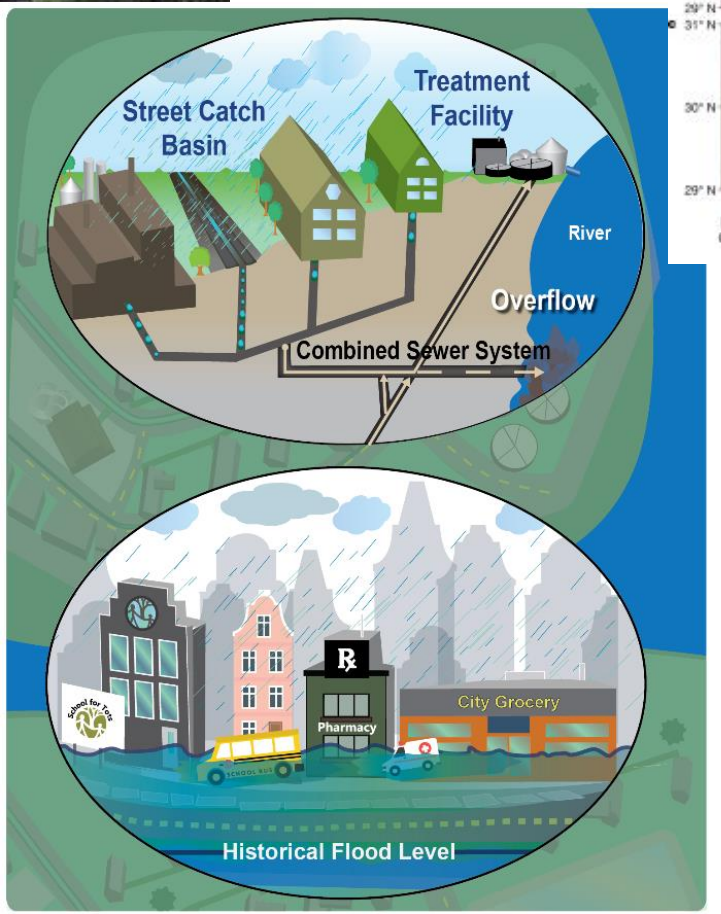
Built Environment, Urban Systems, and Cities

Cascading Consequences of Heavy Rainfall for Urban Systems

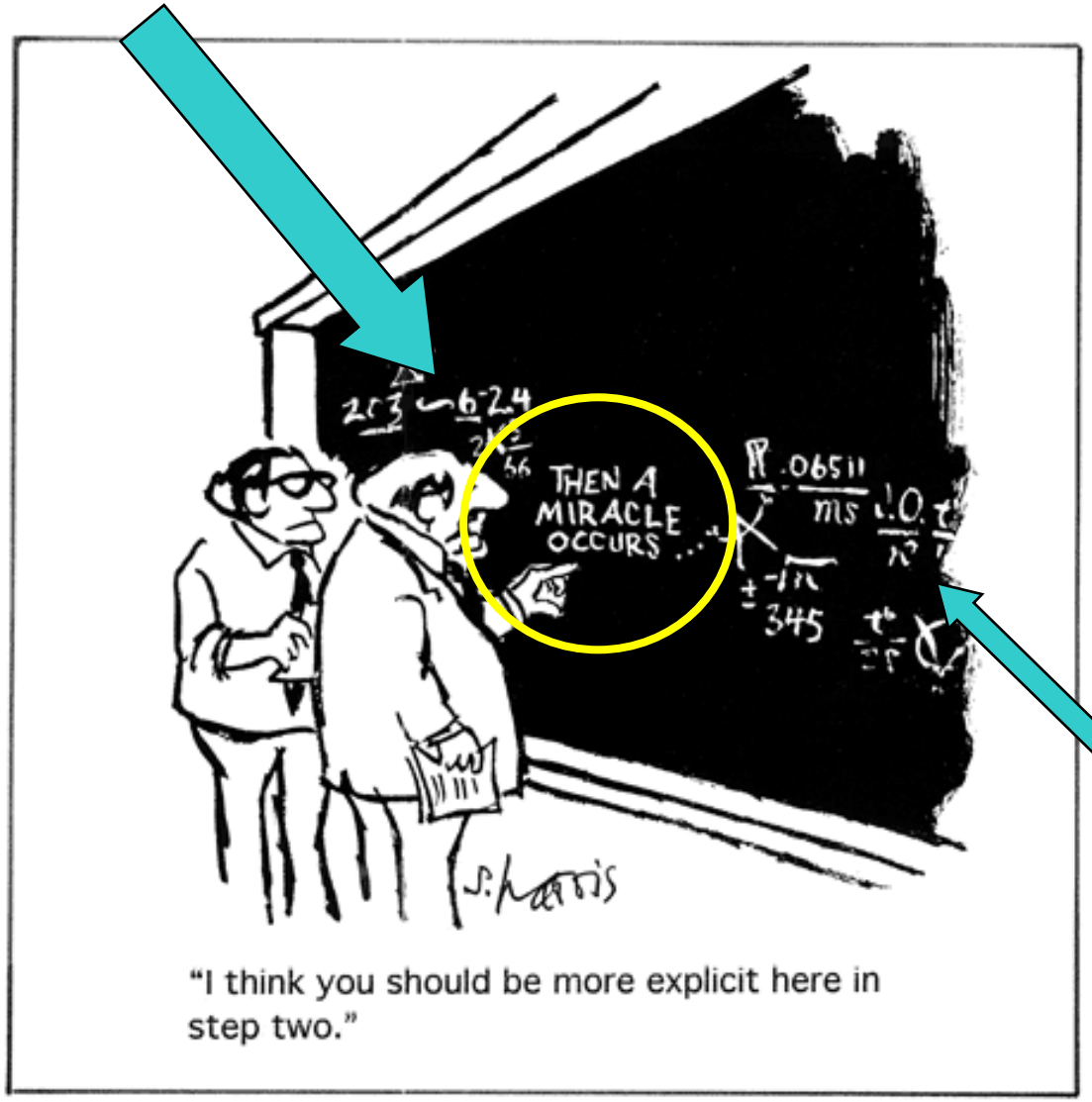
- In cities with combined sewer systems, storm water runoff flows into pipes containing sewage from homes and industrial wastewater.
- Increase risk of exposure to waterborne diseases and toxic chemical plant releases
- Closed roads and disrupted mass transit prevent residents from going to work or school and first responders from reaching those in need. *Source: EPA.*



(Zhang et al 2018)



Climate observations, predictions, projections



Improved Response

"I think you should be more explicit here in step two"