Index to State of America's Water Infrastructure Rethinking Water 2022.

- The Resource
  - Climate
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  - Dams
  - Conveyance – Pipes and Sewer Systems
  - Water and Wastewater Treatment systems
- Affordability, Financing/Investment

COLUMBIA CLIMATE SCHOOL
COLUMBIA WATER CENTER

Columbia World Projects

COLUMBIA | ENGINEERING
Earth and Environmental Engineering

sciensWATER
Making sense of water

Climate

- Drought
- Extreme Precipitation
- Streamflow
- Floods
- Sea Level Rise

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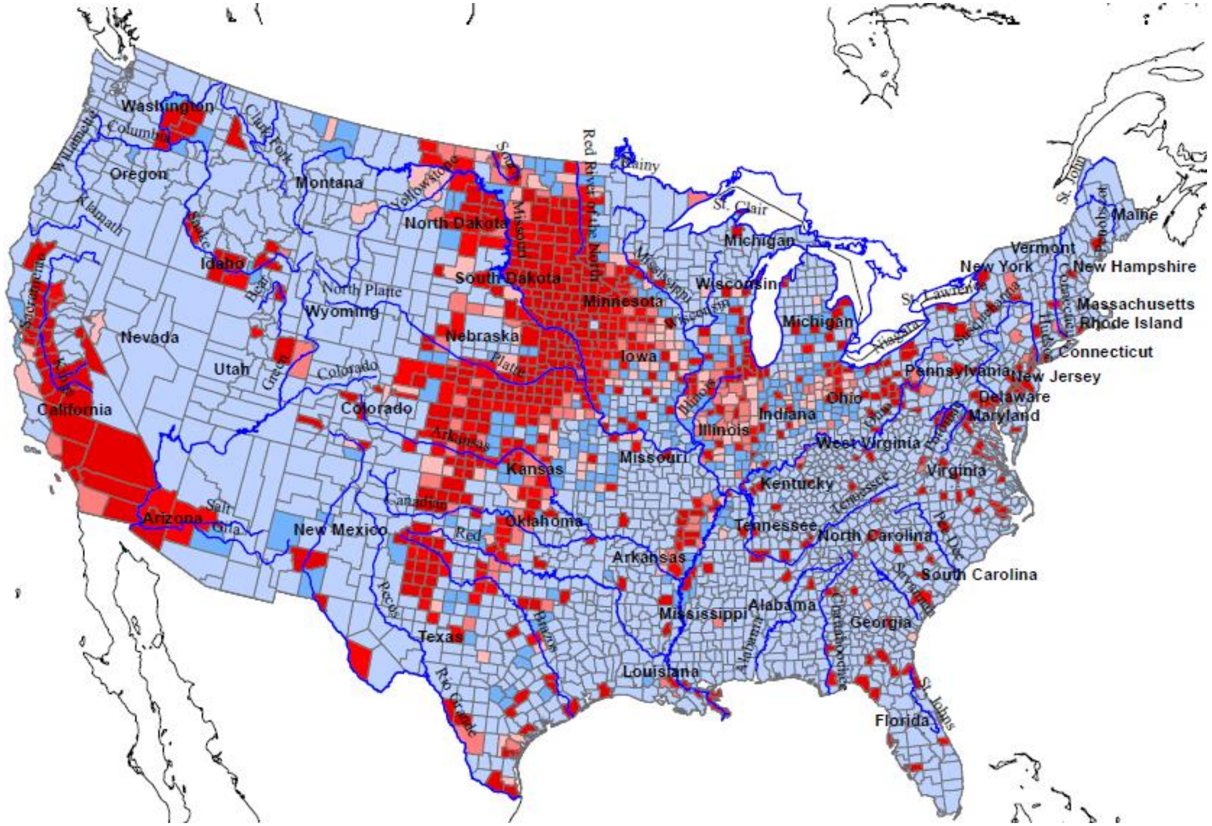
Drought Sensitive Water Stress Index

Increasing Water Stress is a challenge for cities, energy, industries and agriculture across the country



The Columbia Water Stress Index

Low

Moderate

High

Our index accounts for climate variability

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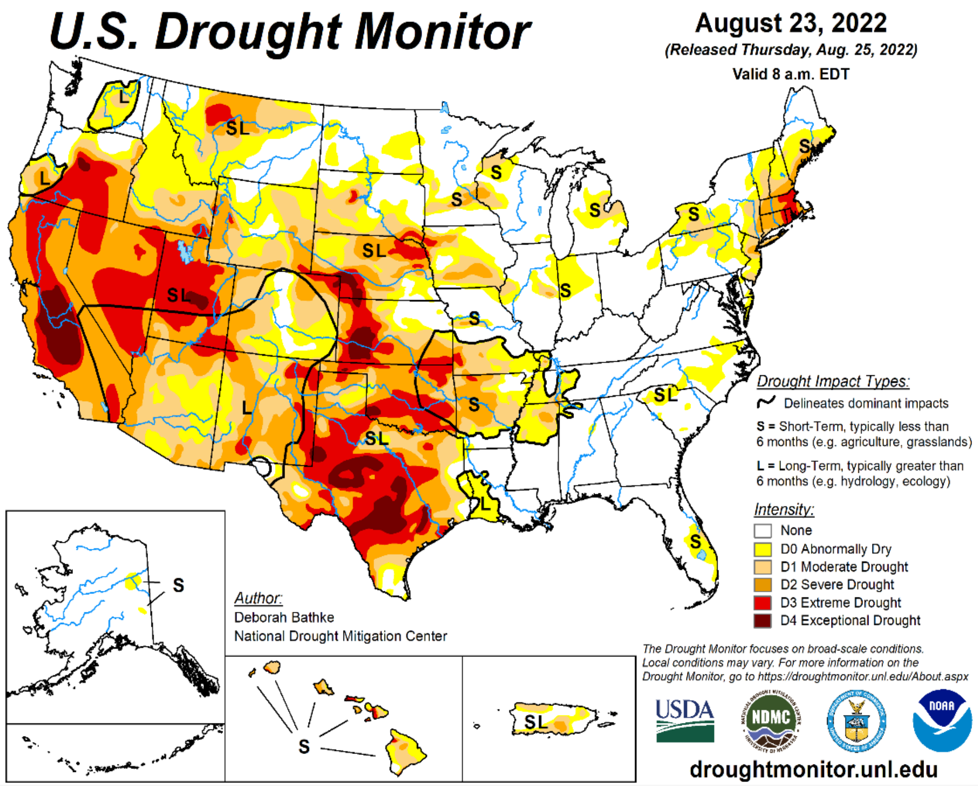
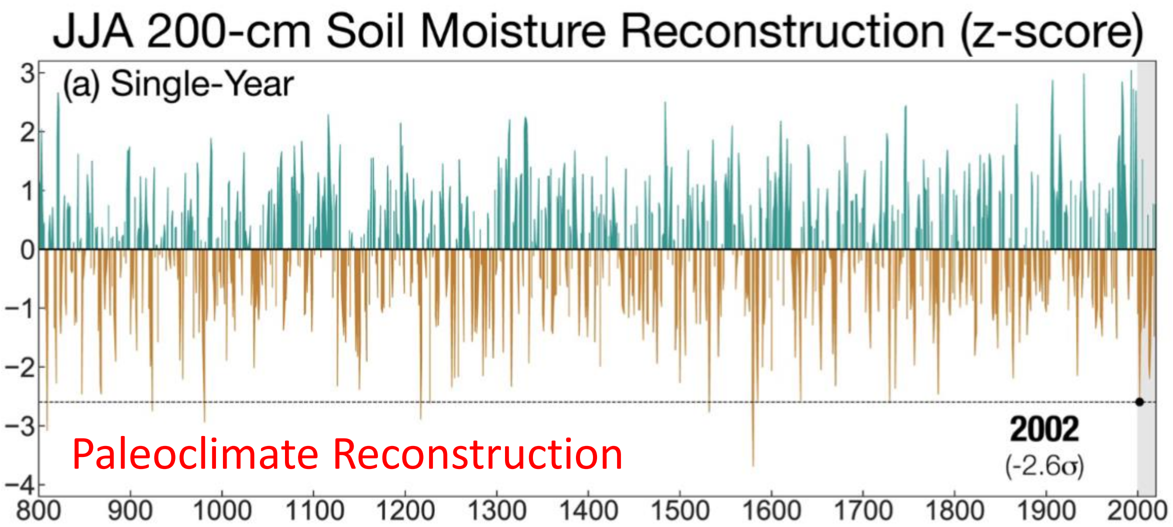
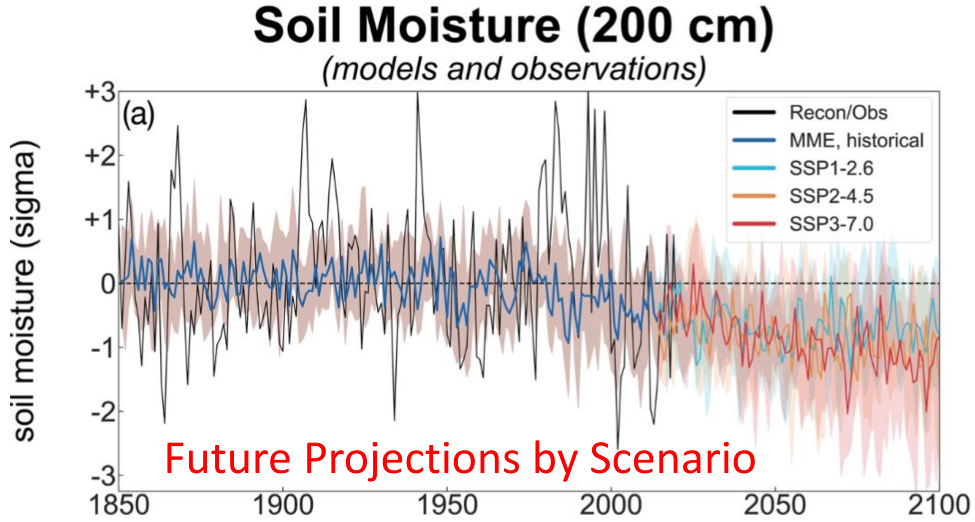
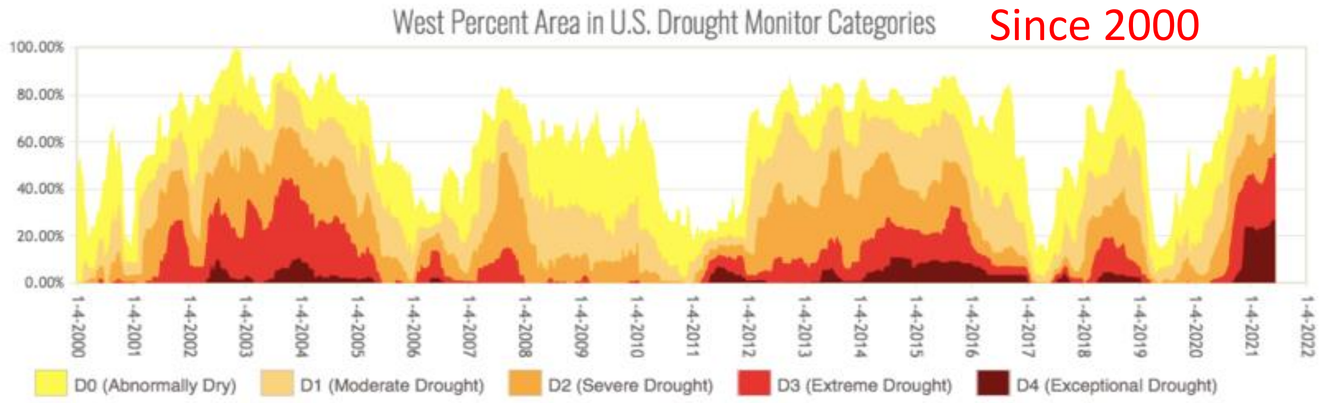
Drought









https://droughtmonitor.unl.edu/

Steep increase projected in Southwestern US Drought as indicated in soil moisture in future climate change scenarios

Cook, B. I., Mankin, J. S., Williams, A. P., Marvel, K. D., Smerdon, J. E., & Liu, H. (2021). Uncertainties, limits, and benefits of climate change mitigation for soil moisture drought in southwestern North America. *Earth's Future*, *9*(9), e2021EF002014.

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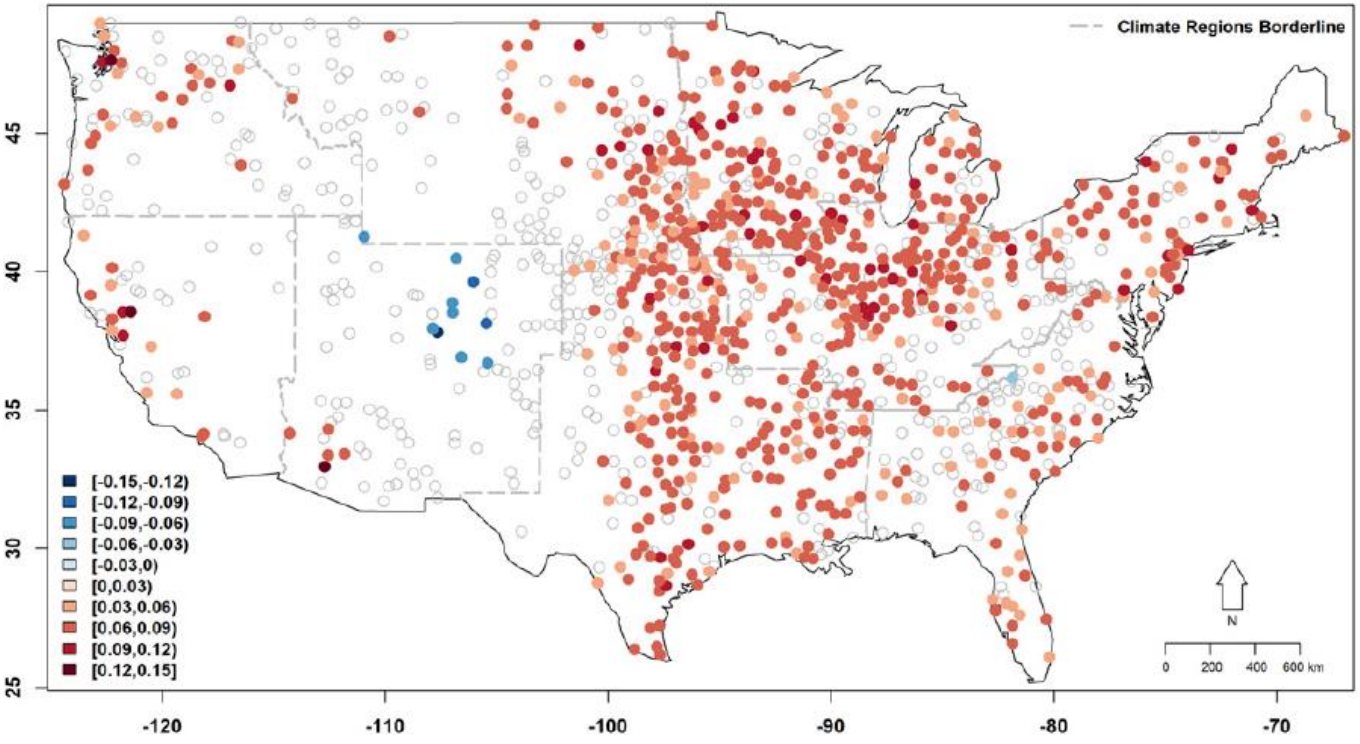
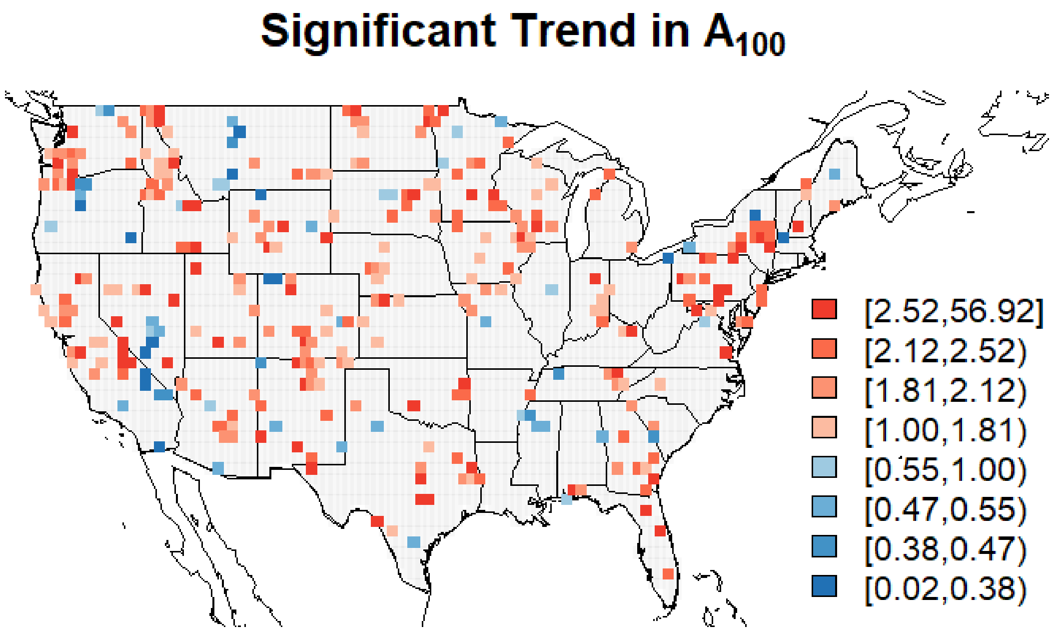
Extreme Precipitation





Trends (red increasing, blue decreasing) in "Once in a 100 year" daily rainfall over the last 43 years

Hwang, J. and U. Lall, (2022) Bivariate Trends in Extreme Daily and Antecedent Precipitation across the USA, Columbia Water Center Working Paper

Trends (red increasing, blue decreasing) in daily rainfall > 95th percentile of rain on rainy days

Statistically significant trends in both maps are in red and blue

Armal, S., Devineni, N., & Khanbilvardi, R. (2018). Trends in extreme rainfall frequency in the contiguous United States: Attribution to climate change and climate variability modes. *Journal of Climate*, *31*(1), 369-385.

See also https://nca2014.globalchange.gov/report/our-changing-climate/heavy-downpours-increasing

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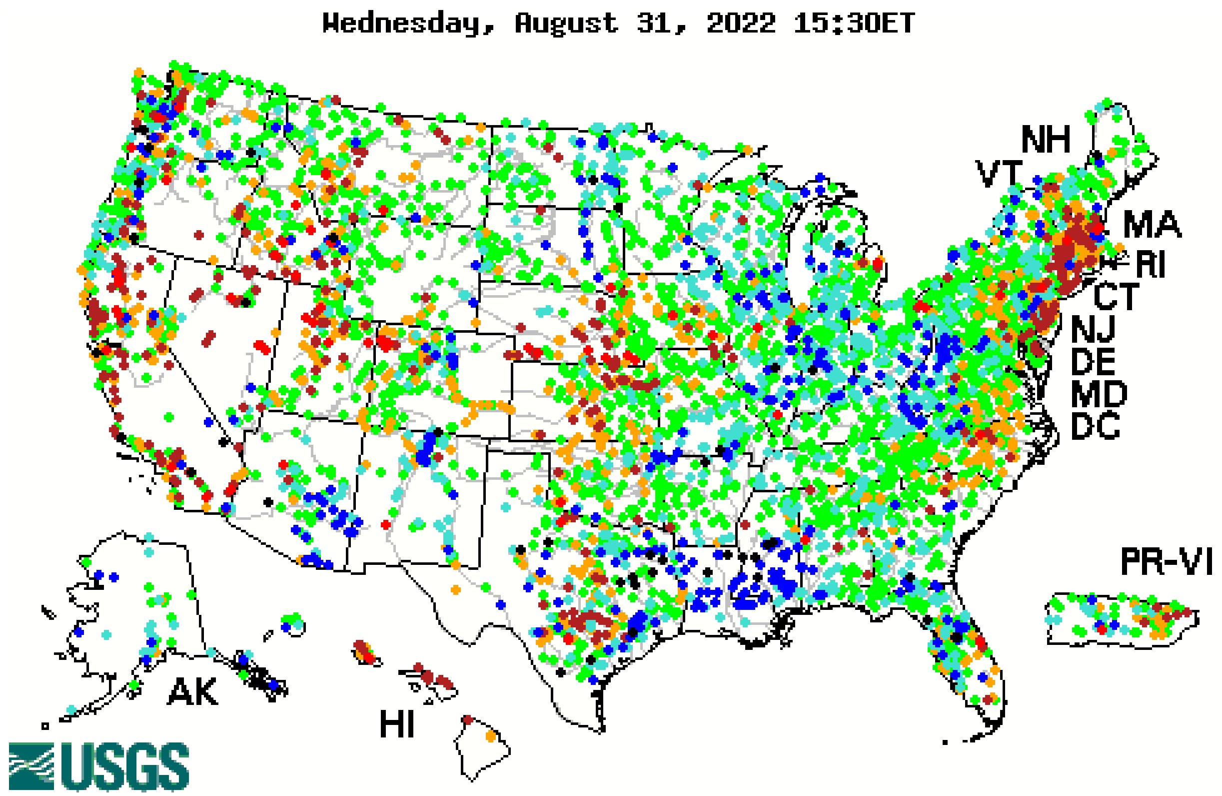
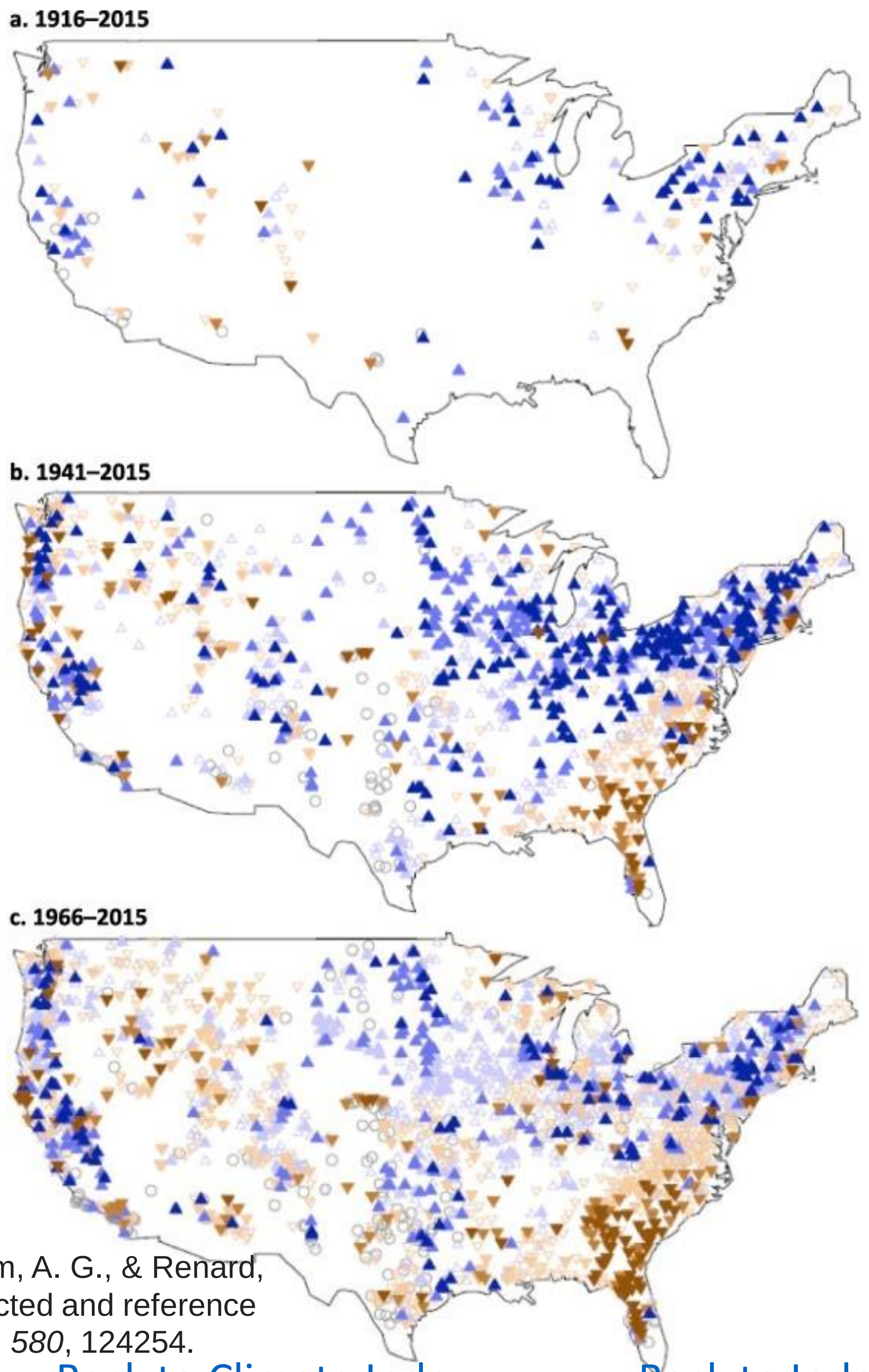
Streamflow



Daily streamflow status https://waterdata.usgs.gov/nwis/rt

USGS | National Water Dashboard

Trends in annual 7-day low streamflow based on different periods of record



Dudley, R. W., Hirsch, R. M., Archfield, S. A., Blum, A. G., & Renard, B. (2020). Low streamflow trends at human-impacted and reference basins in the United States. *Journal of Hydrology*, *580*, 124254.

Low Flow trends are regional – due to climate and regulation of flows

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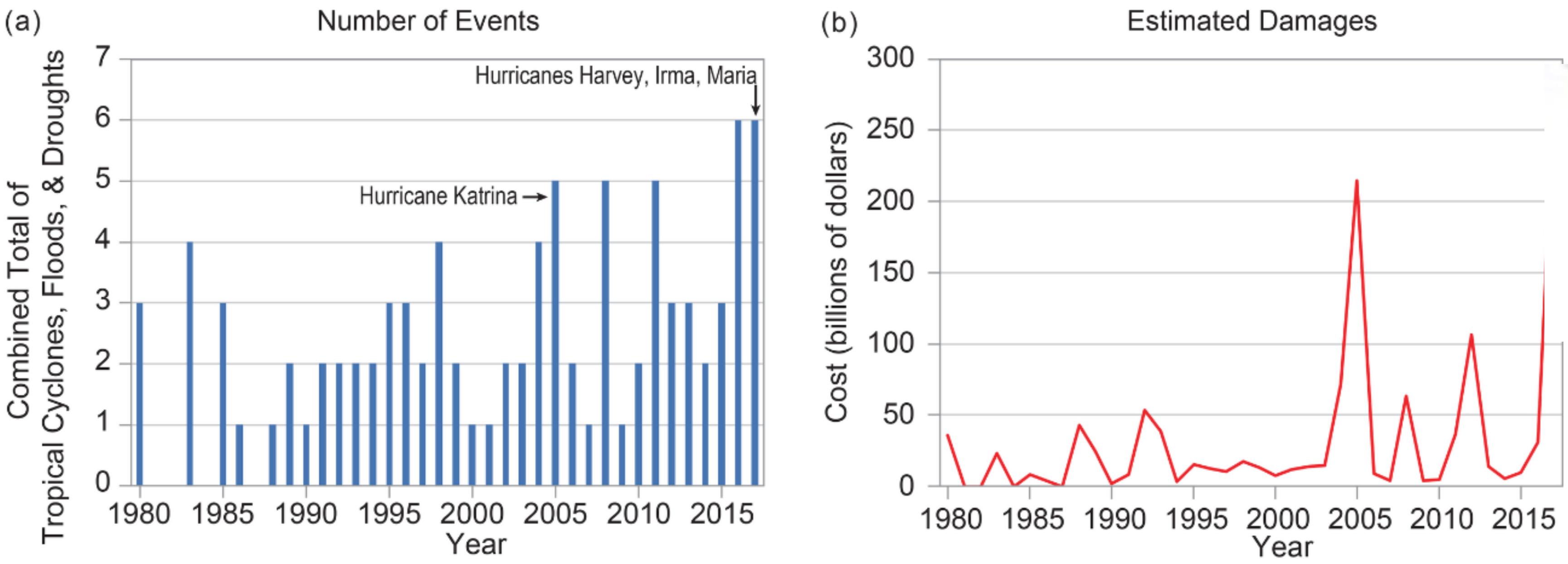
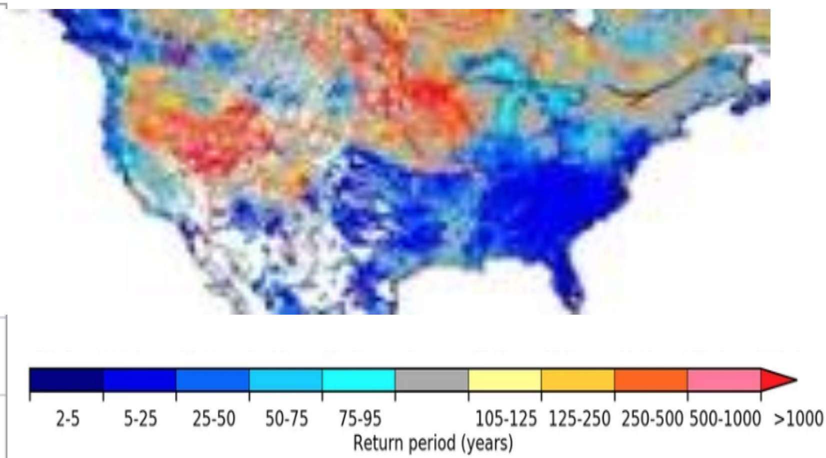
Floods



Number of water-related billion-dollar disaster events each year in the United States and the associated costs (in 2017 dollars, adjusted for inflation)

NOAA NCEI, 2018: Billion-Dollar Weather and Climate Disasters [web page]. NOAA National Centers for Environmental Information, Asheville, NC.

https://nca2018.globalchange.gov/chapter/3/



Projected change in flood frequency. Median return period (years) in future (2071–2100) for discharge corresponding to a 100-year flood in the past (1971–2000), using CMIP6 models with (SSP5-RCP8.5) scenarios

Hirabayashi, Y., Tanoue, M., Sasaki, O., Zhou, X., & Yamazaki, D. (2021). Global exposure to flooding from the new CMIP6 climate model projections. *Scientific reports*, *11*(1), 1-7.

Increasing flood losses amplify concerns with projected flood risk changes (past 100 year event becomes much more frequent over much of USA

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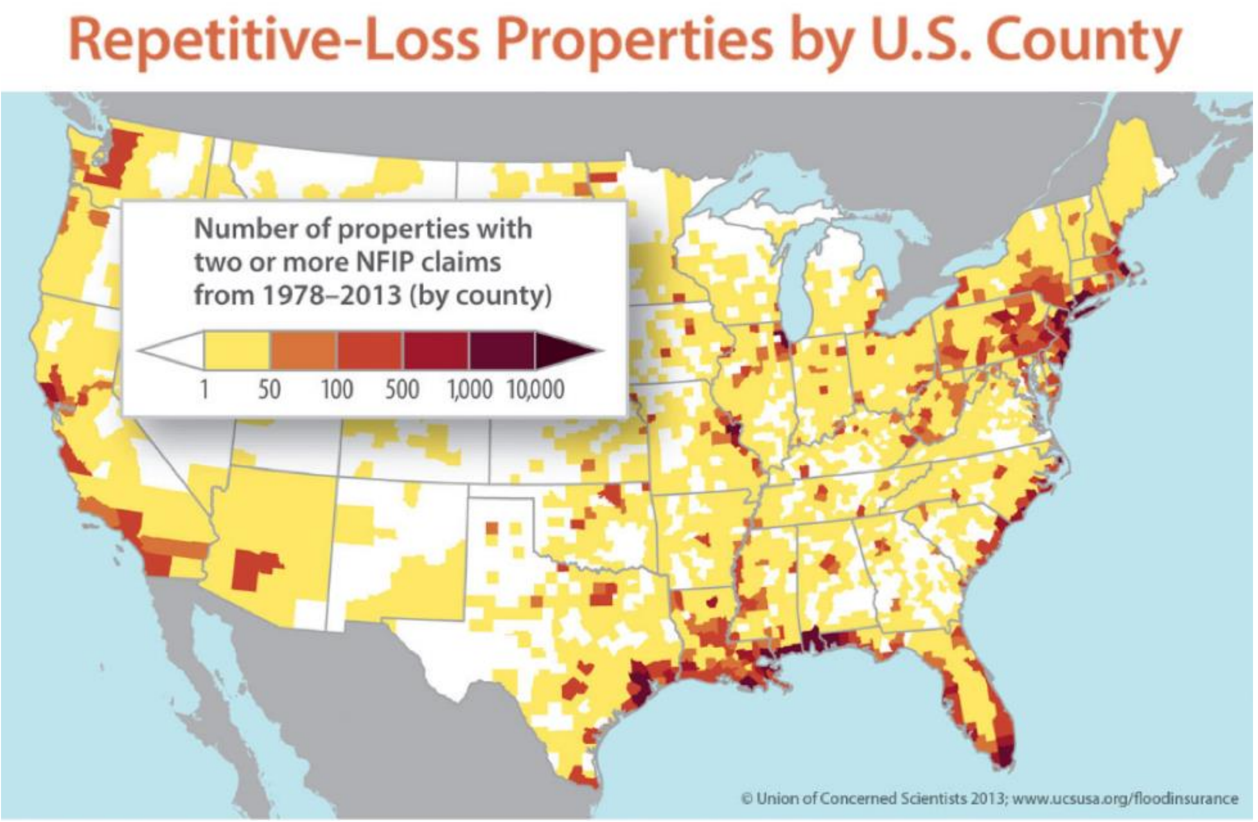
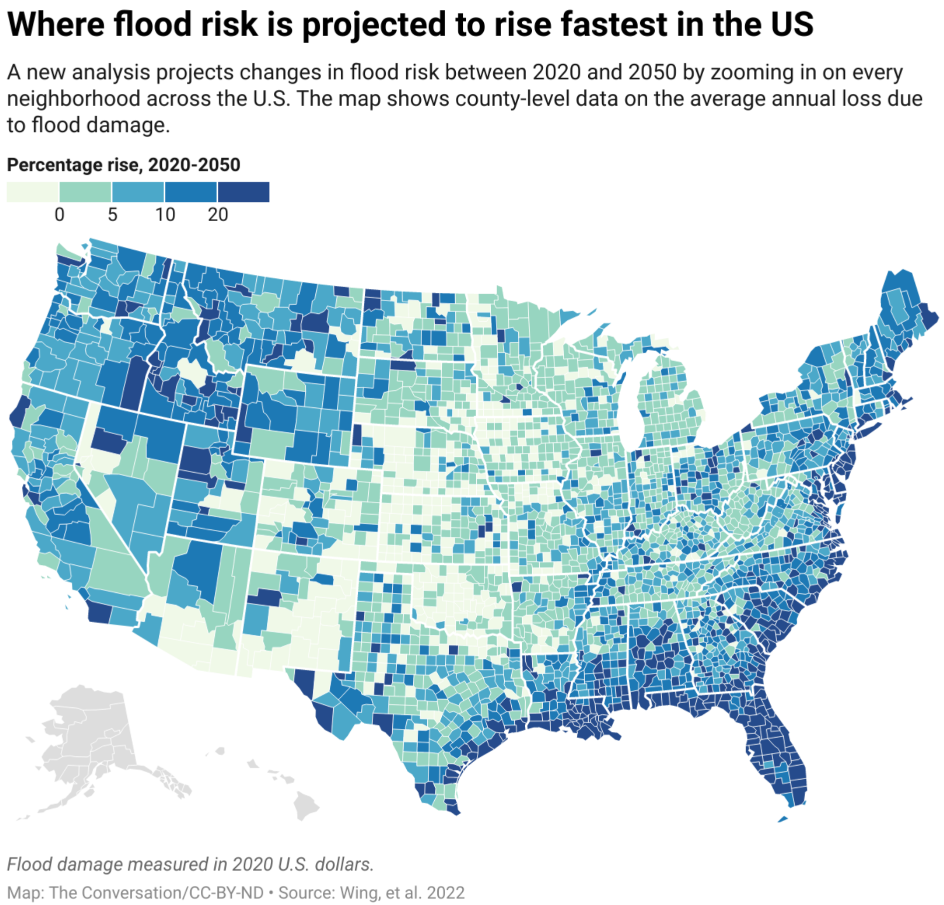
Floods 2





[Inequitable patterns of US flood risk in the Anthropocene]

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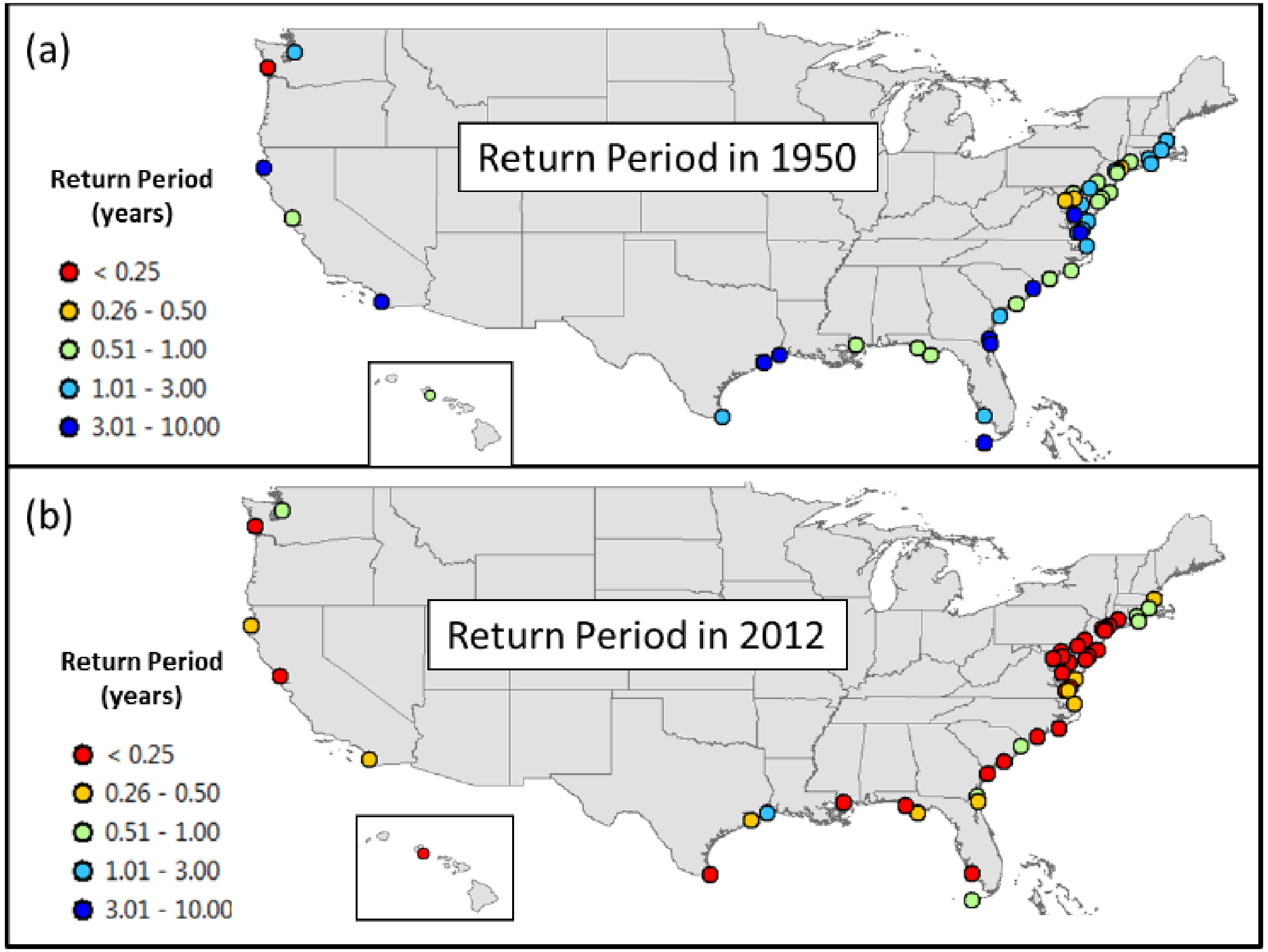
Sea Level Rise

Return Periods of nuisance coastal flooding, affecting transportation, houses, wastewater and water treatment and electricity distribution systems.

Coastal areas have major cities and smaller underserved populations. Sea Level rise threatens their infrastructure and existence.

Nuisance flooding is one measure of potential impacts to date



Sweet, W., Park, J., Marra, J., Zervas, C., & Gill, S. (2014). Sea level rise and nuisance flood frequency changes around the United States. NOAA technical report NOS CO-OPS ; 073;

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Sea Level Rise -2

State-Level Impacts of Sea Level Rise (SLR) by 2100

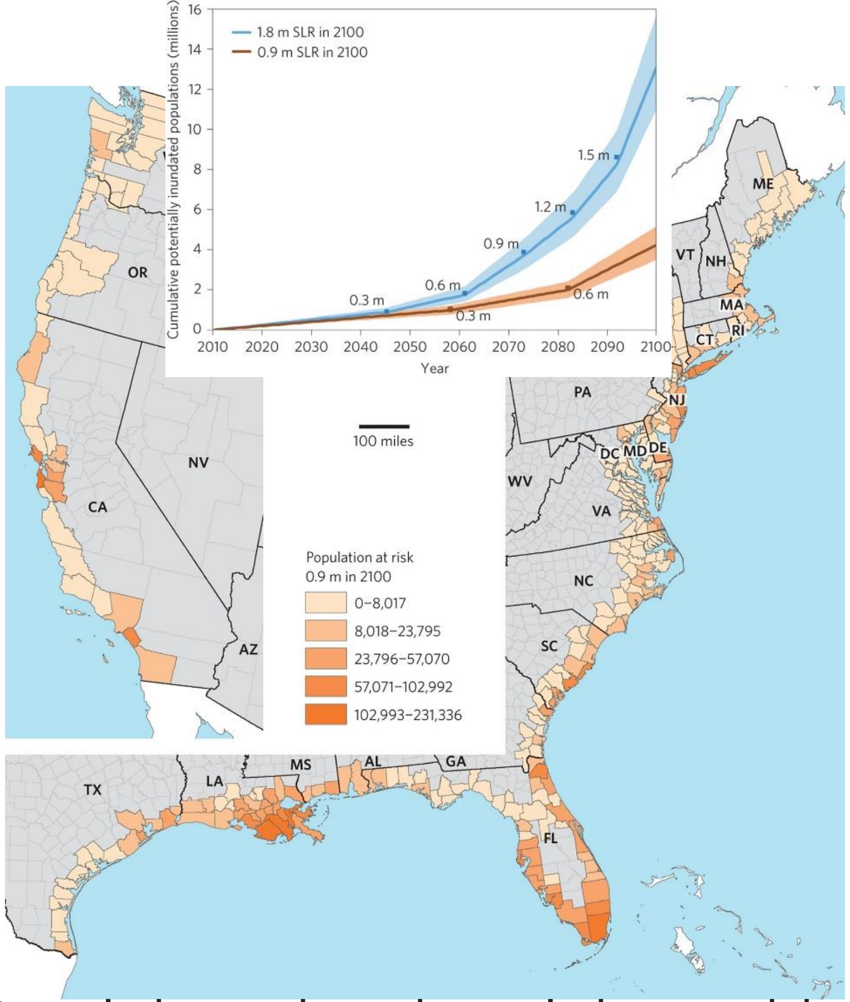
	wastewater treatment plants exposed to SLR-induced flooding						residents served by wastewater treatment plants exposed to SLR-induced flooding (thousands)					
	1ft	2ft	3ft	4ft	5ft	6ft	1ft	2ft	3ft	4ft	5ft	6ft
Maine	5	5	6	10	13		8	8	29	50	65	
New Hampshire	2	2	3	3	3		28	28	41	41	41	
Massachusetts			4	7	7				1,757	1,960	1,960	
Rhode Island			1	1	2				8	8	14	
Connecticut	4	7	9	11	14		137	236	288	384	585	
New York		10	14	22	37			1,217	1,791	1,954	5,581	
New Jersey		16	19	28	36			1,004	1,046	3,347	4,246	
Delaware		1	3	3	5				2	2	13	
Pennsylvania												
Maryland		8	9	16	20			23	174	197	1,833	
Washington, D.C.												
Virginia		2	3	4	5			540	789	1,107	1,108	
North Carolina		3	6	9	12			20	32	44	175	
South Carolina	1	3	4	6			128	337	462	466		
Georgia	1	3	4	8				145	145	195		
Florida	2	6	14	28			1	304	421	1,460		
Alabama												
Mississippi		1	2	2	4	4		28	46	46	69	69
Louisiana			16	21	34	38			50	103	196	207
Texas			19	24	30	34			506	528	593	1,483
California	8	13	15	23			1,037	2,620	2,642	3,871		
Oregon	2	2	4	7			4	4	14	41		
Washington	4	4	7				174	174	198			

National Summary

Low Emissions Scenario (RCP4.5)
105 wastewater treatment plants exposed
4.9 million people affected

High Emissions Scenario (RCP8.5)
272 wastewater treatment plants exposed
21.5 million people affected

Data Source: Hummel, Berry, and Stacey 2018, USGCRP 2018



Cumulative projected populations at risk of SLR under the 0.9 m scenario by 2100 for US

Hummel, M. A., Berry, M. S., & Stacey, M. T. (2018). Sea level rise impacts on wastewater treatment systems along the US coasts. *Earth's Future*, *6*(4), 622-633.

Hauer, M. E., Evans, J. M., & Mishra, D. R. (2016). Millions projected to be at risk from sea-level rise in the continental United States. *Nature Climate Change*, *6*(7), 691-695.

Sea Level Rise projections suggest increasing future impacts

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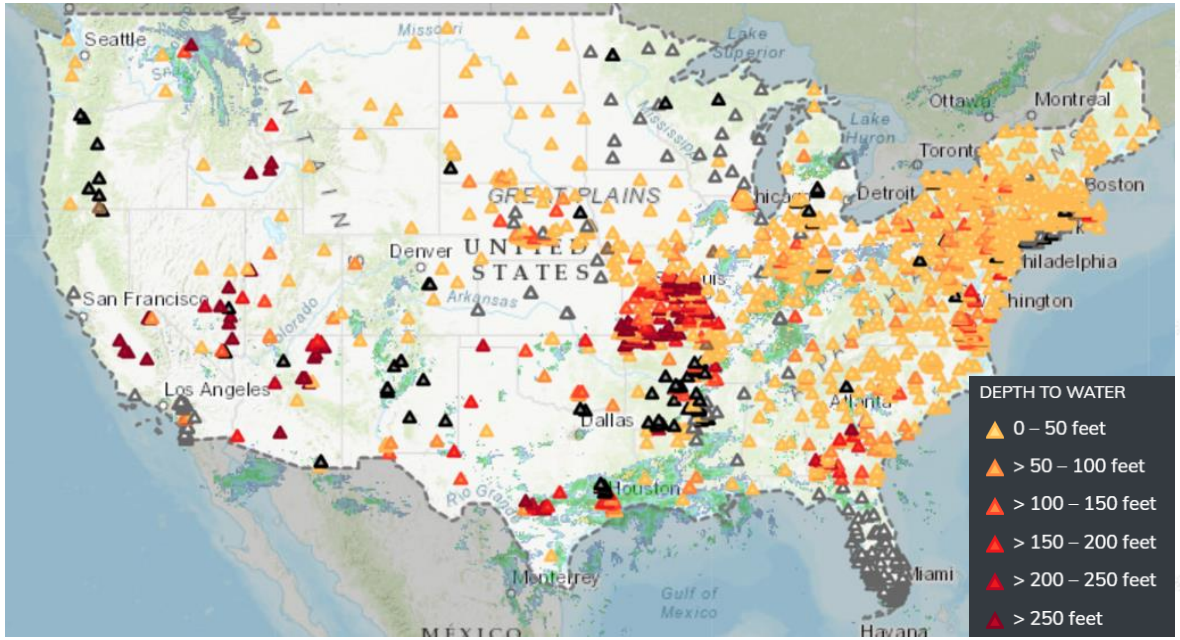
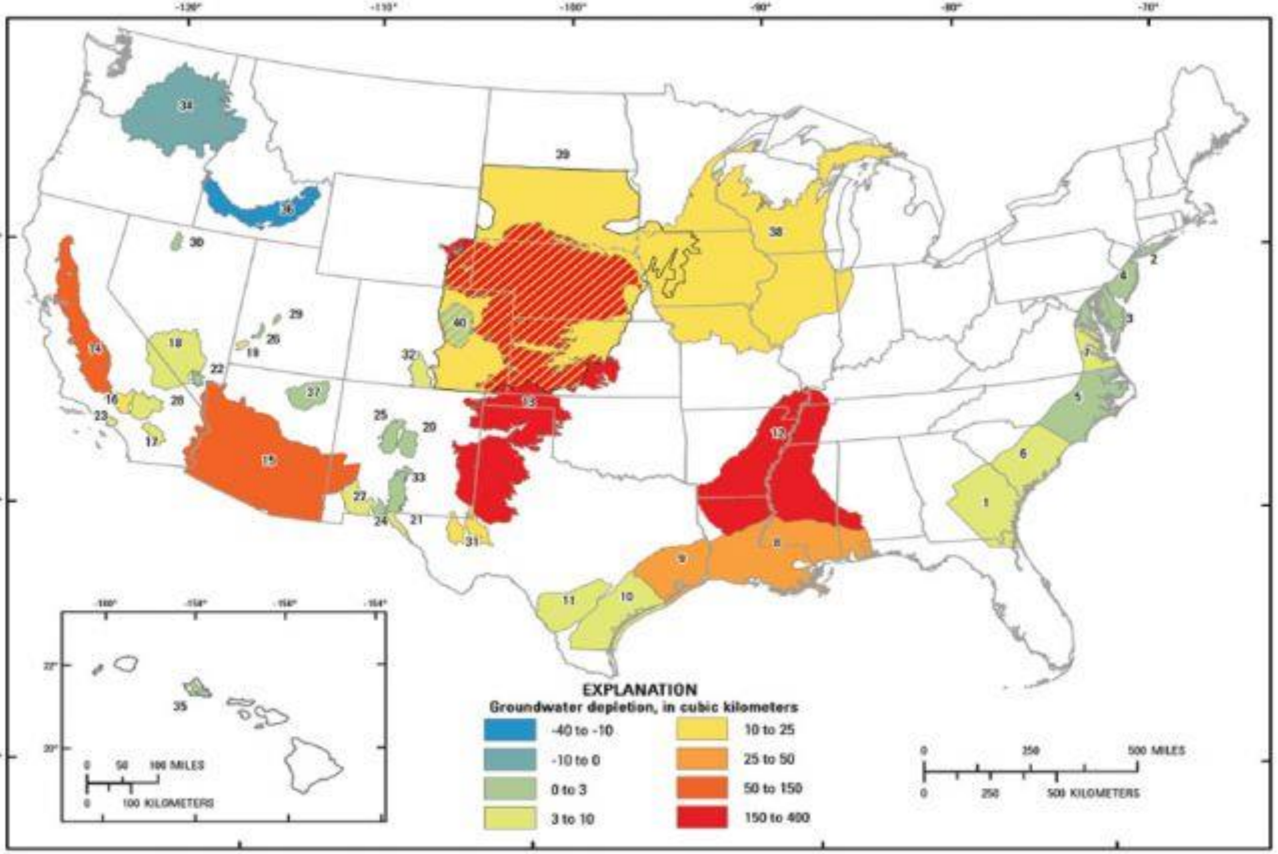
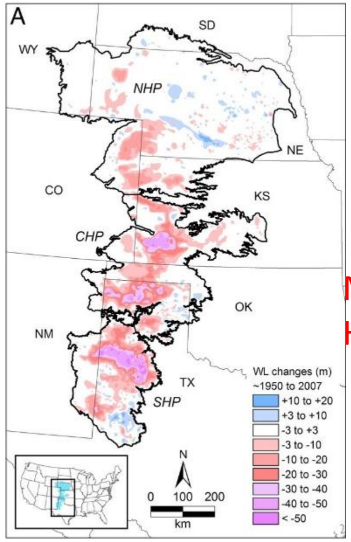
Groundwater





[USGS | National Water Dashboard](#)

[Gw-conditions animation (usgs.gov)](#)



[US Groundwater Depletion](#)1900-2008-USGS

Measured groundwater level changes from ~1950 to 2007 in the High Plains aquifer – note the high spatial variability within aquifer

Scanlon, B. R., Faunt, C. C., Longuevergne, L., Reedy, R. C., Alley, W. M., McGuire, V. L., & McMahon, P. B. (2012). Groundwater depletion and sustainability of irrigation in the US High Plains and Central Valley. *Proceedings of the national academy of sciences*, *109*(24), 9320-9325.

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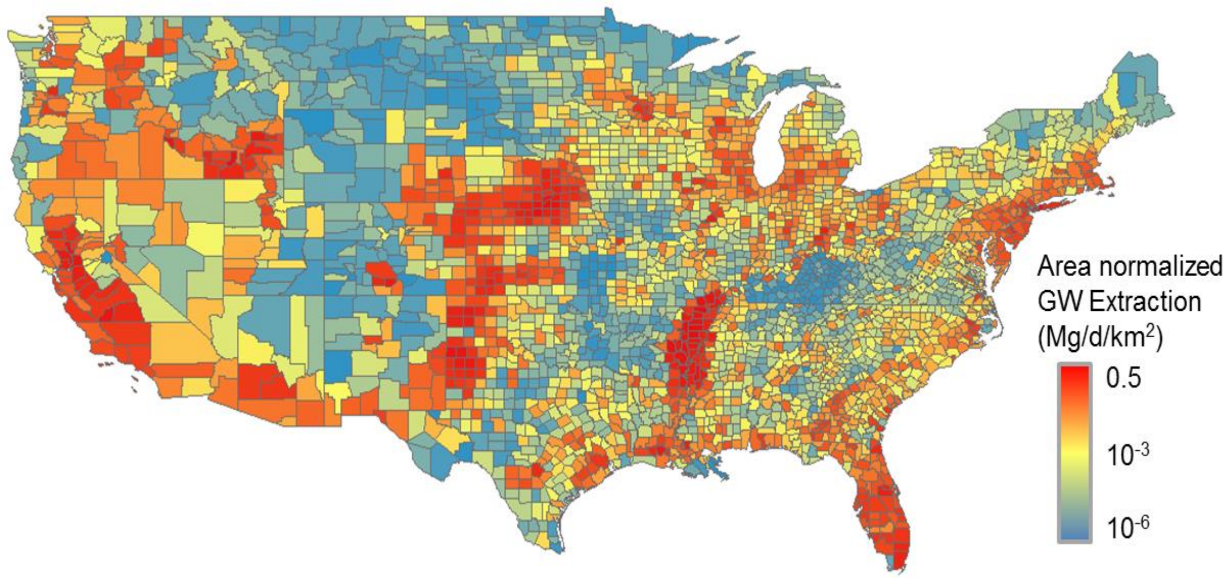
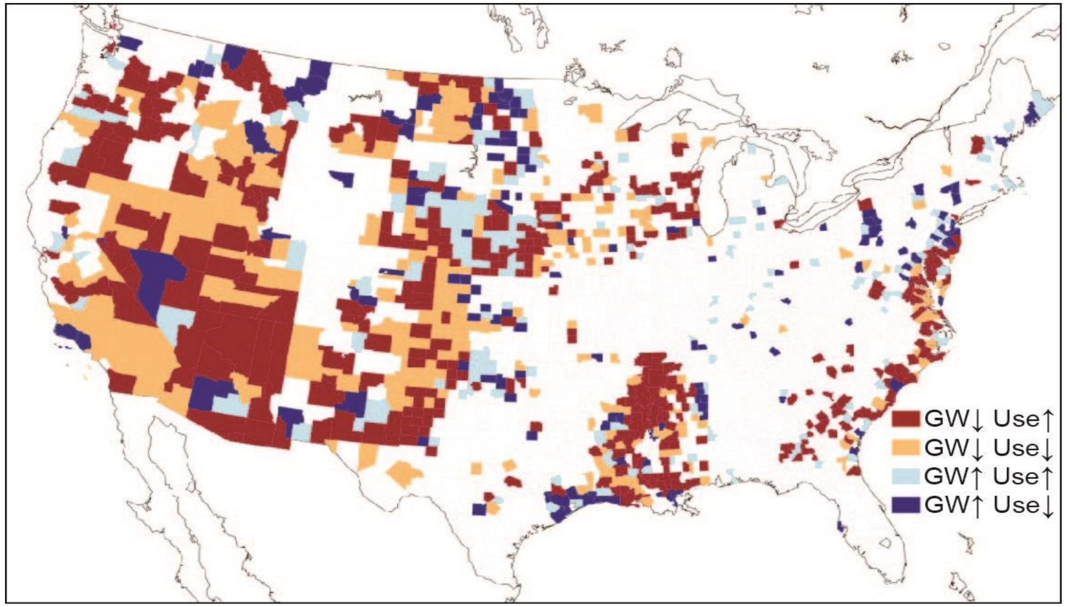
Groundwater

Groundwater Extraction



Depleting Groundwater



Drought accelerates depletion, but growing demands increasingly tap groundwater as surface reservoir construction is expensive and difficult from a regulatory perspective

[Columbia Water Center White Paper:
Assessment of trends in **groundwater** levels across the United States]

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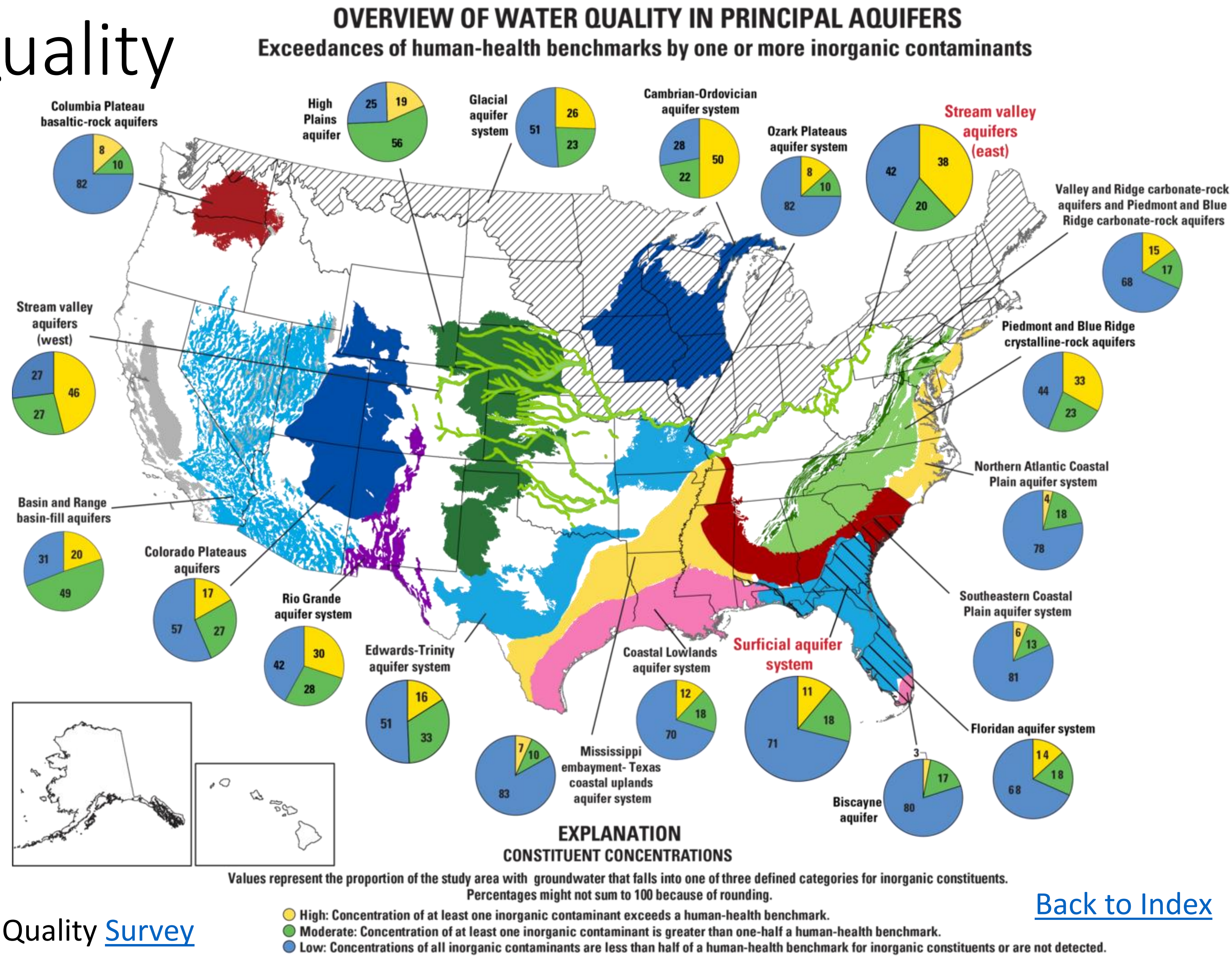
Groundwater Quality

Inorganic contaminants are prevalent in many of the nation's aquifers putting individual well owners and community well owner's at risk, it the water is not treated.



[USGS National Groundwater Quality Survey]

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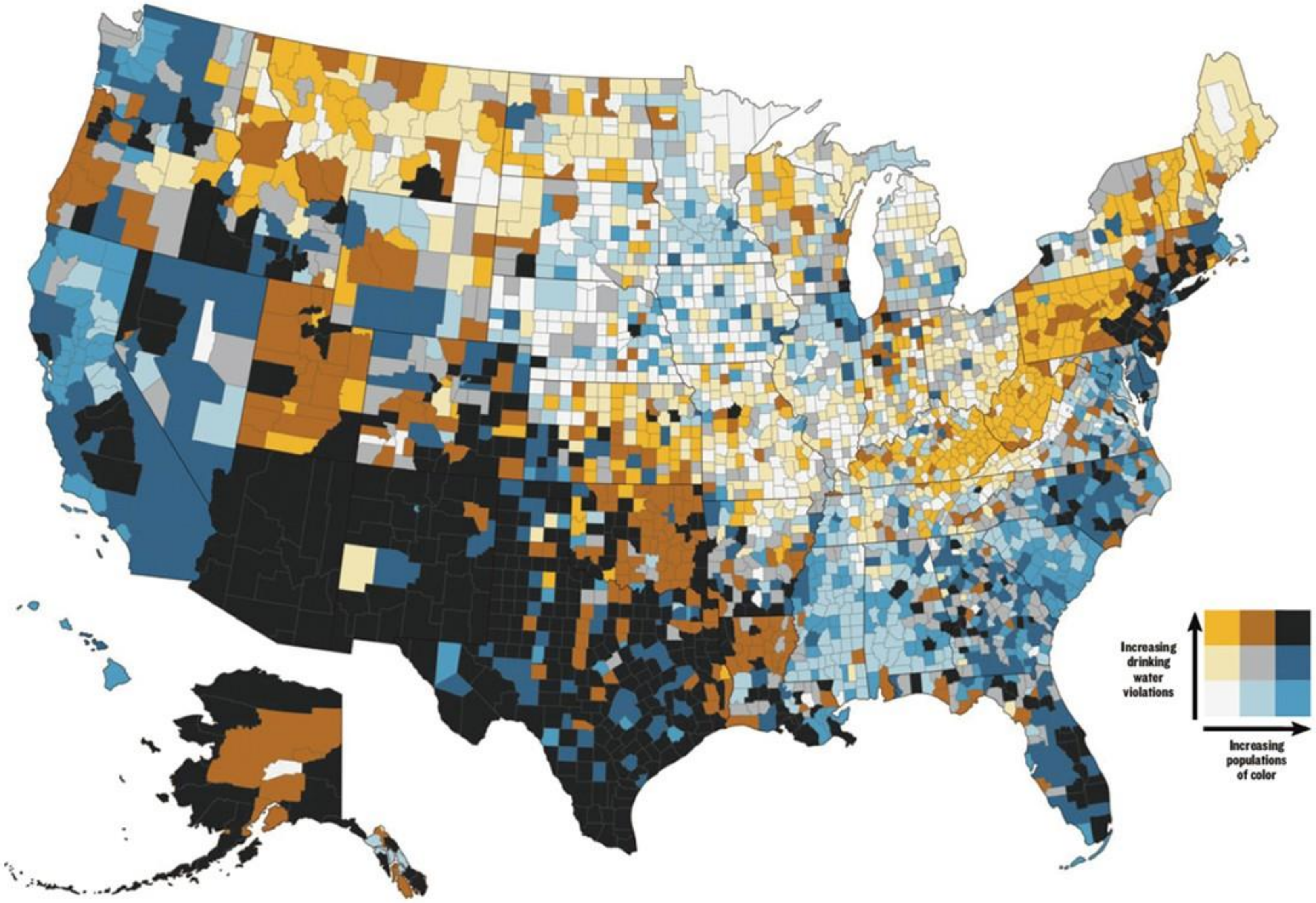
Water Quality

An environmental justice issue?



Health-based violations of the Safe Drinking Water Act and racial, ethnic and language vulnerability vary by county. Darker colors indicate more numerous violations and greater vulnerability.

Violations data are from June 2016 through May 2019, and vulnerability measures are from the 2016 CDC Social Vulnerability Index. (Graphic courtesy of the NRDC via Ensia. First published in the Watered Down Justice Report, Sep. 2019 R 19-09-A.)

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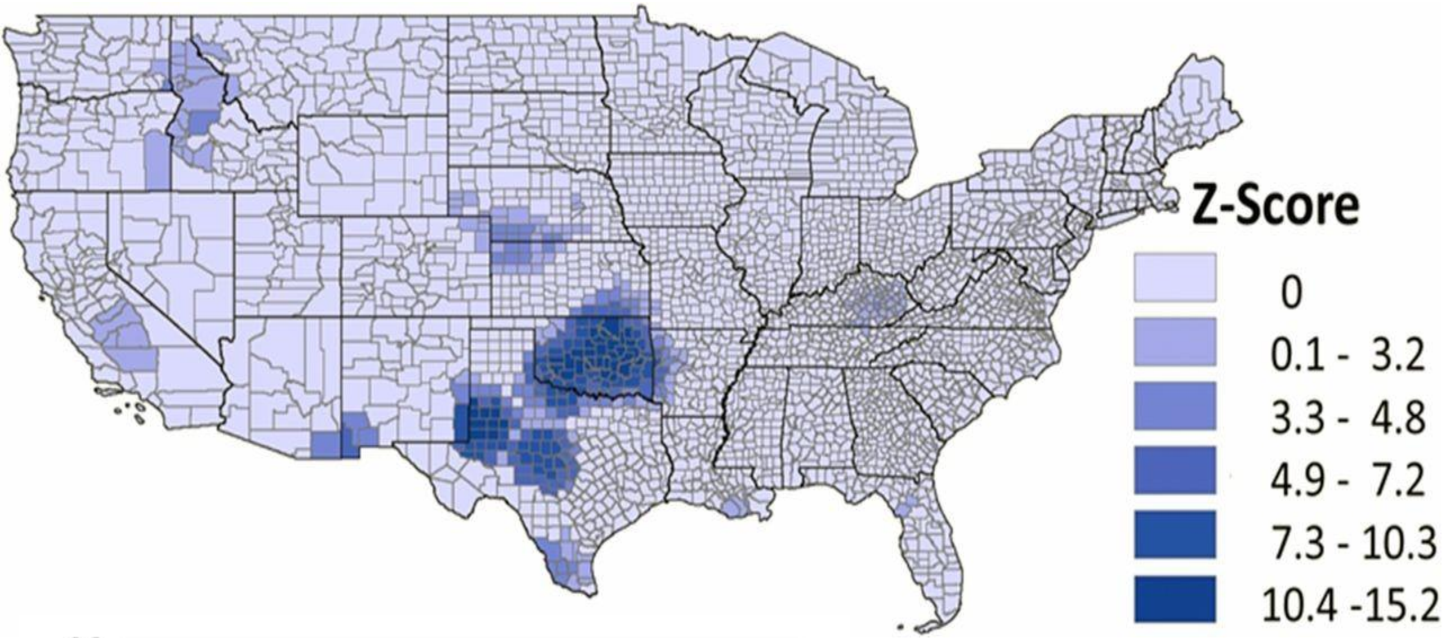
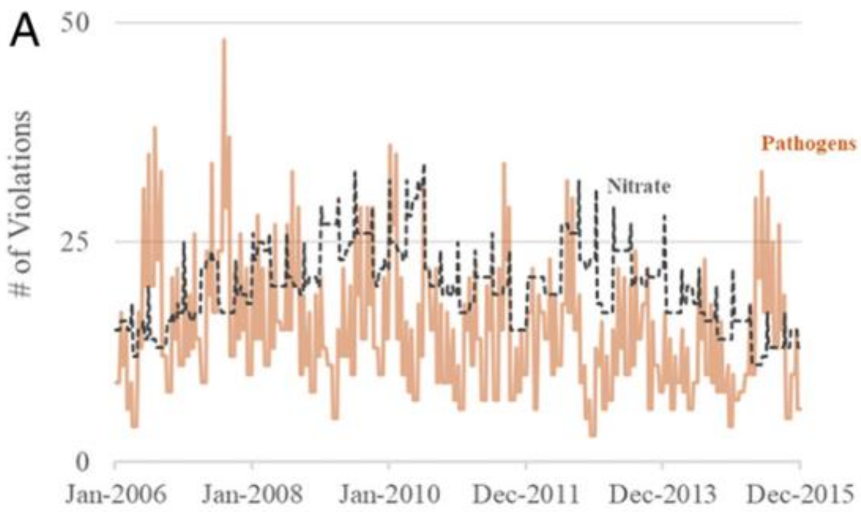
Water Quality 2

EPA Reported Drinking Water Quality Violations from Community Water Systems (CWS)

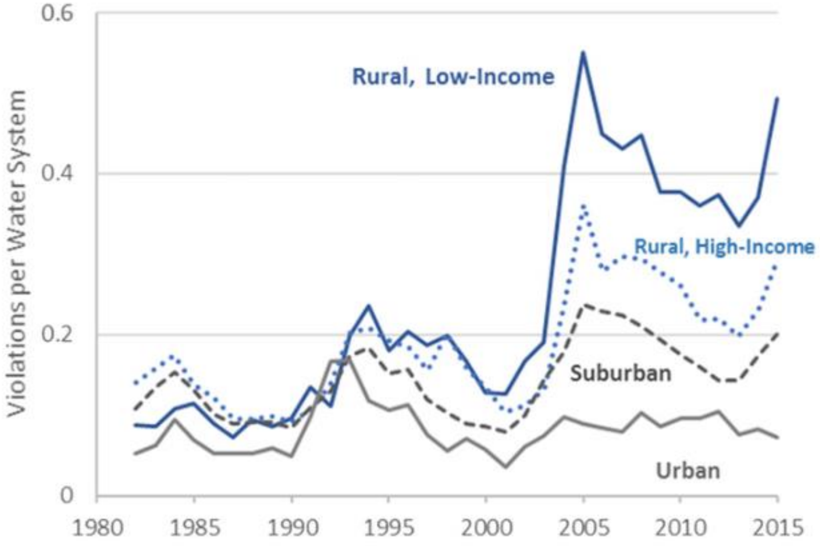
Event Reporting Frequency may not be perfect



Hot spots of health-based violations, 1982–2015 based on total number of violations per CWS



Tier 1 violations of national primary drinking-water regulations for nitrate and for pathogens.



Total violations per water system, by housing density category and income group.

Allaire, M., Mackay, T., Zheng, S., & Lall, U. (2019). Detecting community response to water quality violations using bottled water sales. *Proceedings of the National Academy of Sciences*, *116*(42), 20917-20922.

Allaire, M., Wu, H., & Lall, U. (2018). National trends in drinking water quality violations. *Proceedings of the National Academy of Sciences*, *115*(9), 2078-2083.

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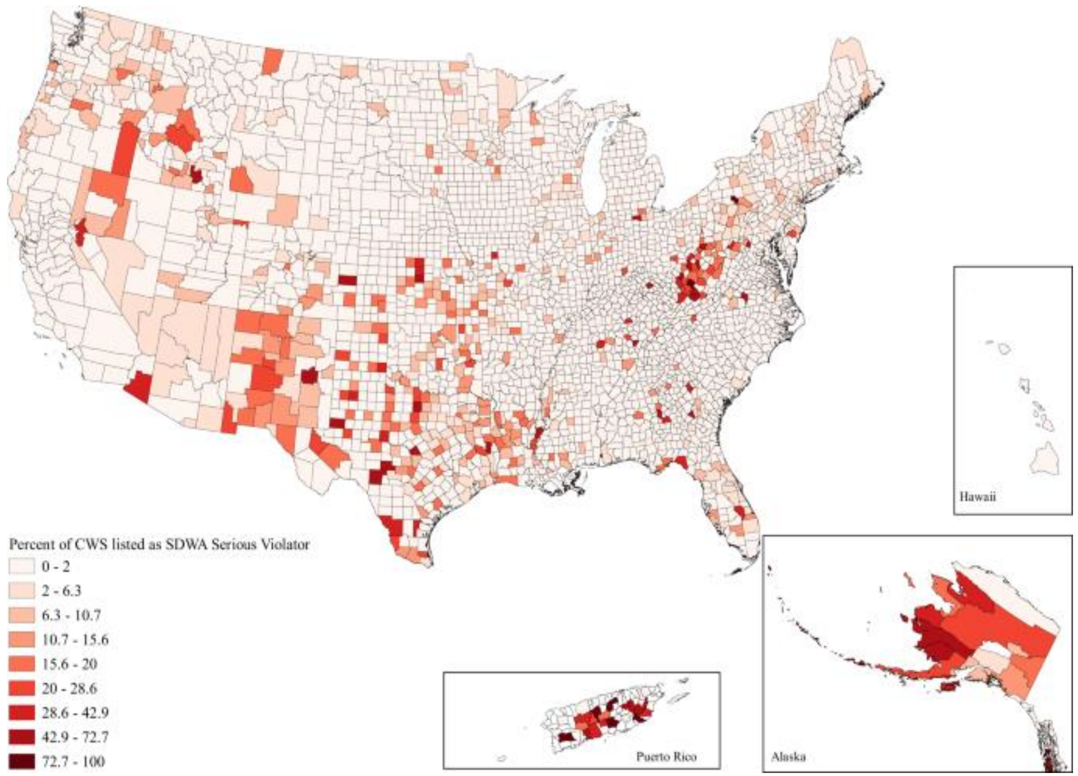
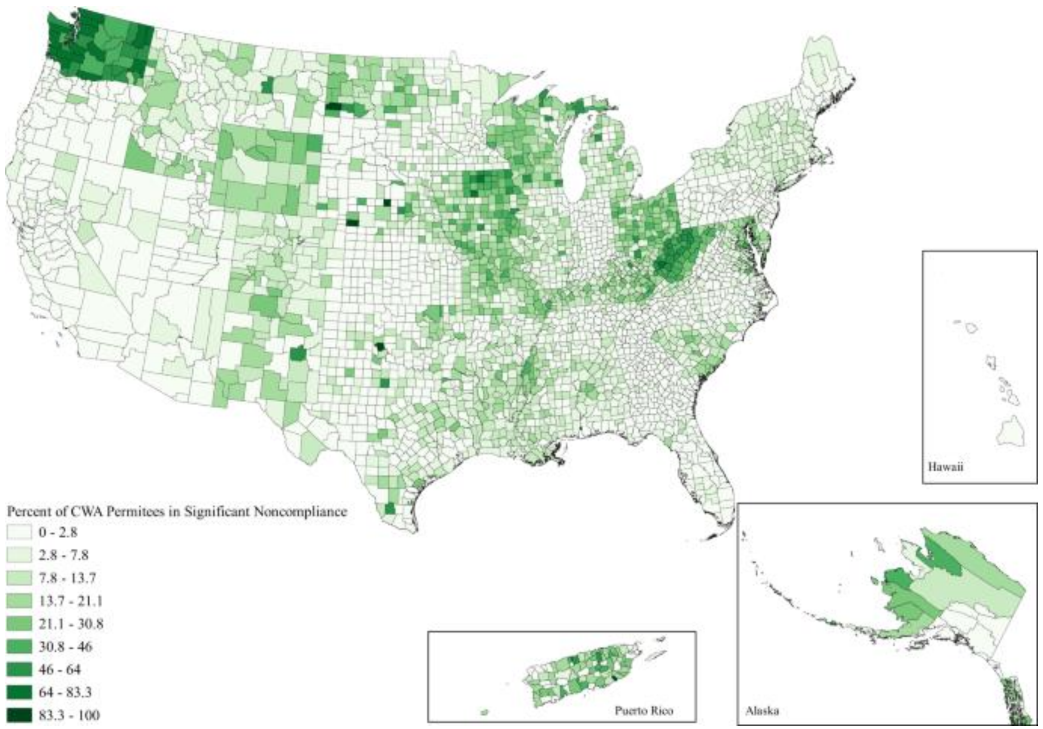
Water Quality 3



Map of the percent of active county community water systems listed as Safe Drinking Water Act (SDWA) Serious Violators.



Map of the percent of county Clean Water Act (CWA) permittees listed as Clean Water Act Significant Noncompliers.

Mueller, J.T., Gasteyer, S. The widespread and unjust drinking water and clean water crisis in the United States. *Nat Commun* **12**, 3544 (2021). https://doi.org/10.1038/s41467-021-23898-z

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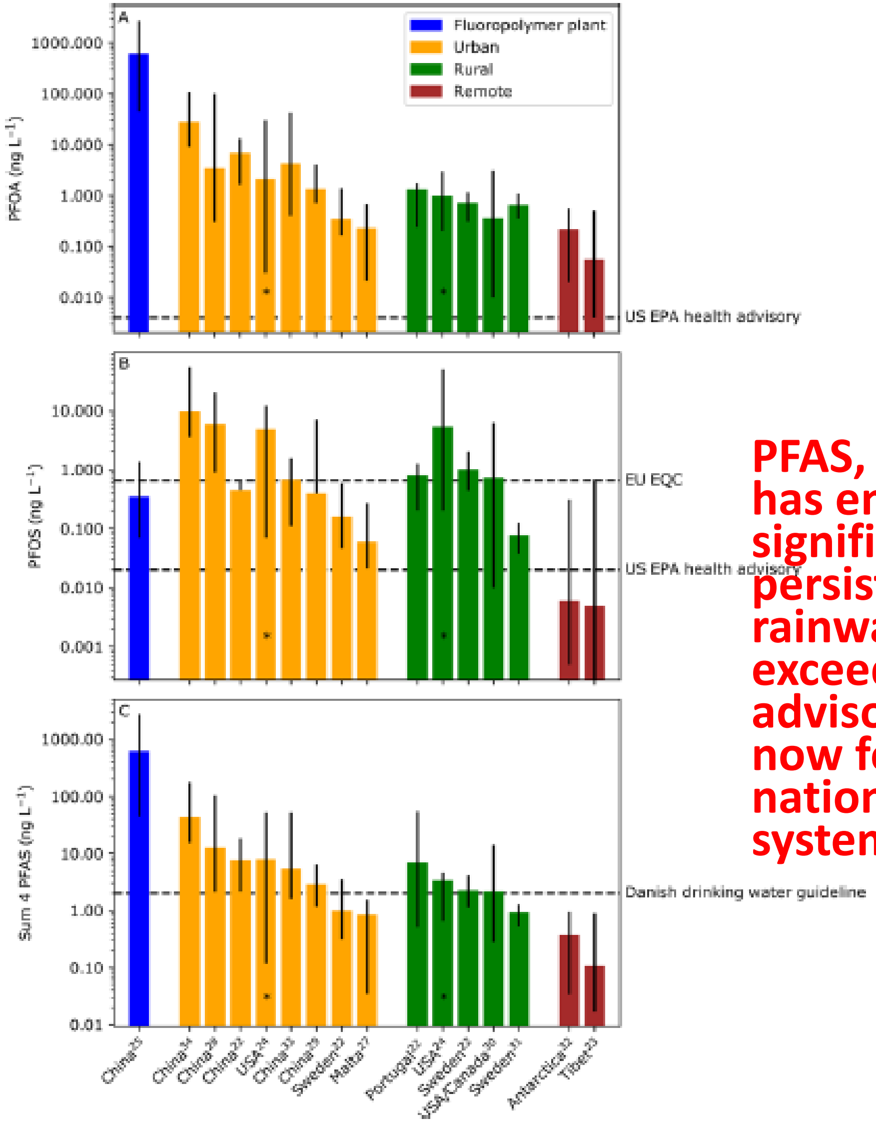
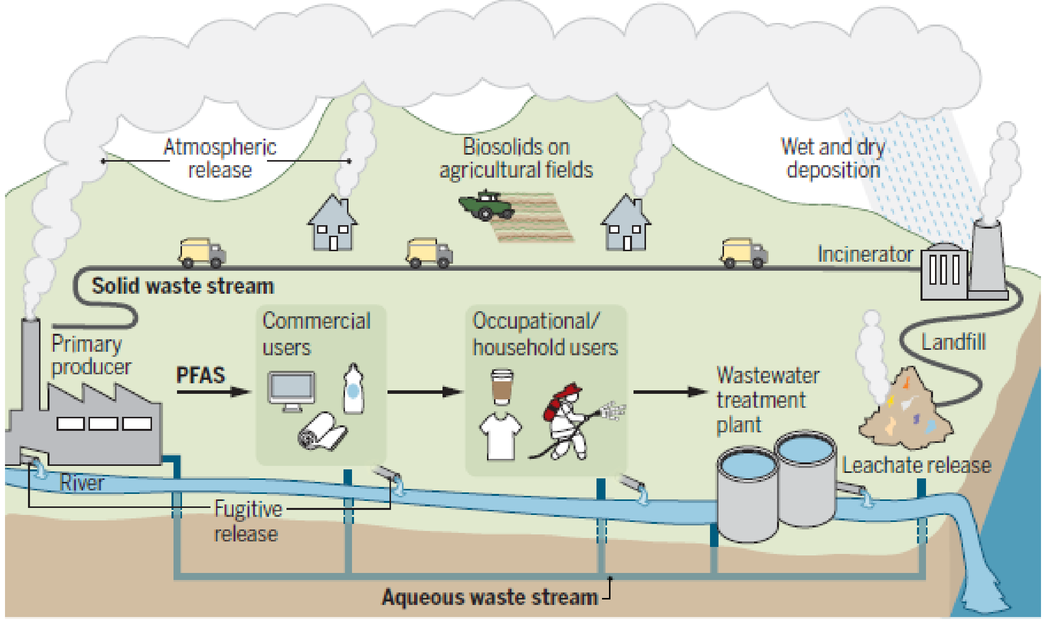
Water Quality 3 -PFAS

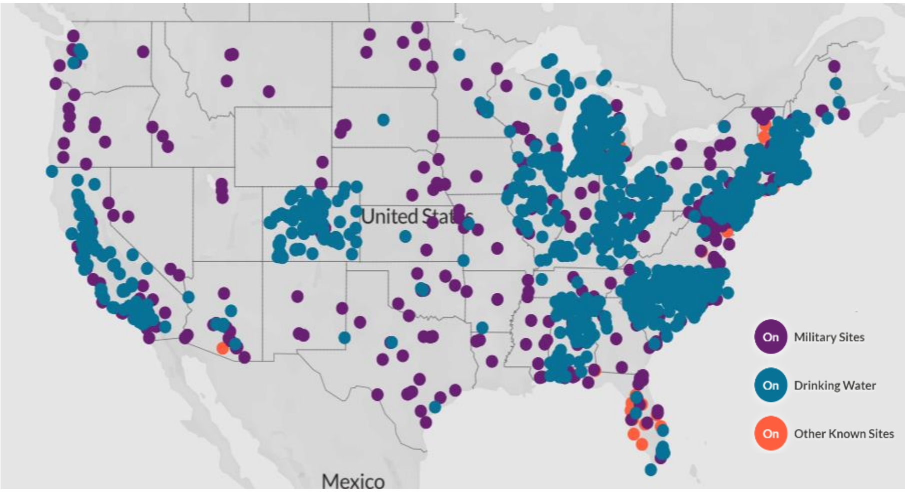


Evich, M. G., Davis, M. J., McCord, J. P., Acrey, B., Awkerman, J. A., Knappe, D. R., ... & Washington, J. W. (2022). Per-and polyfluoroalkyl substances in the environment. *Science*, *375*(6580), eabg9065.

PFAS, a man made chemical has emerged as a significant, pervasive and persistent health risk: rainwater concentrations exceed USEPA health advisory levels, and it is now found in many of the nation's water supply systems



The PFAS life cycle. PFAS product flows from primary producer to commercial user to consumers to disposal. Each step is attended by atmospheric and aqueous fugitive releases. Soils constitute a long-term environmental sink, slowly releasing PFAS to the hydrosphere and allowing uptake in biota, but the ultimate reservoir is deep marine sediment.



Cousins, I. T., Johansson, J. H., Salter, M. E., Sha, B., & Scheringer, M. (2022). Outside the Safe Operating Space of a New Planetary Boundary for Per-and Polyfluoroalkyl Substances (PFAS). *Environmental Science & Technology*.

[PFAS Contamination in the U.S. (June 8, 2022)](#) – **EWG.org**

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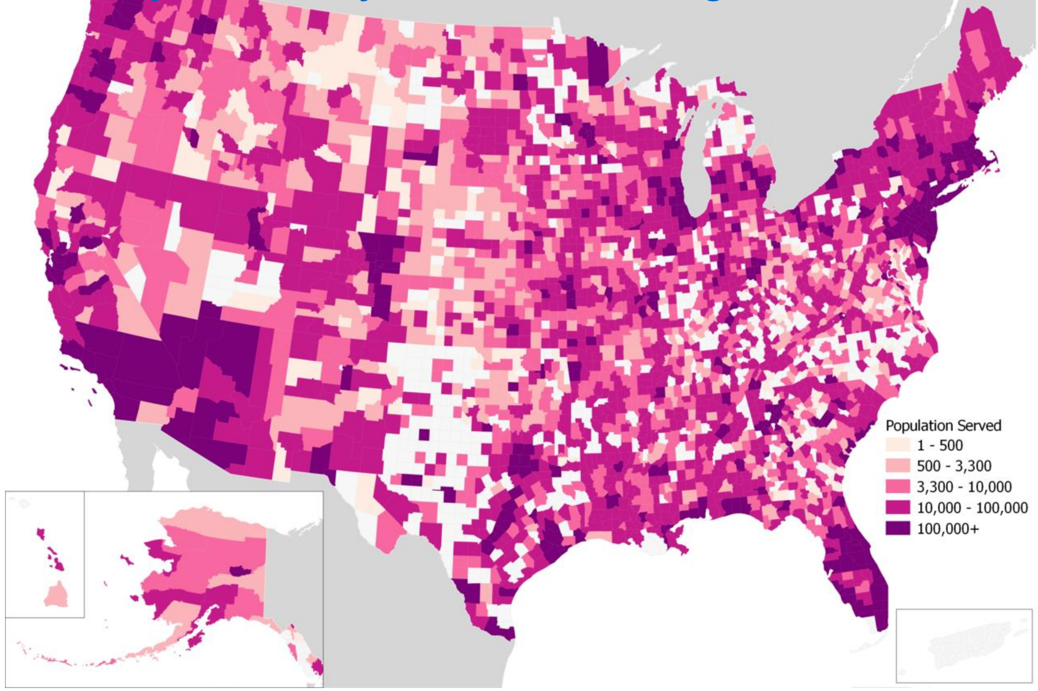
[Millions Served by Water Systems Detecting Lead - NRDC]

Water Quality 4 -Lead

“Between January 1, 2018 and December 31, 2020, there were **12,892 violations** of the Lead and Copper Rule by **7,595 community water systems** in the United States. These systems served **27,521,741 people”**. - NRDC

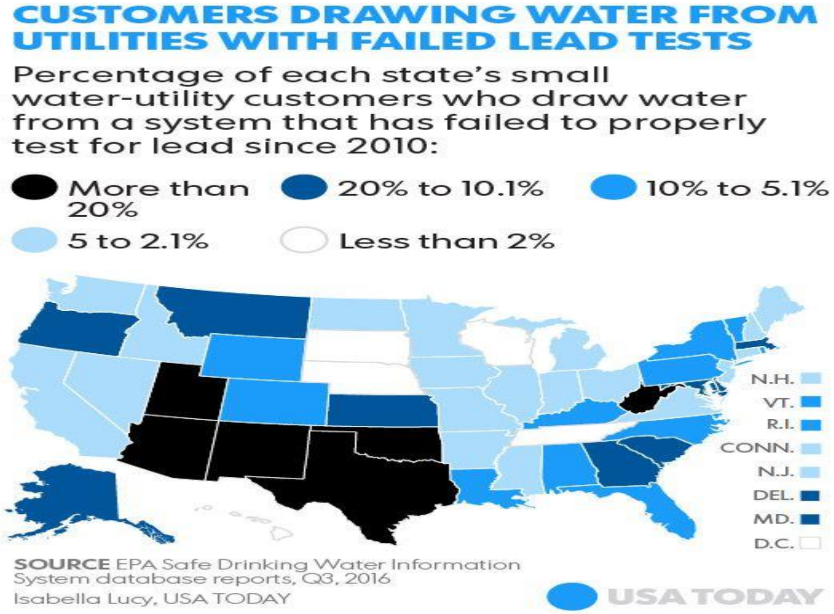


At least 33 US cities used water testing 'cheats' over lead concerns (*Guardian*)

Water departments to change lead-testing methods after investigation

4 million Americans could be drinking toxic water and would never know

RANGER, TEXAS — THE LEADERS OF THIS FORMER OIL BOOMTOWN NEVER GAVE 2-YEAR-OLD ADAM WALTON A CHANCE TO AVOID THE POISON.



Lead Poisoning Afflicts Neighborhoods across California

Dozens of California communities have seen recent rates of childhood lead poisoning exceed those of Flint, Mich.

Thousands of U.S. Areas Afflicted with Lead Poisoning beyond Flint's

The Michigan city doesn't even rank among the most dangerous lead hotspots in America

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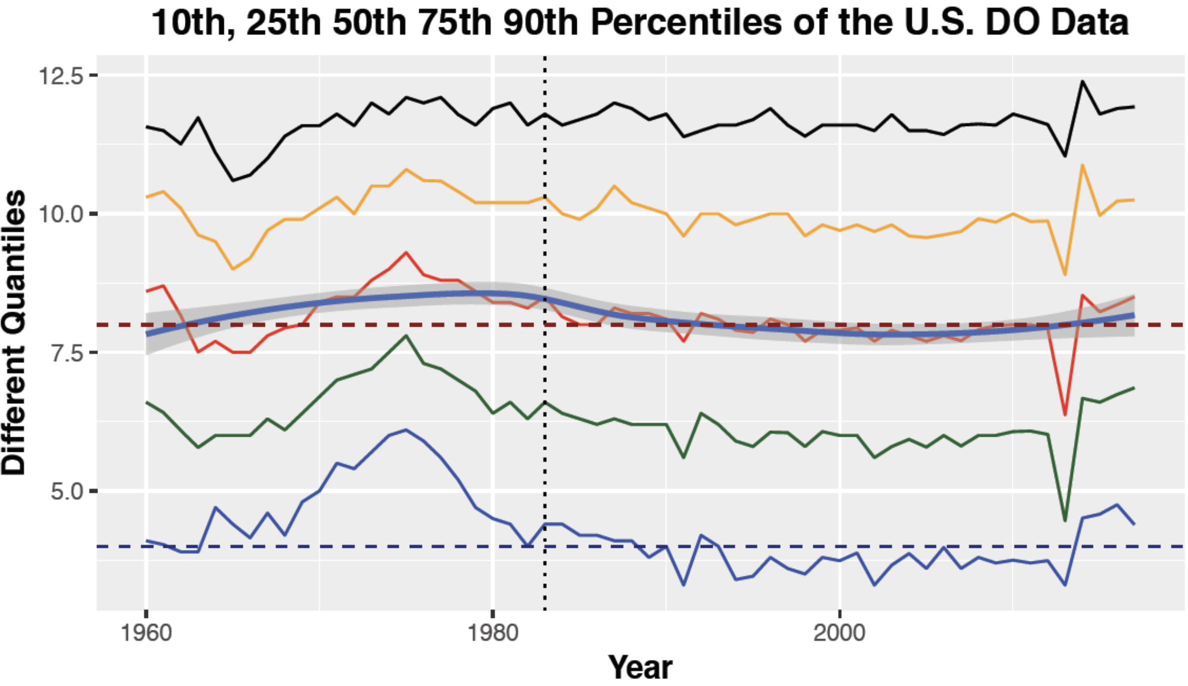
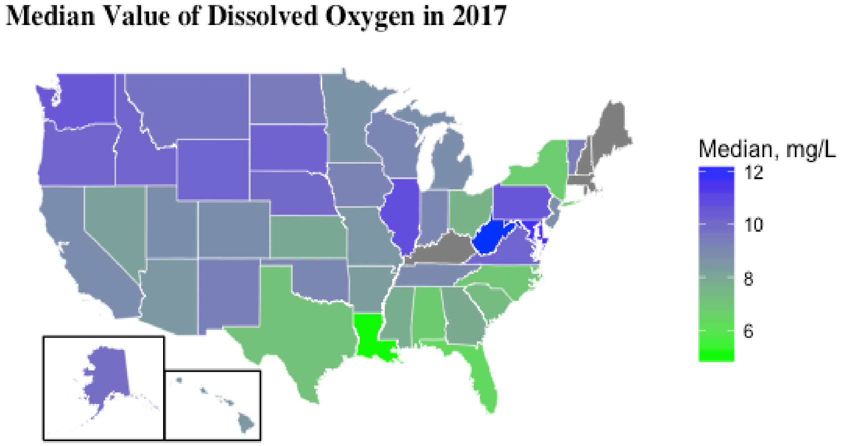
Water Quality 5

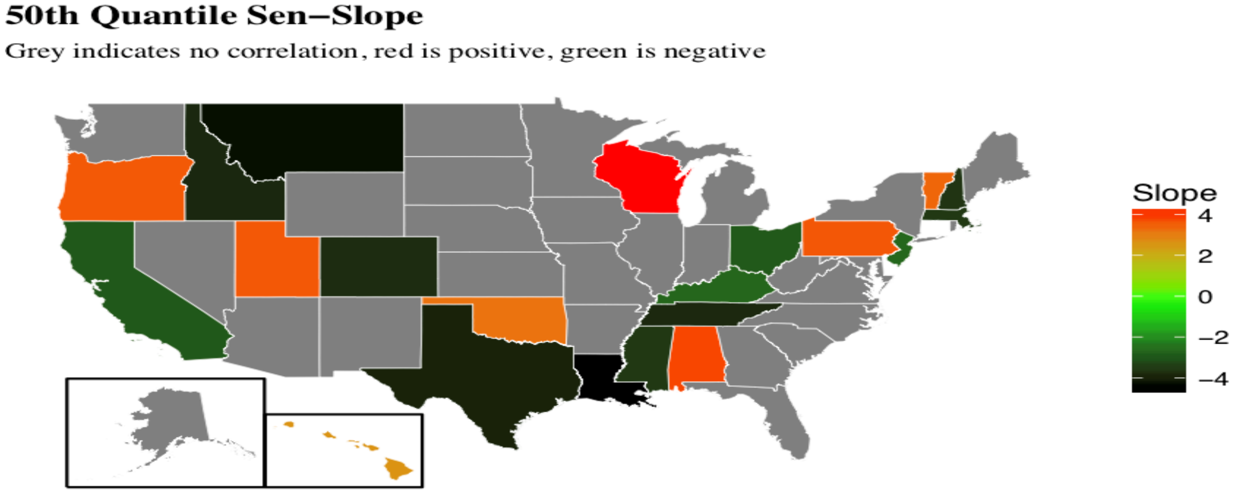
Streams and rivers continue to face non-point source pollution with little improvement in dissolved oxygen – a critical endpoint for healthy ecosystems



Nationally averaged statistics of dissolved oxygen in US waters using all available data from USGS and USEPA . The improvement in Dissolved Oxygen in the 1970s after the passage of the Clean Water Act has not held up!



A desirable level of dissolved O_2 is 8 mg/l. Less than 4 mg/l can be critical. Warmer water cannot hold as much oxygen



Trends in Dissolved Oxygen post 1983 by state. Note red is a positive trend indicating an improvement in dissolved oxygen and green is negative indicating a deterioration.

Columbia Water Center Analyses done by Yueli Liang & Leigh Ramsey.

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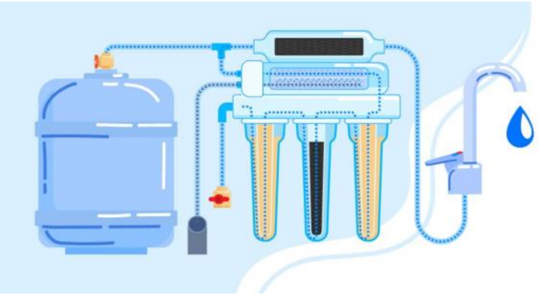
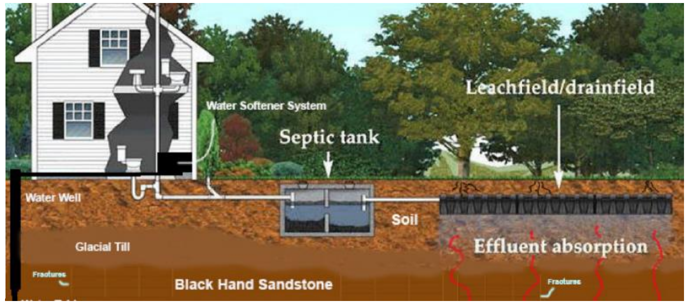
- Conveyance – Pipes and Sewers
- Water and Wastewater treatment
  - Wastewater treatment and Reuse







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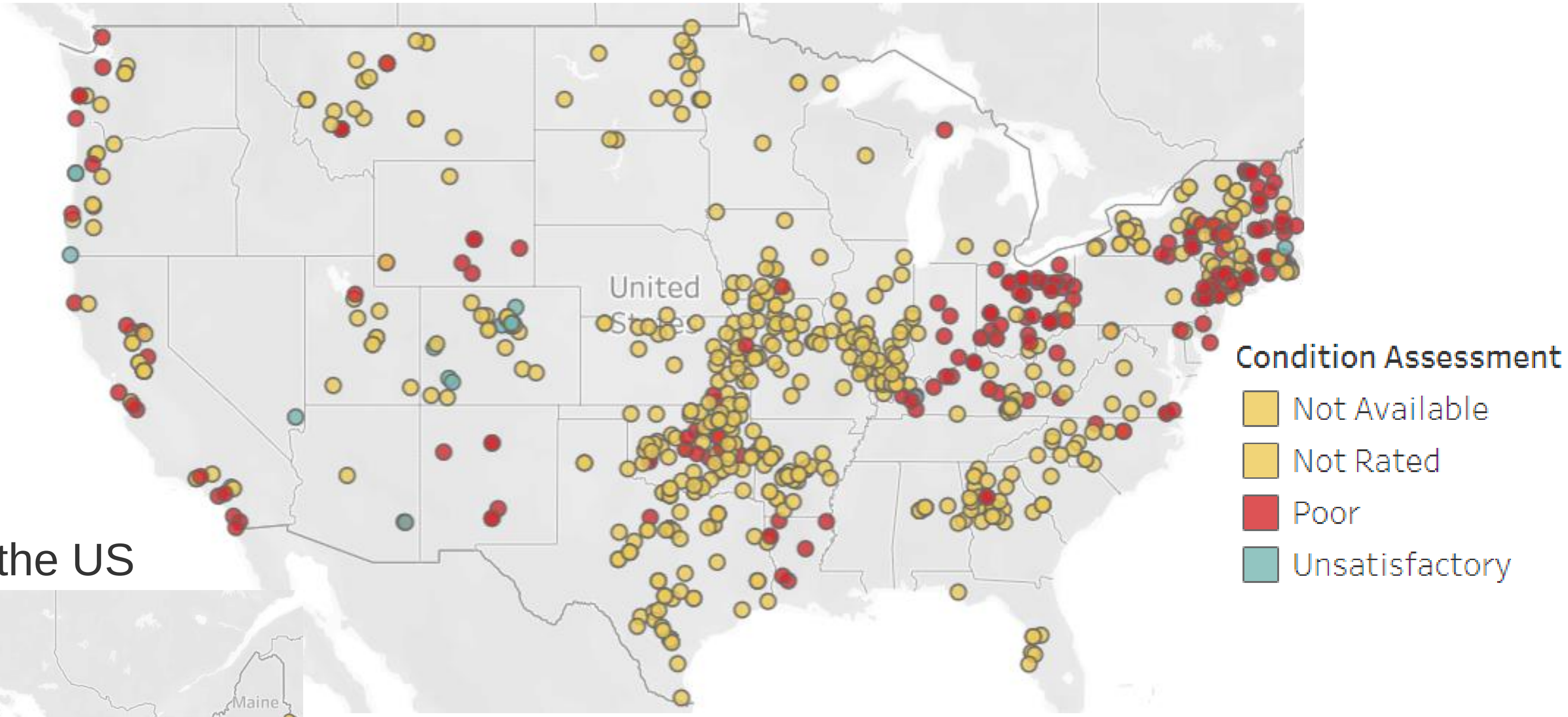
Dams

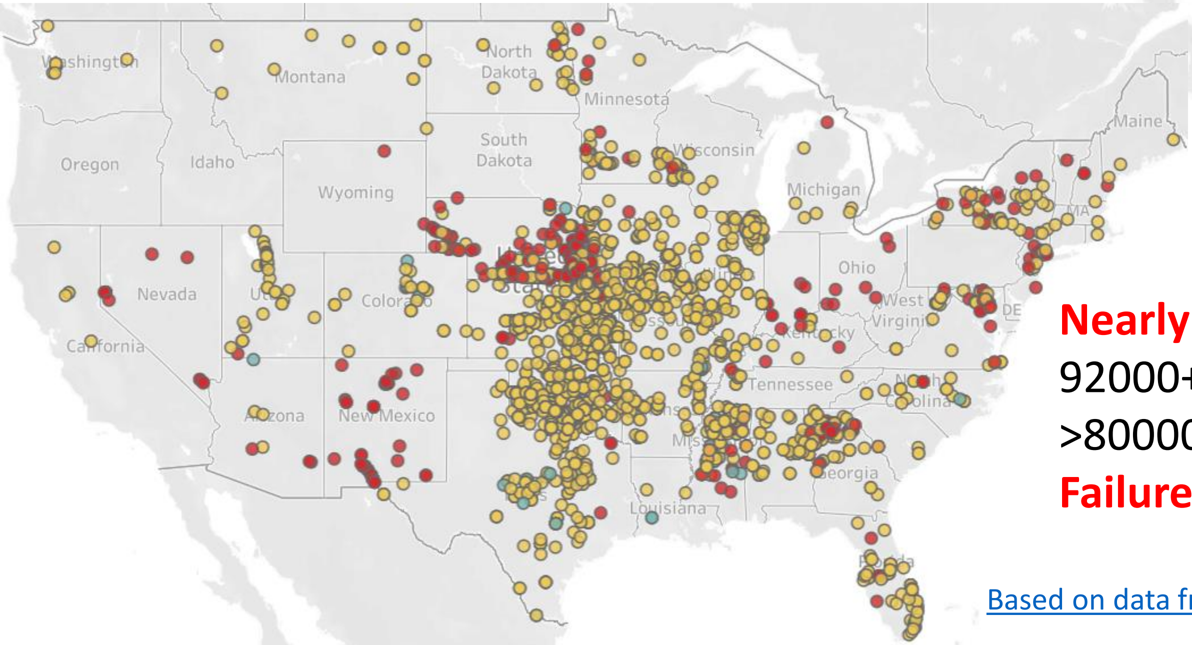
[Risk Assessment of Non-Federal Dams across the United States](#)

(follow this link to an interactive tableau of dam status)

State of Water Supply Dams across the US



State of Flood Control Dams across the US



Nearly 2/3rds of dams are rated poor, unsatisfactory or unrated

92000+ dams total

>80000 non-federal dams

Failure consequences largely unknown

Based on data from National Inventory of Dams

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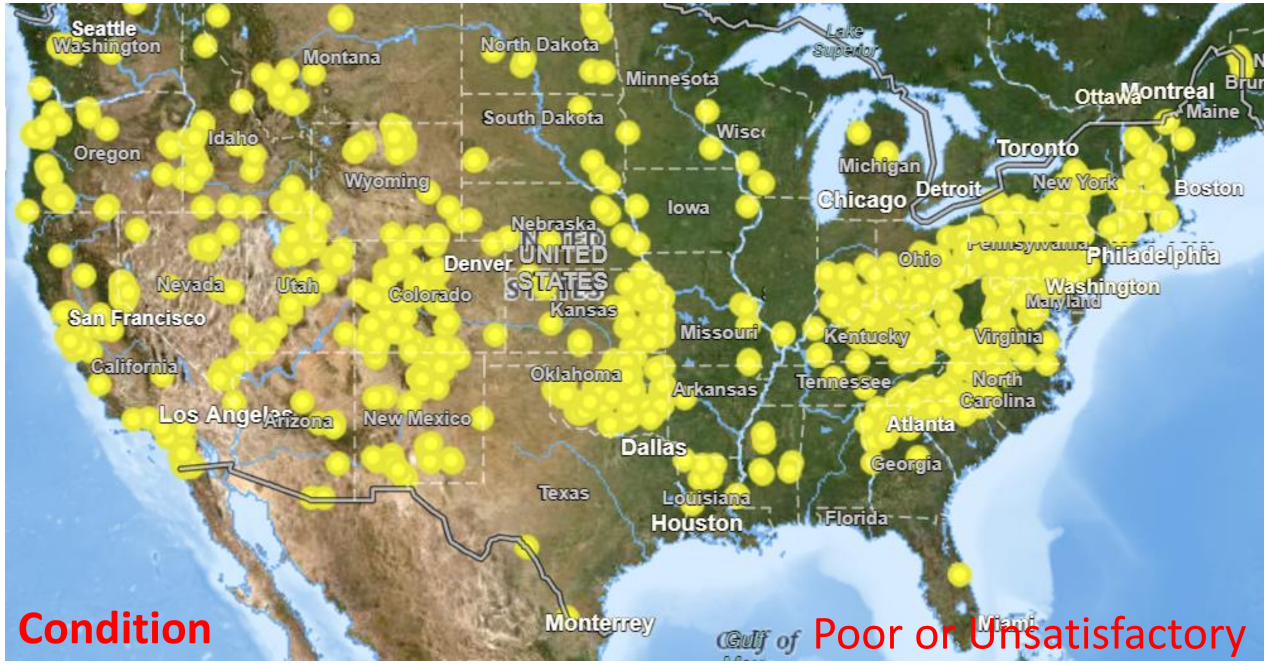
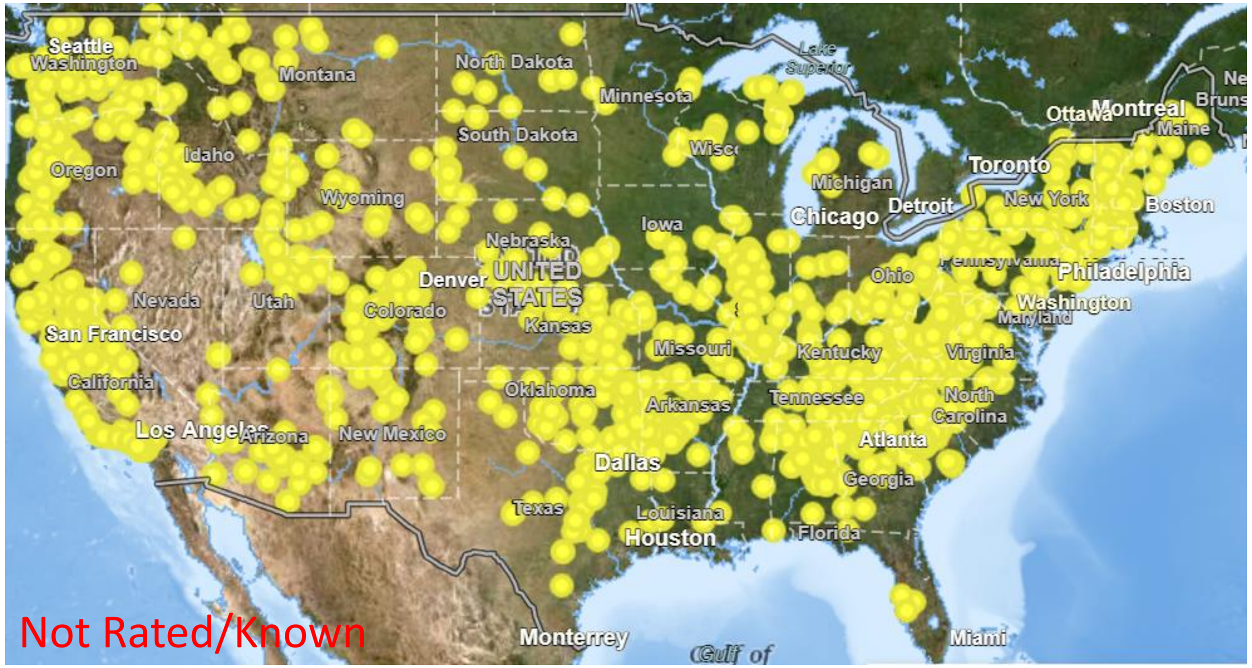
Dams 2





Dams Taller than 50 ft and rated High Hazard

Unsatisfactory 251
Poor 1701
Fair 3842
Not Rated 2136
Not Available 2588
5794 + 4724 = 10518

Satisfactory 4350
(43% of those rated/known in this category)
(29% of all dams in this category)

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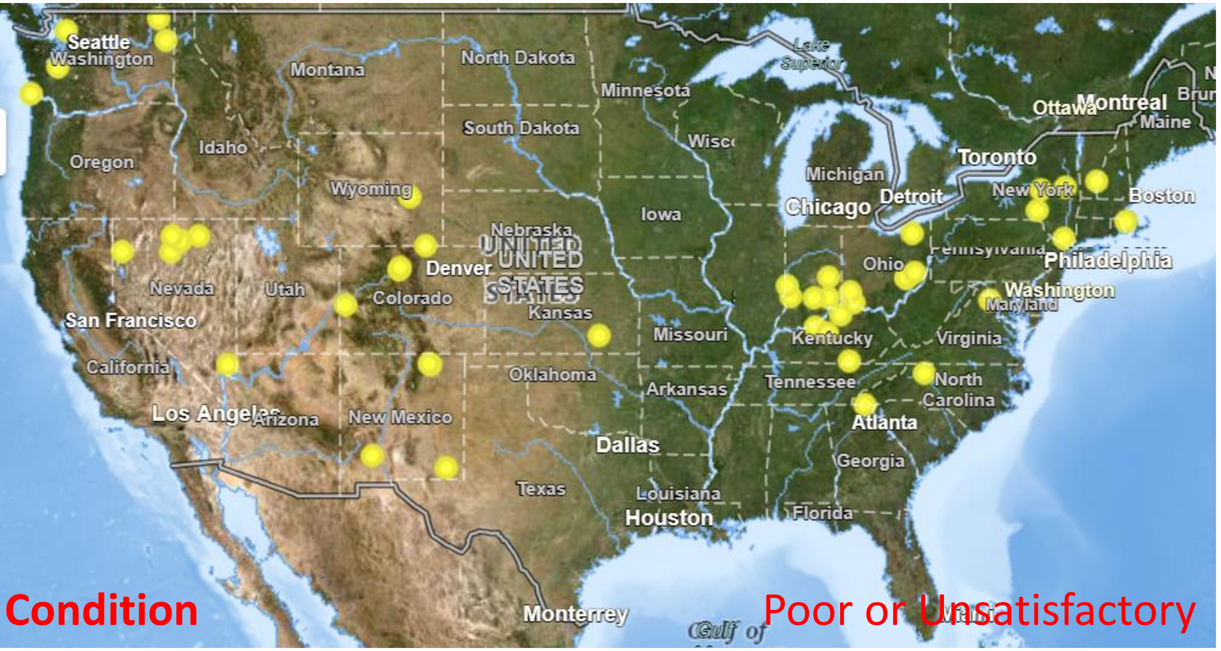
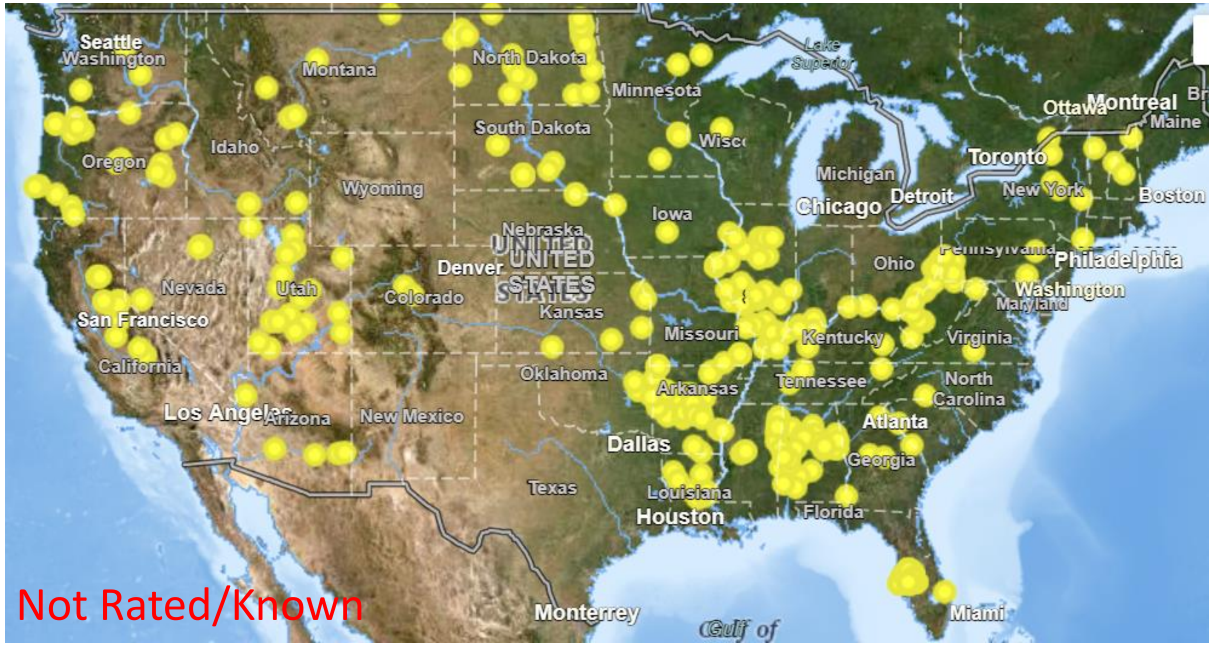
Dams 3





Dams Taller than 50 ft and rated Significant Hazard

Unsatisfactory 115
Poor 1362
Fair 2289
Not Rated 3224
Not Known 1149
3766+ 4373 = 8139

Satisfactory 2182
(37% of those rated/known in this category)
(21% of all dams in this category)

18657 Total High and significant hazard ratings with poor, fair unsatisfactory or not rated
74% of dams in these 2 categories of concern!!

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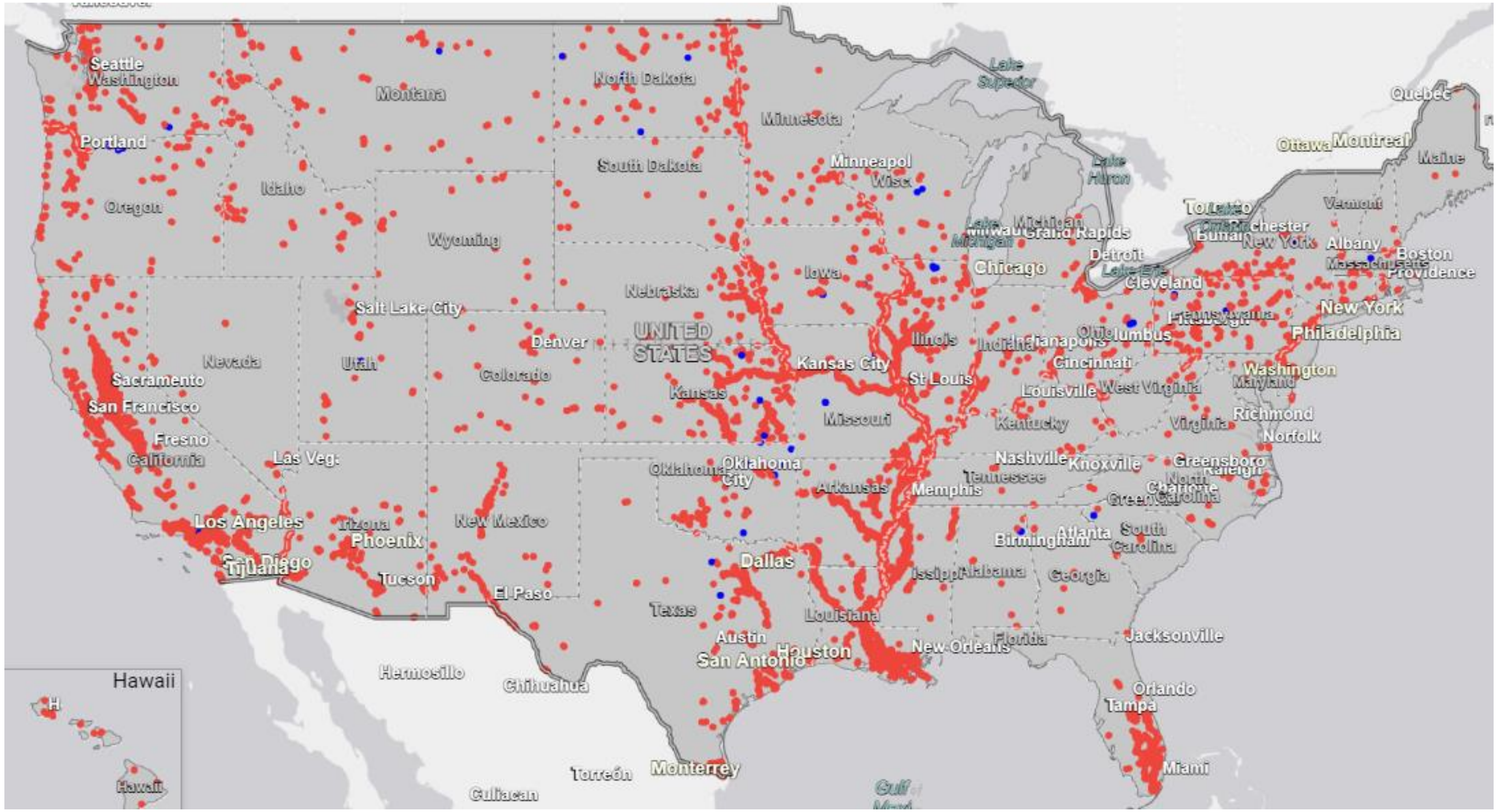
Levees

Age and condition of levees, or safety information is not publicly available



National Inventory of Levees

Of interest re hydrologic alteration by levees:

Knox, R. L., Morrison, R. R., & Wohl, E. E. (2022). A river ran through it: Floodplains as America’s newest relict landform. *Science Advances*, *8*(25), eabo1082.

Knox, R. L., Morrison, R. R., & Wohl, E. E. (2022). Identification of artificial levees in the contiguous United States. *Water Resources Research*, *58*(4), e2021WR031308.

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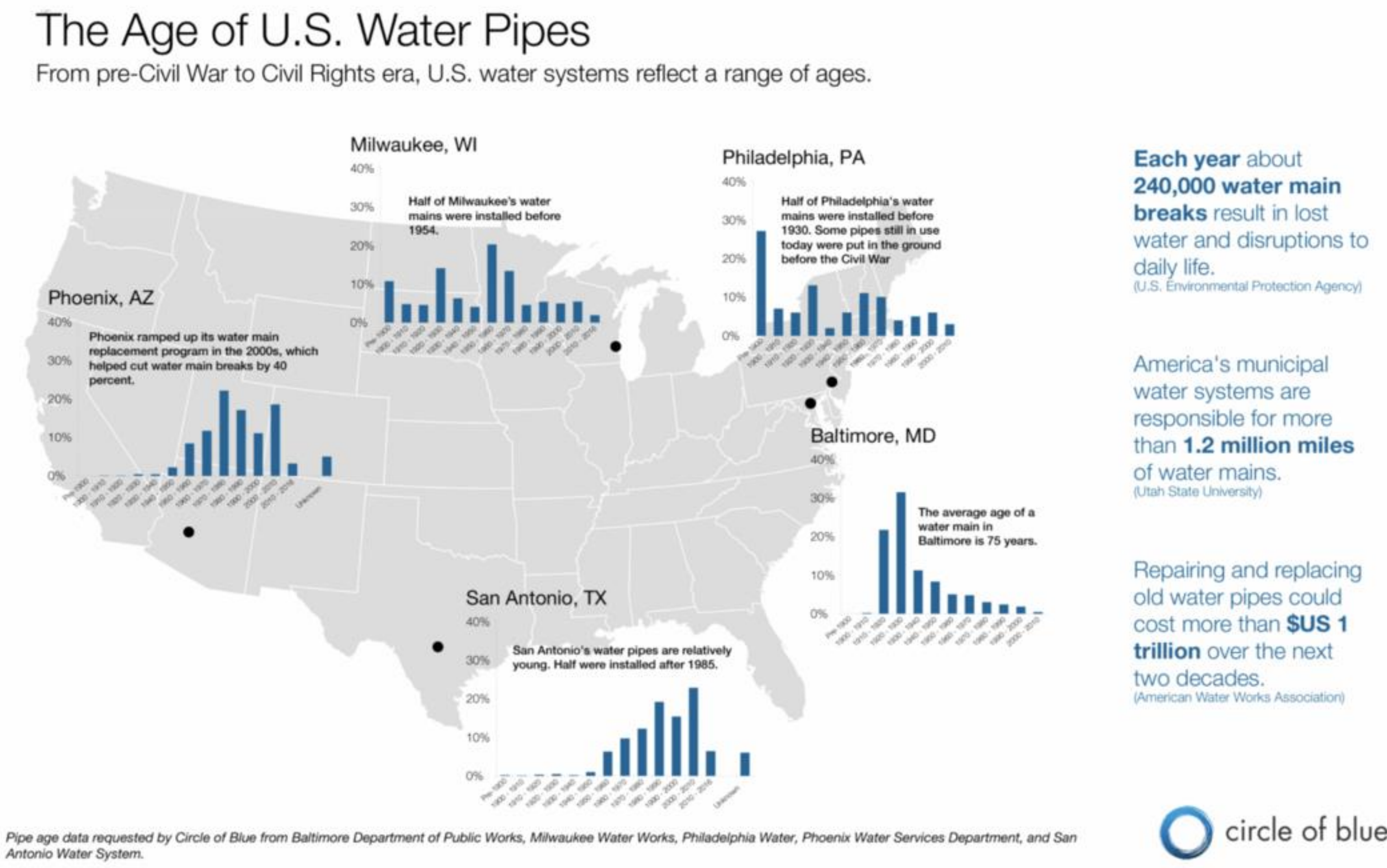
Conveyance – Pipes and Sewer Systems

These account for~ 70% of the cost of urban water and wastewater systems, and are expensive to maintain. Failing main pipes are a frequent cause for boil water notices for drinking water.

Busted sewers can be a significant and persistent pollution source.

A shift to more decentralized treatment systems could be beneficial



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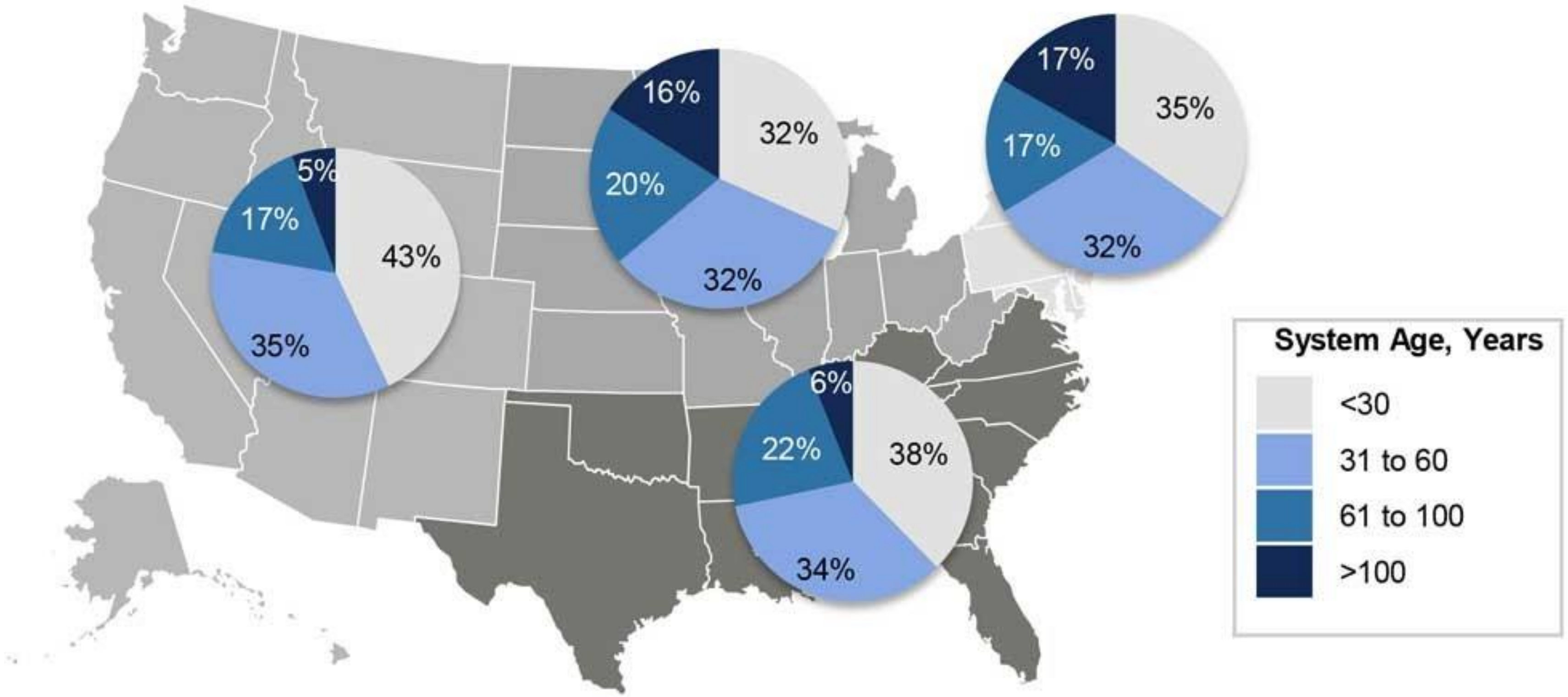
Conveyance – Pipes and Sewer Systems 2

Aging Infrastructure and deferred maintenance are the primary contributors to pipe failure

Climate, soil and seismic conditions are also important factors



Average Age of Pipe Infrastructure by Region - Waterfm.com

PipeId is a data base of pipe types, materials and condition for a number of utilities hosted by Virginia Tech

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Conveyance – Pipes and Sewer Systems 3

FIGURE 37: PERCENT WATER LOSS VERSUS UTILITY BREAK RATES

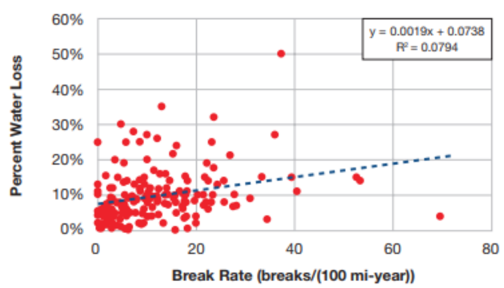
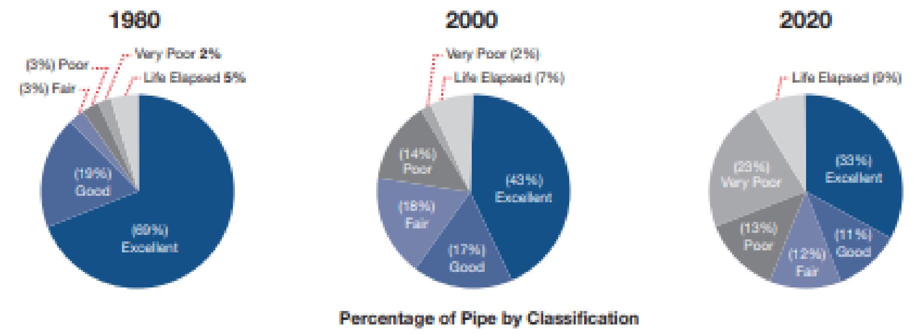


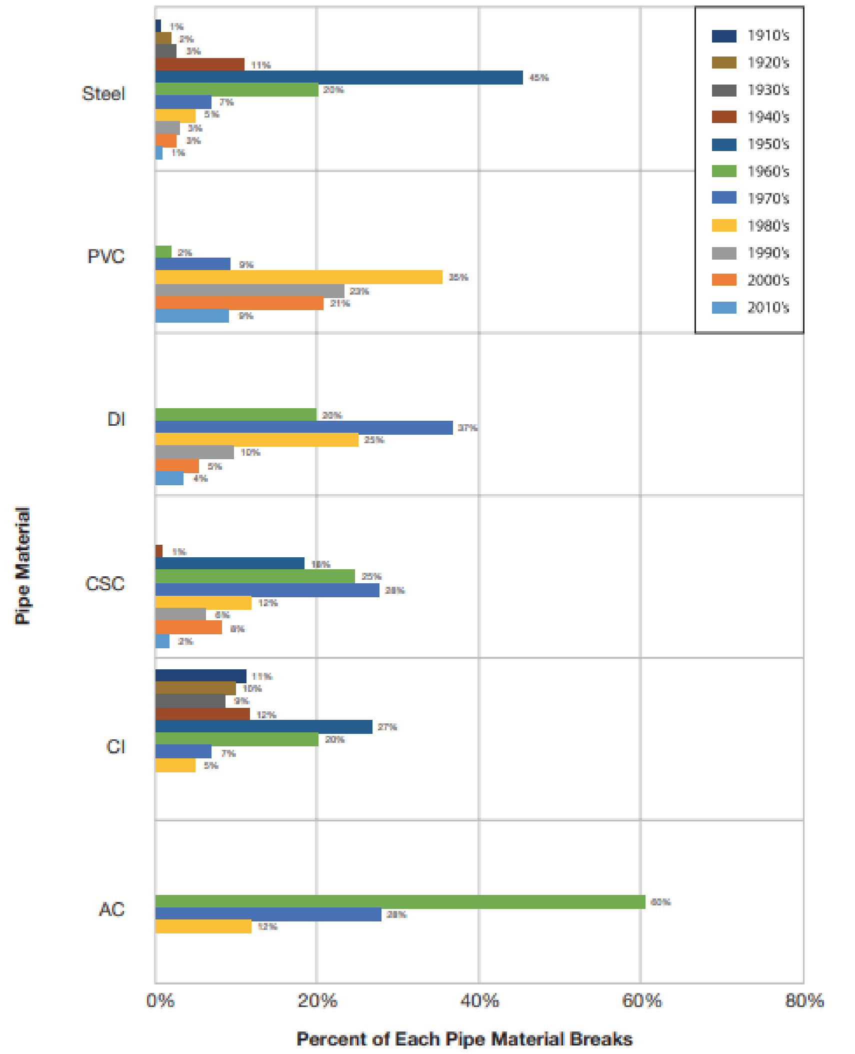
FIGURE 38: ASSESSMENT OF PIPE CONDITION WITH TIME (FROM EPA, 2002)



Questions	Average or Response
Typical age of failing water main	50 years
Expected life of new water mains	84 years
Percentage with plan to replacing water mains	77%
Percentage regularly replacing water mains	58%
Percentage of total water main length replaced annually	0.8%
Percentage of water mains beyond useful life but lack funds to replace (overall response)	16%

[Water Main Break Rates In the USA and Canada: A Comprehensive Study](#) – Utah State University

FIGURE 26: PERCENT OF FAILURES PER DECADE OF INSTALLED PIPE MATERIAL



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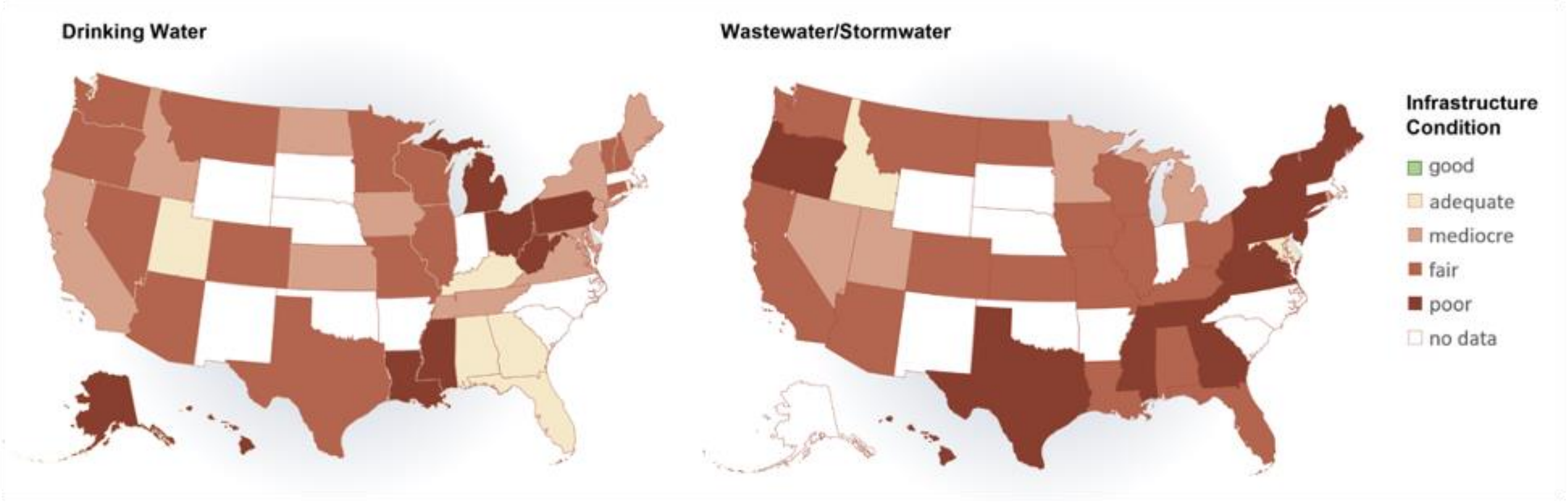
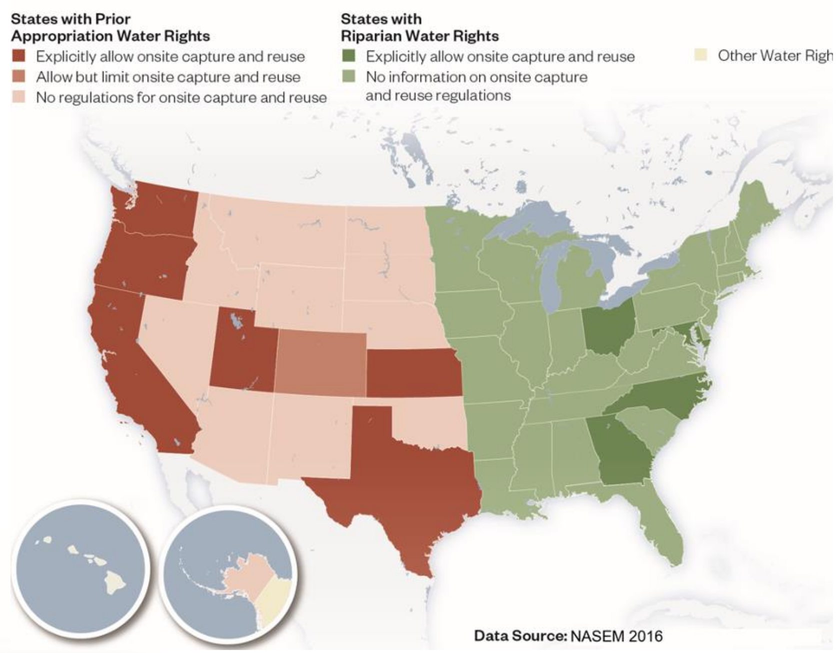
Water and Wastewater Treatment Systems



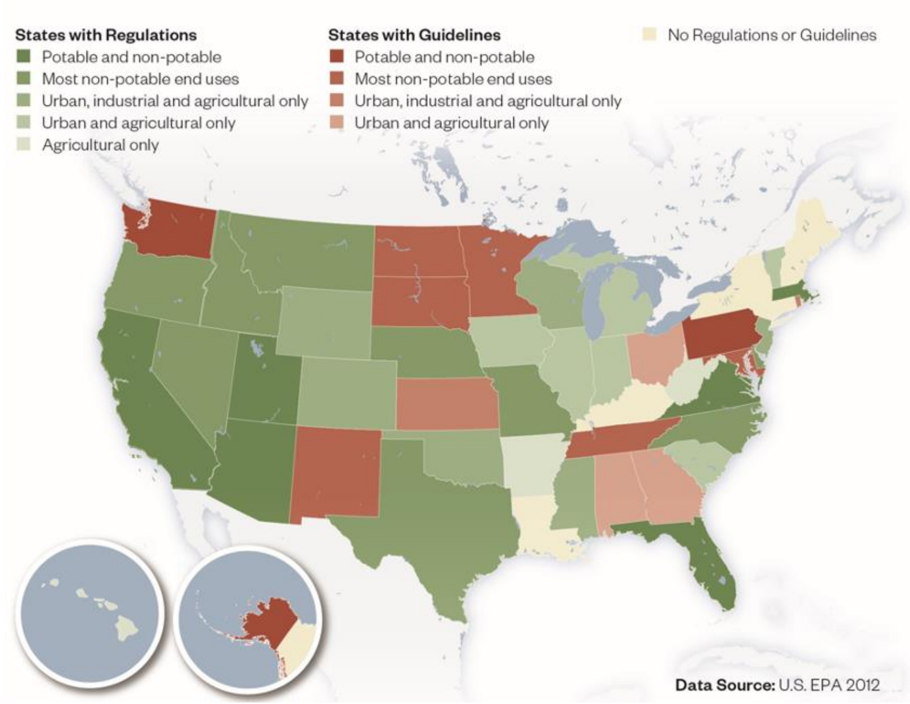
The condition of centralized water infrastructure in the US. Conditions are based on state-level infrastructure report cards from assessments conducted in 2015 or later. The labelled conditions correspond to the following grades: “good” is a B or above, “adequate” is a B- or C+, “mediocre” is a C, “fair” is a C-, and “poor” is a D+ or below. No states received a rating higher than a B- in any water infrastructure category. Repair and replacement needs are highest in the Northeast and South regions.

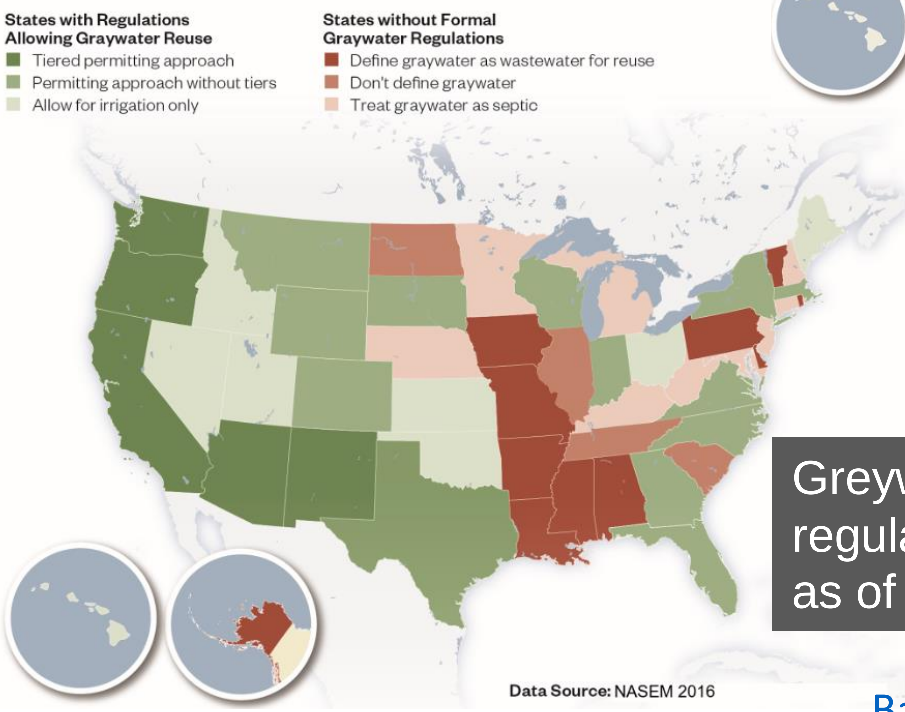
[State Infrastructure Rankings | ASCE's 2021 Infrastructure Report Card]

Water and Wastewater Treatment Systems: Reuse



Domestic wastewater reuse regulations by state as of 2012.





Rainwater and stormwater reuse regulations by state as of 2016.

Greywater reuse regulations by state as of 2016.

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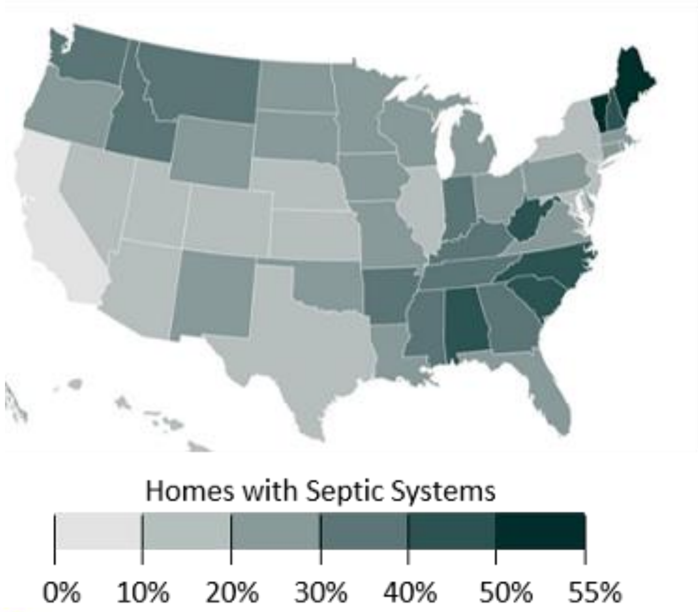
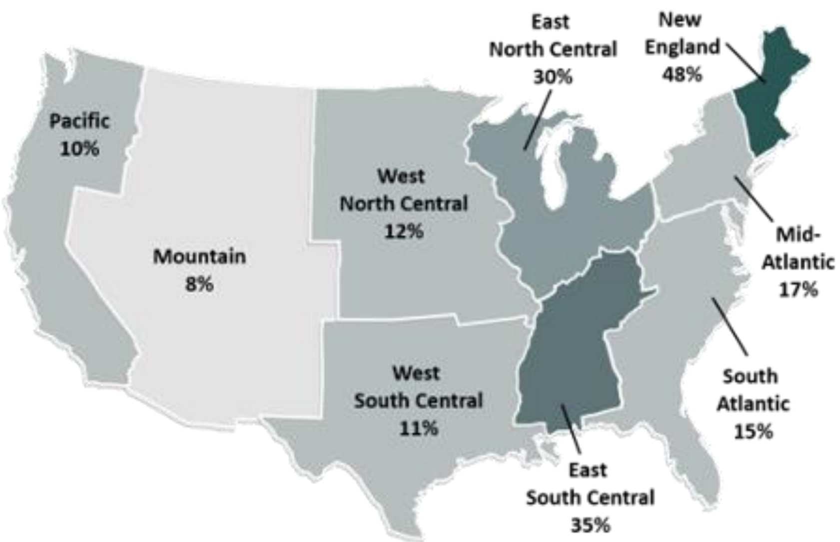
Water and Wastewater Treatment Systems: Septic Systems

Existing Homes as of 1990

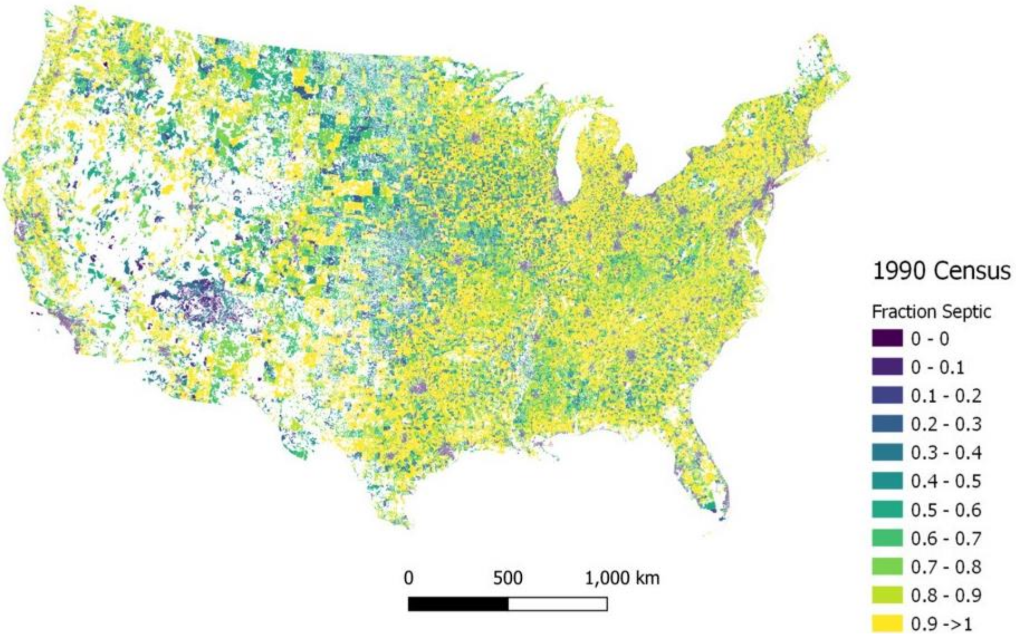


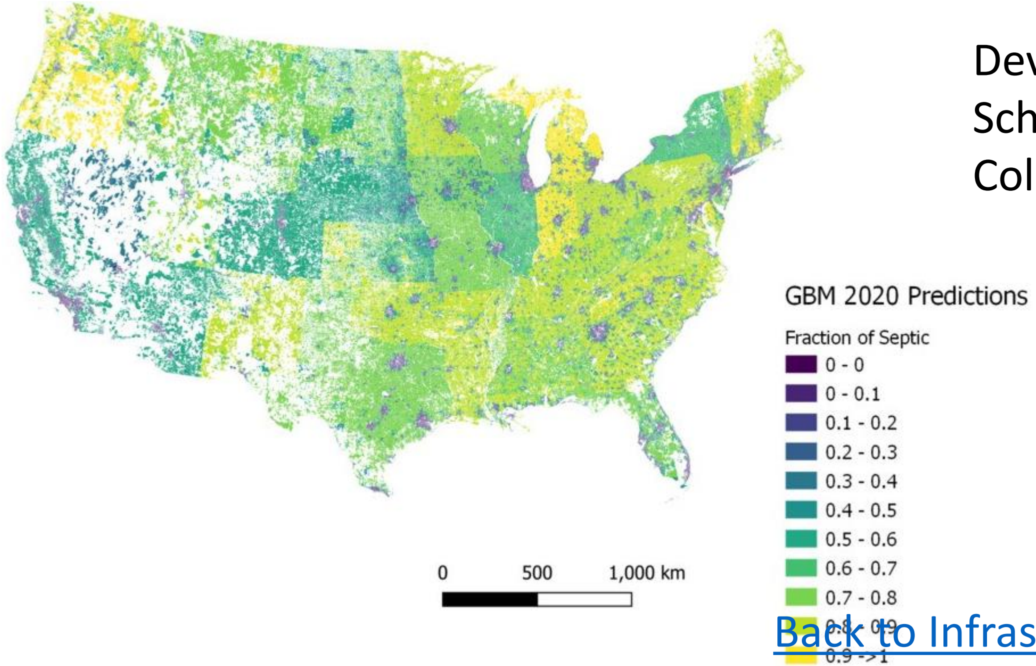
Newly Constructed Homes 2009-2019



[Characteristics of New Housing > Highlights (census.gov)]

Septic Systems can be effective for low density areas. Climate, soil, and lack of maintenance can lead to high failure rates, pollution and health risks





Developed by Sara Schwetschenau, Columbia Water Center

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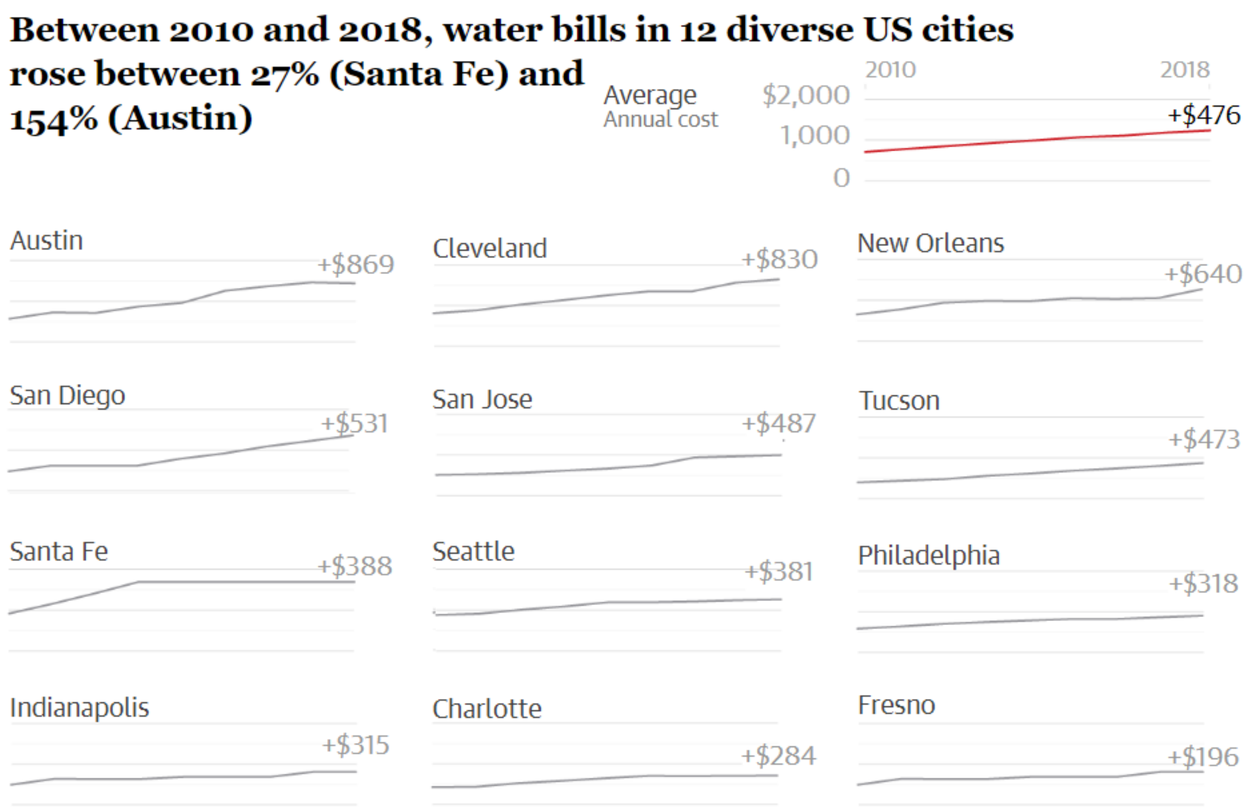
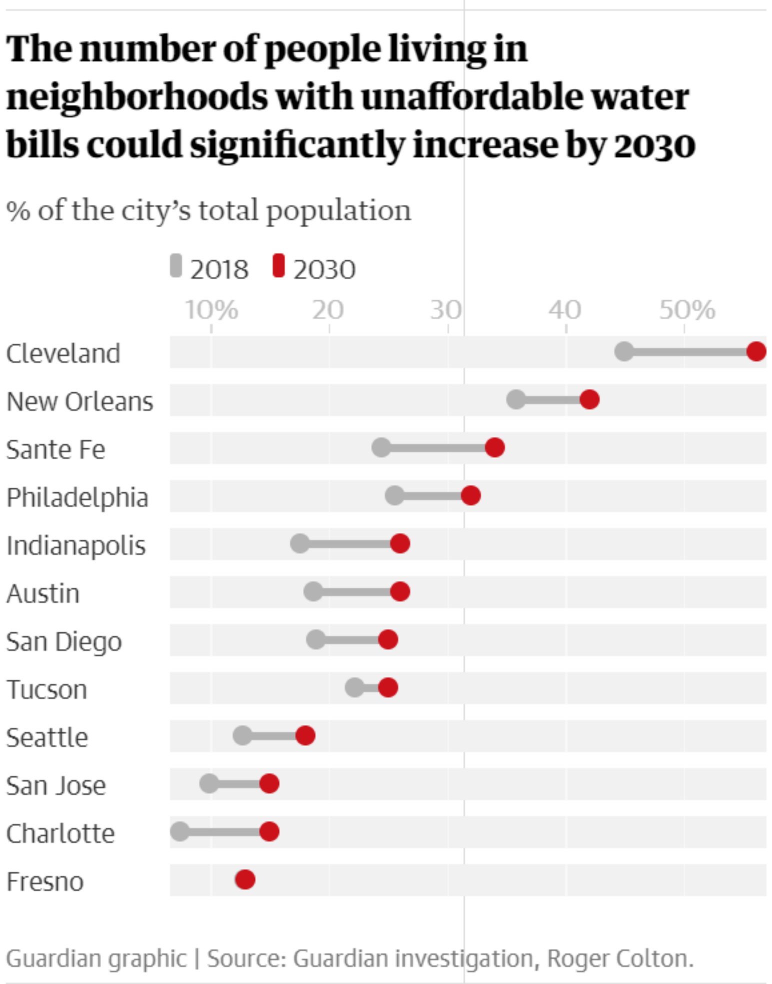
Affordability, Financing/Investments





[Revealed: millions of Americans can't afford water as bills rise 80% in a decade](#) – Guardian, 2020

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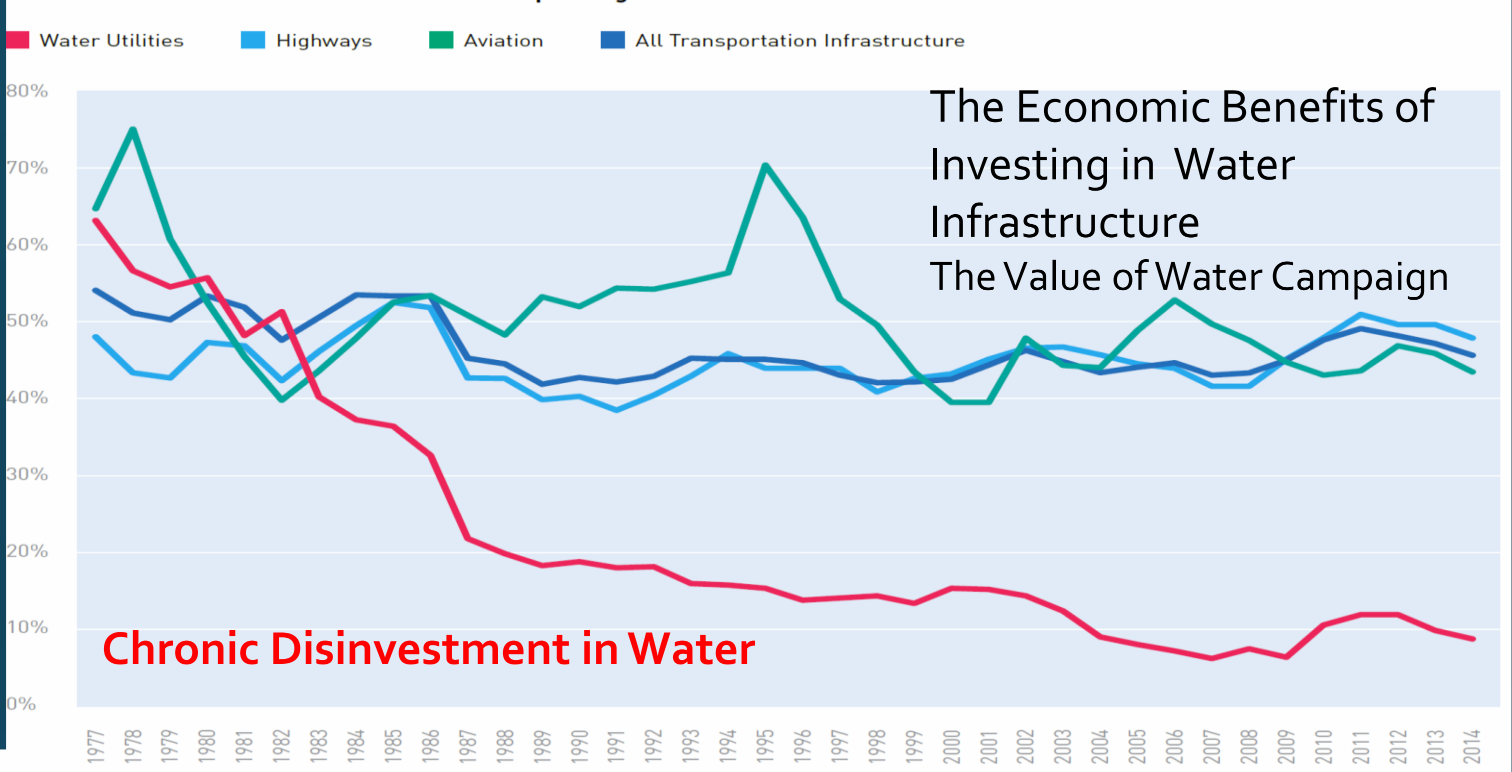
Federal Investment in Water Utility Infrastructure



Source: CBO 2015.

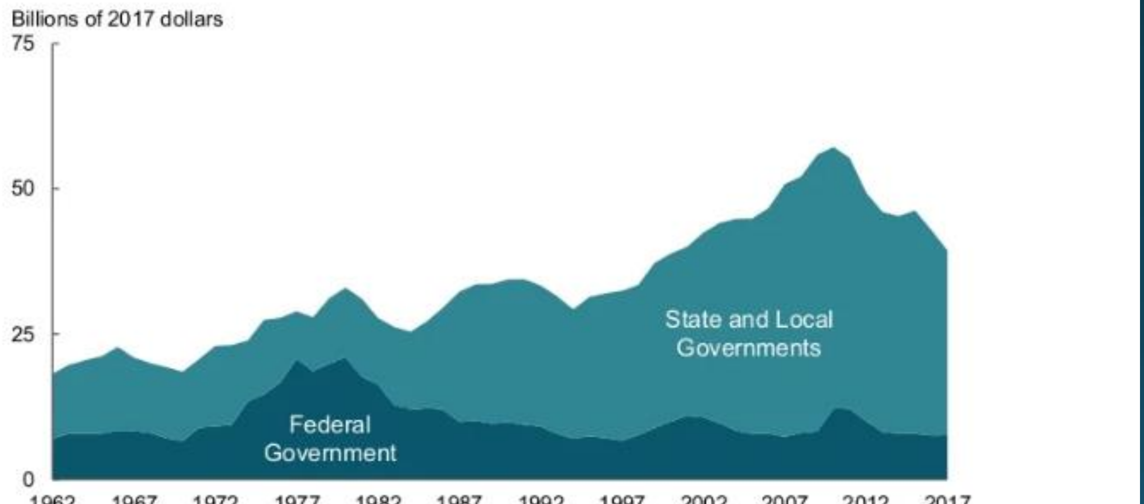
Annual Federal Investment Per Capita

Recipient	Per Capita Federal Investment
IT Infrastructure (Federal Departments)	$251
Research & Development—Defense	$245
Research & Development—Civilan	$208
Higher Education Grants	$143
Highways	$136
Other Transportation Infrastructure	$55
Energy Infrastructure	$46
Water Infrastructure	$11

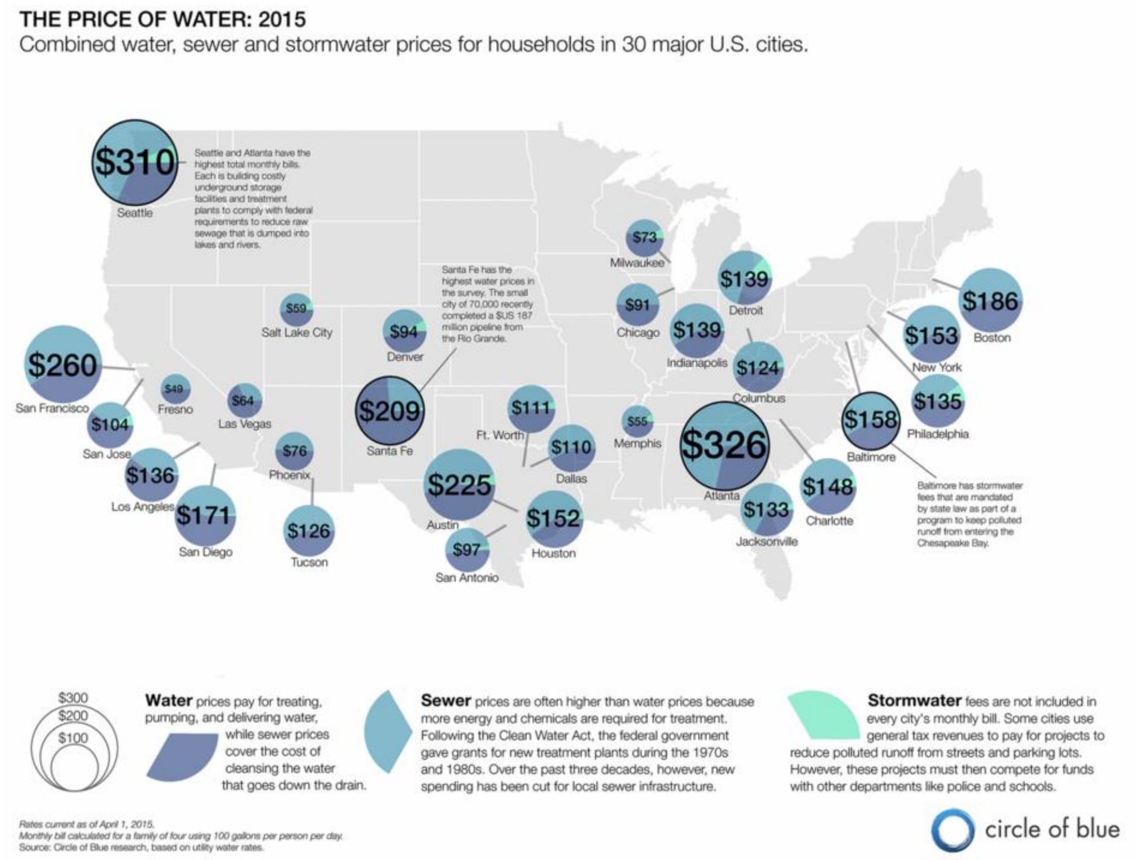
Values expressed in 2014 dollars. Source: CBO 2015, CBO 2013, GAO 2016.

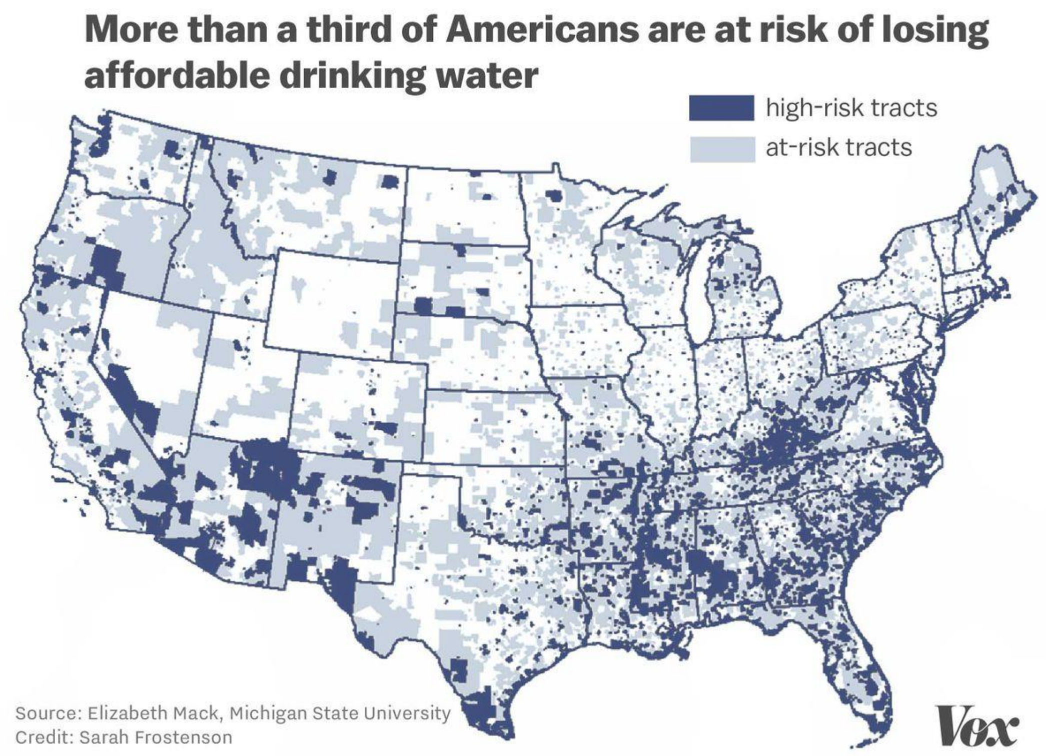
Water Infrastructure: Sources of Nondefense Investment, 1962 to 2017

Congressional Budget office



Affordability, Financing/Investments, Governance





[A burgeoning crisis? A nationwide assessment of the geography of **water affordability** in the United States]

[How should **water affordability** be measured in the United States? A critical review]

[Measuring **water affordability** and the financial capability of utilities]

Water and wastewater bills have been rising at nearly twice the rate of inflation since 2000, as utilities spend to patch or restore failing infrastructure, leading to concerns of affordability for lower income (often minority) populations

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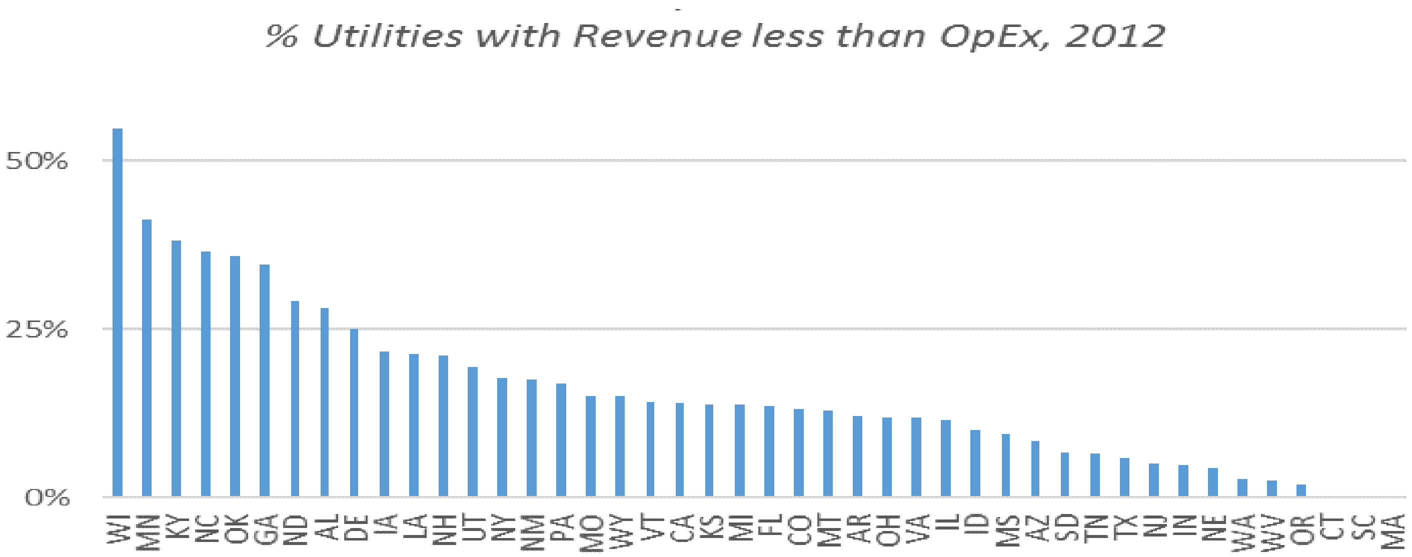
Utility Finance

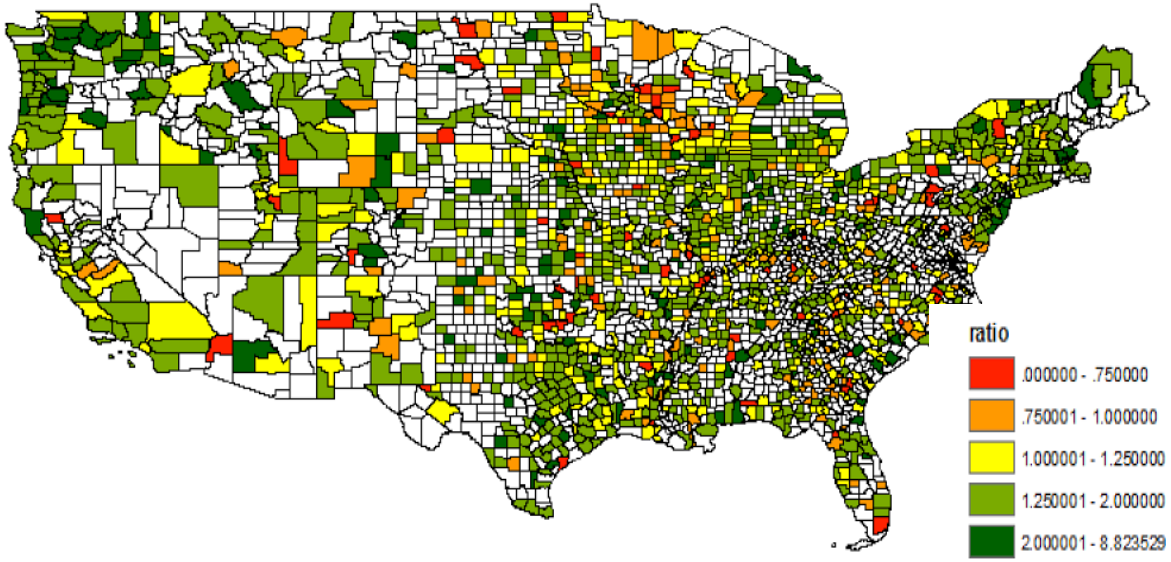
Ratio of Revenue to Operating Expenses, 2012

Many utilities fail to cover annual costs (Operation & Maintenance), leading to deferred maintenance and failure

Challenges:

- Low water rates
- Declining per capita use
- Future capital needs





Strained finances:

- *Wisconsin*
- ***Minnesota***
- *Kentucky*
- *North Carolina*
- ***Oklahoma***
- ***Georgia***

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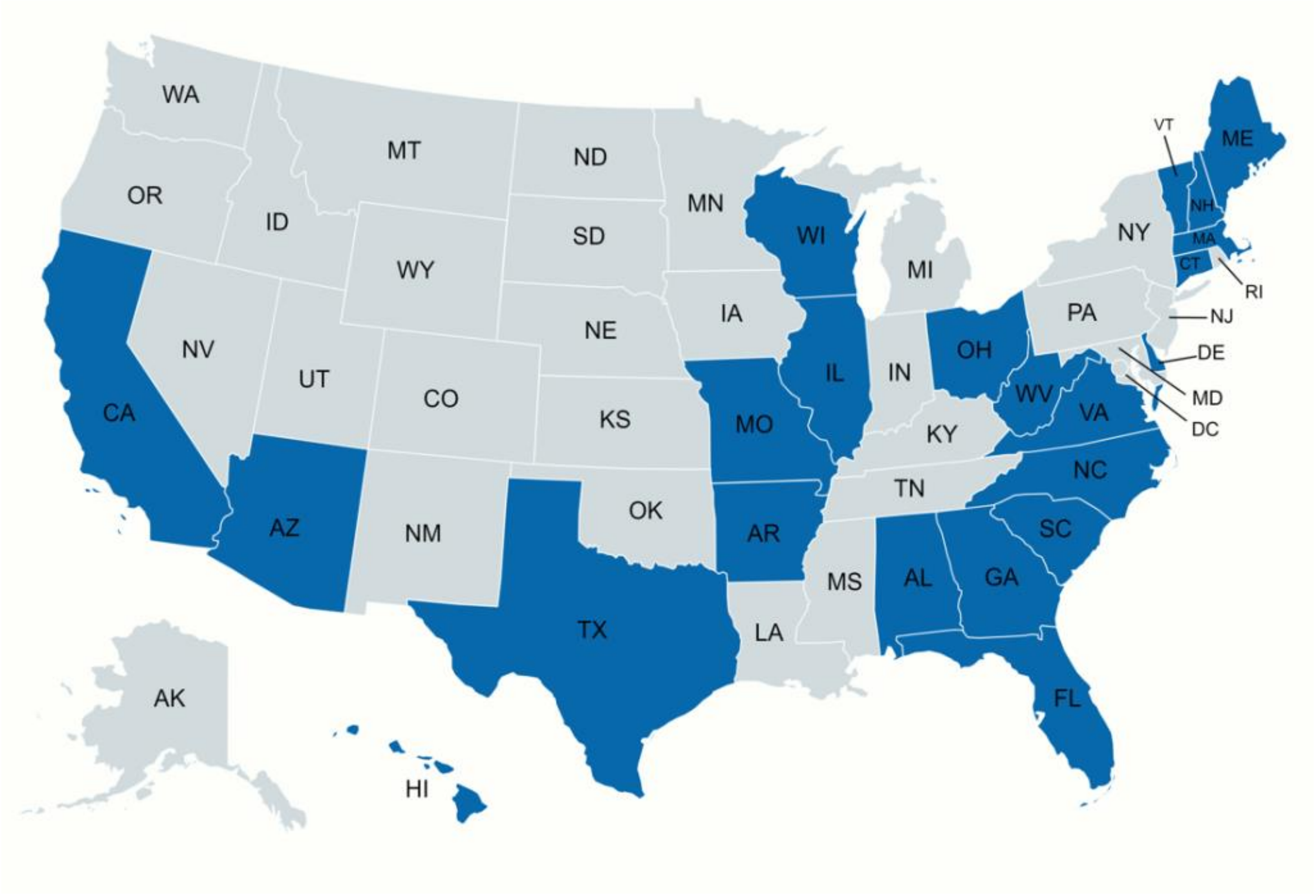
Affordability and Finance Data



Univ of N. Carolina Environmental Center has extensive Dashboards that allow an exploration of metrics for the states in the map on the left

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