The United States Water Crisis

How changes to the natural water cycle and increasing demand are causing water stress

Andrew Levinson
M.S. Data Visualization Candidate, Parsons School of Design
B.S. Accountancy, DePaul University

Submitted in partial fulfillment of the requirements for the degree of Master Science in Data Visualization at Parsons School of Design.

Thesis Advisors
Daniel Sauter
Aaron Hill

May 2019

Table of Contents

Abstract

By 2030, the global demand for freshwater will exceed global supply by 40%.[1] In 2017, Cape Town, South Africa made headlines as it approached "Day Zero"—the day the water taps run dry and personal water allocation is controlled by government rations. While a day zero scenario for the United States is still far away, significant water stress is currently occurring throughout the country far quicker than previously anticipated. Instead of viewing these case studies as isolated events, Americans need to treat these as warning signs that require immediate action and long term strategy shifts.

This project visualizes the global growing water stress gap, highlights individual case studies in the United States, and provide a strategy for key investment areas as well as behavioral changes that make the most significant impact. Culminating in an investment vs. behavioral simulation, this project emphasizes the concept that water stress relief and water conservation is not an all or nothing approach. Investments in crumbling infrastructure, agricultural technologies to avoid over-abstraction of groundwater, and local water management all play critical roles in delaying extreme water stress scenarios.

In the future, our relationship with water will be challenged. Modern diets, population growth in water-scarce cities, and water intensive industries all need to be carefully transitioned. However, in order to change our relationship with the most valuable natural resource on Earth, critically significant water stress throughout the country must be taken seriously before the problems escalate to unmanageable levels.

[1] (Connor, 2015)

Introduction

Water is the *"oil of the 21st century."* [2] Due to global population growth and supply stress caused by climate change, humanity must prepare for a massive worldwide transition of water. But while the overall crisis is global, water stress relief is largely a local issue. In the United States, there are a handful of current critical case studies worth exploring. High stress crisis' like the drought in the Southwest region, the over-abstraction of below-ground aquifers (especially the Ogallala in the High Plaines), and major infrastructure issues across the entire country—like contamination in Flint, Michigan, and the trillions of gallons lost through leaky pipes—are just the beginning. As the gap between water demand and supply continues to grow, our options become limited.

The water crisis can be complex and frightening, but it is critical to break down the issues into manageable and strategic parts. This project will consider issues in a twofold approach. First, each issue will be addressed as one of growing demand or one of changing supply. Second, each issue will be broken down in the form of immediate solution(s) as well as an examination of how it challenges our long-term strategic relationship with water. These two parts work hand-in-hand; immediate action to provide water-stress relief in pockets of the country will provide replicable solutions to be applied throughout the country for future acute water-stress and will also, most importantly, buy time as we debate and gather consensus on the massive challenges to Americans' way of life in order to cope with the great water transition of the 21st century.

For example, upgrades to crumbling, unsafe infrastructure are objective problems that must be solved immediately. It is an issue unnecessary of debate because the implications are dire and there is no alternative solution. On the other hand, issues like how to best reverse climate change and augment the unsustainable modern diet are much more nuanced problems that require time, political and civil consensus, and large investments over a long period of time. This project will not simply theorize on the possible crisis and potential solutions, but closely examine critical water stress case studies and subsequent local progress on solutions for these communities.

The water crisis is a vast and complex issue; therefore, it is important to clarify which aspects will not be addressed in this project. While 41% of all freshwater is used in the thermoelectric-power industry to cool electricity-generating equipment [3] , most of that water is returned to the overall supply so this thesis will not cover the effects of energy as it relates to water since those resources are replenished. This project will focus on the consumptive use of

[2] (Liveris, 2008)
[3] (United States Geological Survey, 2015)

water as it relates to demand. Additionally, while the effects of climate change are critical to the overall supply of water, this project will not attempt to provide guidance on the specific methods that can reverse these effect and instead will focus on the allocation of investment dollars and strategies to mitigate increasing demand in order to handle the effects of climate change on the overall water supply. Finally, it will not analyze the geopolitical implications of global water transitions and the change in power structures as a result of the international water crisis. While these issue are of great importance, the primary focus will be on current and future freshwater stress in the United States for which there are directly investable and actionable solutions.

In order to explain these goals, this project will visualize the decreasing renewable water per capita and water usage overall, highlight individual case studies in the United States, and provide a strategy for key investment areas and behavioral changes that make the most immediate impact. It will address key long term issues that deal with our relationship with water and those that simply do not have time to wait.

Treatment

The Water Crisis: a story of growing demand and elusive supply

Usage of water

Water is our most precious resource. As human beings, we have an ever resetting 100-hour internal clock to consume drinking water before we die [4]. Aside from drinking, bathing, and sanitation, it's vital to our lives in almost every other way—from our clothing, to our energy, to our food, water plays a role as an ingredient in just about everything we use and consume. Overall, water usage is typically broken down between three categories: agriculture, industry, and municipal. Agriculture accounts for the largest share of water consumed, at about 63%, followed by the water managed by municipalities and distributed to homes and business at about 22% nationwide, and finally from industrial usage (excluding thermo electrical cooling water which is recycled and not consumer) at about 14%.[5] Although, in some agricultural rural states, like Idaho and Nebraska, municipal usage only accounts for 1% of total water use, whereas in more urban areas like New York and New Jersey, it can account for up to 64% of total usage.[6] Therefore, the investment needs related to infrastructure and irrigation will vary greatly based on the state and in some cases, the individual county.

This is why although the water crisis is global, the stress and solutions are largely local. For example, crisis related to drought in the American Southwest will require different solutions than crisis related to flooding fields in the High Planes, or water contamination in Flint, Michigan. In

[4] (Piantadosi, Claude)
[5] (United States Geological Survey, 2015)
[6] (Gibbons, p 7)

order to best breakdown water crisis issues, it makes sense to categorize those of demand and those of supply, as they require much different solutions.

Demand is Increasing due to Population Growth

As of 2019, the United States population is about 327.2 million. According to the United States Census Bureau, the population will reach 400 million by 2058, or about 0.6% every year.[7] With millions of people living longer lives, demand for municipal water increases proportionally. Demand for industrial and agricultural water also increases due to the need to feed, clothe, and provide energy to more people. While an increasing population isn't inherently a problem, if water isn't managed effectively to handle the increase in demand, water resources will become strained over time. Based on research from the Food and Agriculture Organization of the United Nations, a leading provider of water data via their AQUASTAT database, each country has a relatively static theoretical amount of renewable freshwater. In the United States, that number is 3,069 *10^9 m3/yr*. As the population grows, the total renewable water resources per capita decreases. From 12,505 *m3/inhab/year* in 1987 down to 9,538 *m3/inhab/year* in 2014.[8] That's about a 25% decrease in renewable water resources per person over 27 years with no signs of stopping.

The difficulty in mitigating shifts in water demand is that it requires a monumental shift in our relationship with water and the desire (or lack of) to conserve it. For most people across the United States, they turn on the tap and water comes out—as much as they want, whenever they want. It's hard to imagine a world where water isn't ubiquitously available. Outside of population declines, the only way to reduce demand is through conservation. There are two ways conservation can occur: the first is conservation through socially conscious behaviors and the second is forced conservation through increased water prices. Unless there are significant advancements in water efficiency, the onus will be on consumers to reduce the overall industrial and agricultural demand of water via our consumer behaviors and purchasing habits.

While an increase in population will continue to positively shift the demand curve, changes in taste can counter that shift negatively. Water conservation is less about turning the water off when you brush your teeth and taking shorter showers (although, still important especially in times of extreme water stress), but more about understanding the water footprint embedded in the products we buy and the foods and beverages we consume. While policy action that enables more awareness of water usage like printing the water footprint of a product alongside the nutrition label or bringing awareness to the amount of water necessary for a hamburger might help, it likely would not be enough to significantly reduce demand alone. In reality, Americans learn about the importance of water conservation from a young age, but unless there's an awareness campaign with unprecedented emotional appeal, it's likely there needs to be financial incentives to conserve water.

---

[7] (United States Census Bureau, 2019)
[8] (Food and Agriculture Organization of the United Nations, 2014)

Through subsidies and direct access to water supply, most industries and farmers pay very little or nothing at all for their water; therefore, the true cost of water is not passed down to the consumer. In Diana Gibbons' book, *The Economic Value of Water*, she states, "[w]hen rates paid do not reflect the amount of water used or the marginal cost of providing the water, conservation will only take place under moral suasion or direct regulation." [9] Water pricing is a function of demand in most cases, because as water costs increase, it will likely be "partially absorbed and at least partially passed along" [10] through food and products. Assuming basic economic theory applies to normal goods and those with substitutes, as price increases there's decreasing movement along the demand curve. If McDonald's raises the prices of a double cheeseburger from $1 to $2, demand will decrease. If H&M increases the prices of denim from $40 to $60, demand will decrease. As prices increase for water intensive goods and services, consumers will likely change their buying habits to cheaper non-water intensive goods (pants don't have to be denim; lunch doesn't have to be beef). As demand decreases for these products, production will slow and less water will be consumed, ultimately resulting in less water withdrawn from the Earth—both from the surface rivers and lakes as well as underground aquifers.

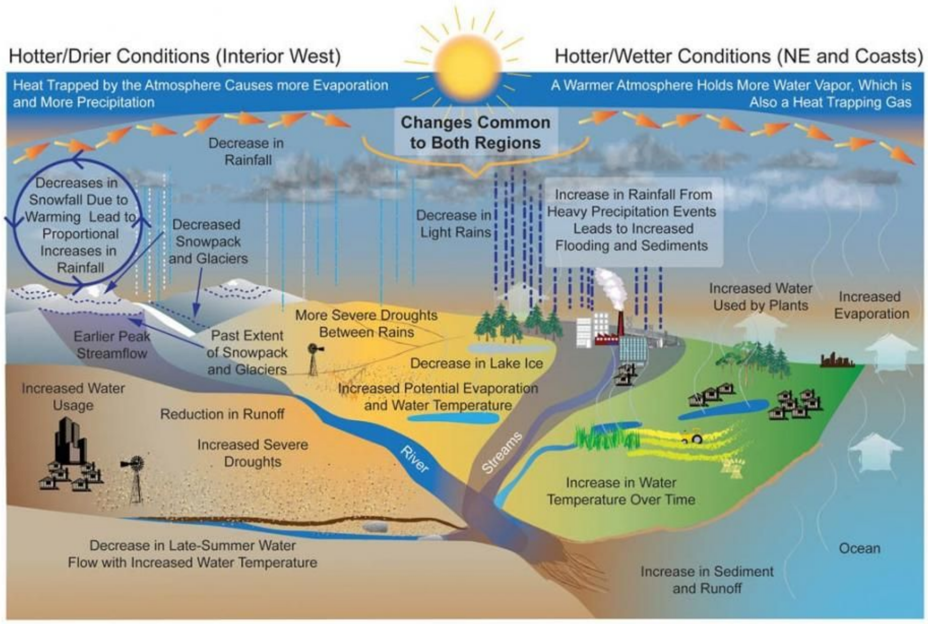
While price increases passed along to the consumer or absorbed by businesses and farmers would be met with backlash, it's important that the socially responsible rhetoric be attached to any proposals—especially ones that may make people's lives more difficult in the short term. As of February 2019, the Green New Deal policy document introduced by Representative Ocasio-Cortez (D-NY-14) and cosponsored by members of Congress has been met with both outrage and embrace. While it's largely a partisan debate about vague policy goals at this point, it's the first time in history millions of Americans are embracing a likely multi-trillion dollar proposal to fight climate change and prepare us for a sustainable future. These embrace of the policies at the expense of potential increased prices is only accepted because of the social and environmental justification of these measures.

Supply is Less Predictable Due to Climate Change

Aside from demand increases due to population growth, there are significant concerns related to the shifting and elusive supply of water due to climate change affecting the natural water cycle of evaporation and precipitation. According to Environmental Protection Agency (EPA) research during the Obama administration, our renewable water resources are becoming less dependable.[11] While the amount of total renewable water resources on average remains relatively static, "warmer temperatures increase the rate of evaporation of water into the

[9] (Gibbons, p 21)
[10] (Gibbons, p 55)
[11] (Environmental Protection Agency, 2017)

atmosphere, in effect increasing the atmosphere's capacity to "hold" water. Increased evaporation may dry out some areas and fall as excess precipitation on other areas."[12]



The graphic above, cited by the Environmental Protection Agency (EPA) and created by the USGS in 2009 shows how climate change has different extreme effects throughout the country.

The problem is our current infrastructure and water collection structures are based on pre-climate change water cycle patterns. The increased temperatures are causing less snowpack on the peaks of the Rocky Mountains, which affects the supply and flow timing of the Colorado River—a critical supply of freshwater for both public supply and irrigation usage. Farmers and municipalities have historically relied on the slow melting of snowpack to deliver surface water through rivers and streams from the mountains in a consistent manner deep into the summer months, when water demand is at its highest. As temperatures rise and heavy rainfalls occur, earlier peak streamflow causes severe droughts in late summer months in the American West and Southwest. As the elevation of the Colorado River decreases, so do its downstream dams and streams which cause a number of problems.

The Colorado River system supplies water for "33 million people in the cities of Los Angeles, Phoenix, Las Vegas, and Denver." [13] Aside from critically important freshwater supply for homes, businesses, and irrigation, hydropower efficiency is affected as well. According to EPA research, "[f]or every 1% decrease in streamflow in the Colorado River Basin, there is a 3% decrease in hydroelectric power generation for the region." [14]

[12] (Environmental Protection Agency, 2017)
[13] (Environmental Protection Agency, 2017)
[14] (Environmental Protection Agency, 2017)

Outside of the West, where drier arid climates become more harsh, in the wet High Planes and East Coast, there are opposite but equally extreme effects. These already wet climates in the Northeast and Midwest are beginning to experience more heavy precipitation events as temperature increases. Heavier rainfalls will overwhelm water infrastructure, like sewer systems and treatment plants. Additionally, "[h]eavy downpours can increase the amount of runoff into rivers and lakes, washing sediment, nutrients, pollutants, trash, animal waste, and other materials into water supplies, making them unusable, unsafe, or in need of water treatment."[15]

Finally, coastal freshwater supplies are at risk due to rising sea levels. As sea levels rise, coastal freshwater supplies "can increase the salinity of both surface water and ground water through salt water intrusion."[16] This means that water managers will either need to seek other water sources (difficult for islands, peninsulas, and other coastal cities), or spend money investing in expensive and environmentally damaging desalination operations. For example, in South Florida, almost all the freshwater is provided by the Biscayne Aquifer (groundwater), recharged by the freshwater of the Everglades. However, "[a]s sea level rises, saltwater will invade part of the Everglades, threatening both that ecosystem and the aquifer that lies beneath it."[17] Additionally, the impacts of dry arid coastal cities like Southern California are at greater risk. During drought conditions surface freshwater supply is limited so many municipalities and farmers rely on precious groundwater deposits—if that groundwater is contaminated or brackish due to high saline content, it becomes more difficult and expensive to use.

Water Sources and Issues with Groundwater Depletion

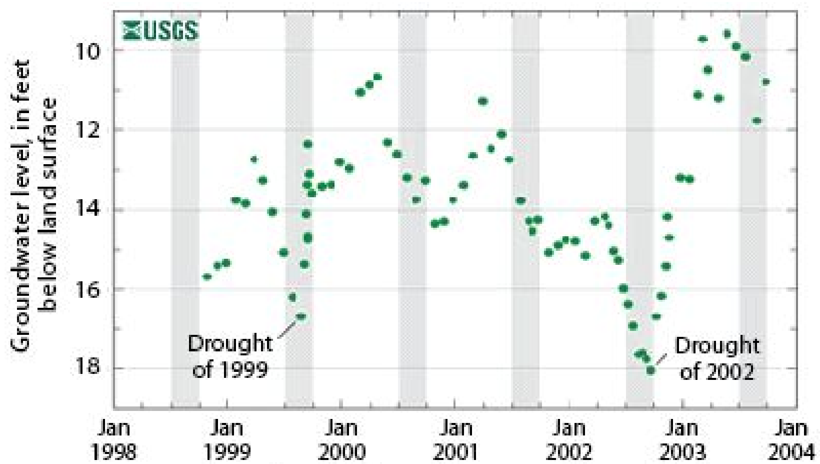
Freshwater withdrawals are split between surface water and groundwater aquifers. Surface waters include above-ground fresh and brackish water collected from rivers, lakes, and streams. Historically most freshwater collection came from surface water; however, water managers across the United States have increasingly turned to another source of freshwater—groundwater. Groundwater comes from aquifers beneath the surface of the Earth. Some are just below the surface containing water that's only a few hours or days old; some are hundreds of feet below the surface containing water that about 100 years old; and some can be thousands of feet below ground containing water that's several thousand years old. The deeper the water level is, the more expensive it is to pump to the surface.

Groundwater accounts for 31% of world's freshwater supply and about 20% of all water withdrawn in the United States is groundwater.[18] Most of that water withdrawn is for consumptive use in irrigation and public usage, with some cities and rural communities relying almost exclusively on groundwater for drinking water needs (private and public sources). The USGS describes groundwater as our water "bank account" because it acts as a savings

[15] (Environmental Protection Agency, 2017)
[16] (Environmental Protection Agency, 2017)
[17] (Environmental Protection Agency, 2017)
[18] (United States Geological Survey, 2015)

collection below the ground. We need to treat it the way a person treats their savings account. It is okay to dip into when funds are low (droughts) but cannot be relied on for long periods of time or else it will dry up.

When droughts cause a lack of surface water supply, water managers rely more on groundwater. This is okay in the short term, but can be dangerous in the long run. Groundwater is replenished from precipitation slowly seeping back into the ground. Climate change also plays a role in this process because higher temperatures mean increased evaporation which slows the refilling of aquifers in addition to their already slow rates. The USGS has cited a correlation between drought and overpumping leading to groundwater declines. The USGS produced chart below demonstrates how groundwater levels, measured in feet below land surface, increase sharply during periods of drought—up to 18 feet below the surface during the drought of 2002 (up from about 8 feet in normal conditions).

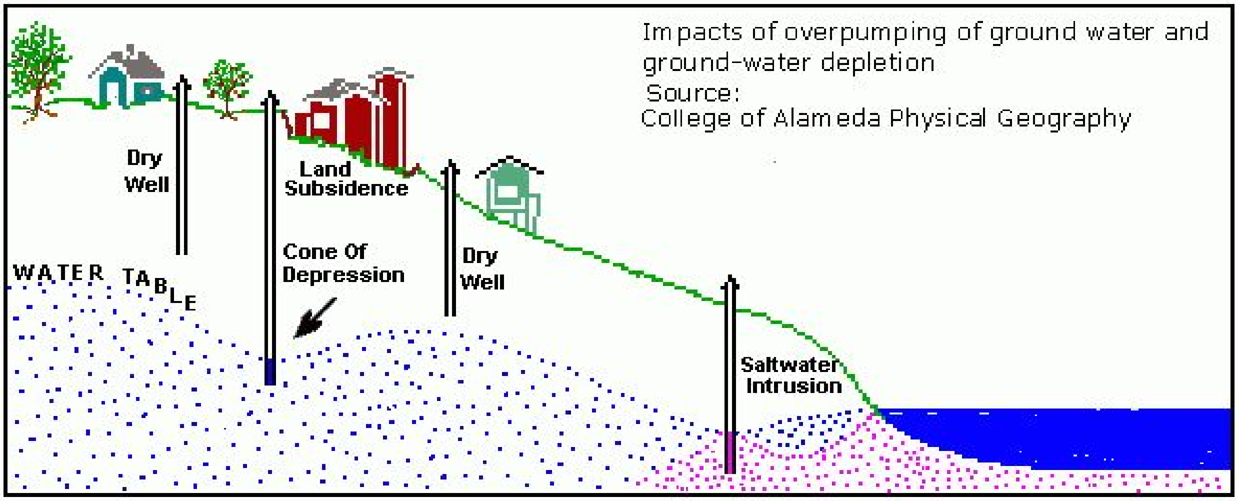


A 5-year groundwater-level hydrograph for water-table-aquifer observation well M0 Eh 20 in Montgomery, Maryland, showing seasonal variations in groundwater levels and the low levels during the droughts of 1999 and 2002.

In some cities, there’s over pumping without drought, like in the Chicago-Milwaukee area. Since 1864, groundwater has been the “sole source of drinking water for about 8.2 million people in the Great Lakes watershed.”[19] Long-term pumping has been lowering groundwater levels gradually since pumping began. The USGS estimates levels groundwater levels in the Chicago area to have lowered by 900 feet. Additionally, over-abstraction is occuring in the Atlantic Coastal Plain, West-central Florida, the Gulf Coastal Plain, the High Plains, the Pacific Northwest and the Desert Southwest—all seeing water level declines from groundwater pumping.[20]

[19] (United States Geological Survey, 2016)
[20] (United States Geological Survey, 2016)

The USGS cites the overpumping of groundwater “a real and serious problem in many places of the Nation and the world.”[21] Aside from water levels decreasing and wells drying up from over-abstraction, there are other significant adverse effects from groundwater depletion. Some of those negative effects include the “drying up of wells, reduction of water in streams and lakes, deterioration of water quality, increased pumping costs, and land subsidence.”[22]



The graphic produced by the USGS and displayed above illustrates these adverse impacts.

Doing More with Less Water

It is clear that growing demand (population growth) and changing supply (climate change) are reducing renewable freshwater per capita and creating, at times, severe pockets of water stress across the country. The solutions to these problems can be more difficult and complex than understanding the problems themselves. Solutions come in the form of dollar investments or strategy and behavior. Often, strategic and behavioral changes tend to be cheaper but slower and more difficult to enact, whereas investment dollars can be allocated immediately and objectively. **Ultimately, the goal of each policy, investment, or conservation action should be to reduce the overall water withdrawn from the Earth.** As was displayed in the previous supply and demand sections, the problems are local so the solutions must be too.

Investments

After water is withdrawn from surface or groundwater supplies, it is treated and delivered to its destination depending on its ultimate use. For water meant for the public supply—water that ultimately makes it to homes and businesses for personal consumption—the EPA provides strict treatment standards and delivery through special drinking water infrastructure. A

[21] (United States Geological Survey, 2016)
[22] (United States Geological Survey, 2016)

well-documented but significantly underfunded water issue is the United States' crumbling drinking water infrastructure. According to the American Society Of Civil Engineers' (ASCE) 2017 Infrastructure Report Card, both the overall infrastructure of the US as well as the drinking water infrastructure both received a grade of D. They estimate that it will cost about $1 trillion to repair old drinking water infrastructure just to get us through the next 25 years.[23] Part of their research was informed by the EPA's drinking water survey (released every 5 years) which analyses the investments necessary to maintain the nations drinking water infrastructure.

This research reveals that of the one million miles of pipes across the country, most of them were build in the 20th century with lifespans of just 75-100 years. Due to this aging infrastructure well overdue for repairs, there are about 240,000 water main breaks per year that lose over 2.1 trillion gallons of treated water a year, or six billion gallons per day from leaking pipes.[24] For perspective, that's enough to cover the personal water use of about 50 million Americans daily treated direct water needs for consumption (drinking, cooking, bathing, cleaning, lawn care, etc.).[25]

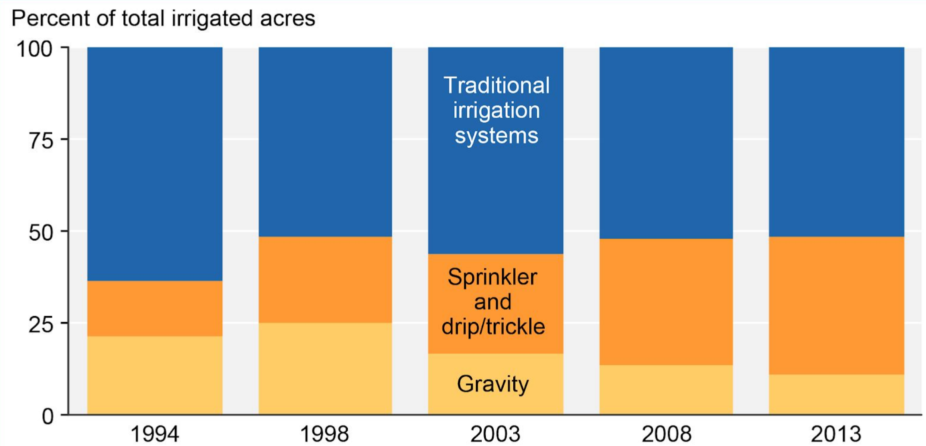
In addition to the six billions gallons of treated water lost every day from crumbling infrastructure, there are also severe concerns about clean water and public safety. One of the biggest and most high-profile examples in the past few years has been the crisis in Flint, Michigan. Aging pipes and inadequate water treatment caused up to 12,000 cases of lead poisoning[26] and twelve deaths.[27] The most recent estimates show there are still 2,500 lead service lines still in place as of April 2019.[28]

Because of climate change, increased flooding occurrences and frequency puts pressure on drinking water infrastructure in the Midwest, High Plaines, and Northeast as well. Water treatment plants can become "overwhelmed" by large amounts of water from rainfall.[29] Runoff from rivers and lakes can send debris, waste, and other garbage into the water supply requiring additional treatment.

[23] (American Society Of Civil Engineers, 2016)
[24] (American Society Of Civil Engineers, 2016)
[25] (Water Research Foundation, 2016)
[26] (Gaskin, Jamie, 2016)
[27] (Shamus, 2015)
[28] (Schwartz, 2019)
[29] (Environmental Protection Agency, 2017)

Improving agricultural efficiencies is an additional area of investment opportunity across the country. In the graphic below, produced by the USDA, there are still many farms that could benefit from smarter irrigation systems and move away from inefficient traditional irrigation systems like simply flooding the fields (over 50%).

Irrigated acres by system type, 17 Western States, 1994-2013



More efficient *gravity* irrigation includes furrow irrigated acres using above- or below-ground pipe, or a lined open-ditch field water-delivery system, plus acres in flood irrigation (between borders or within basins) on farms using laser-leveling and pipe or lined open-ditch field water-delivery systems. More efficient *pressure-sprinkler* irrigation includes acres irrigated using either drip/trickle systems or lower-pressure sprinkler systems (pressure per square-inch (PSI)< 30). The remaining irrigated acres were categorized as using "traditional" irrigation systems
Source: USDA, Economic Research Service using USDA, National Agricultural Statistics Service, Farm and Ranch Irrigation Survey (FRIS) data, various years.

Sprinkler and drip/trickle irrigation uses much less water but can be expensive. Investments are needed to make these efficiency conversions. According to the USDA, “about 90 percent of farms reporting irrigation improvements in 2013 received no public financial assistance (in the survey year). About 30 percent of the farms receiving public assistance for irrigation investments made use of the USDA Environmental Quality Incentives Program (EQIP), though these farms represented fewer than 5 percent of all irrigated farms that made irrigation investments in 2013.” [30] From this data, it’s clear that more public investment opportunities are possible.

Behavioral Changes

In the United States, each person uses about 123 gallons of water a day through direct personal consumption (both indoor and outdoor use) in the form of drinking water, cooking, cleaning, hygiene, and lawncare.[31] [32] Incentives to change these behaviors can come in the form of

---

[30] (United States Department of Agriculture, 2019)
[31] (United States Geological Survey, 2019)
[32] (Water Research Foundation, 2016)

financial reimbursement. For example, in Atlanta, Georgia, residents qualify for a $100 if they replace their toilet with a water-efficient one. [33]

While direct consumption can be important, especially during a water shortage, most of the water we use as consumers is embedded in our virtual water footprint. This represents the water that is used as an ingredient and in production in the products we buy and the food we eat. According to the Water Footprint Calculator methodology, the average US resident uses 2,200 gallons of water per day, after factoring in virtual water usage.[34] This is clearly a much bigger impact than personal direct consumption. Additionally, just diet alone for an average American represents almost 1,400 gallons of water; whereas, a vegetarian diet consists of about just 790 gallons of water per day.[35] That's a 43% reduction based on diet alone. Educating the public on these differences is the first step in a long road to reduce water usage.

Water policy is quite difficult, but what's most important to understand is that this is not an all or nothing approach. Ultimately, our relationship with water needs to change and that can only happen with a combination of behavioral changes and infrastructure investments.

Visualization Project

Data & Methodology

Given the wide scope of my project and the well-documented nature of this topic, I relied heavily on United States governmental agency data. Luckily, data from the United States Geological Survey and Environmental Protection Agency covered most of the needs for my project.

Data was mostly collected from US governmental organizations, including: the United States Geological Survey (USGS), the Environmental Protection Agency (EPA) [both the current website and the archived version which included climate change data until January 19th, 2017], the United States Department of Agriculture (USDA), and the United States Bureau of Reclamation (USBR) amongst other non-governmental sources for which you can find the direct links to the data in the sources section below:

[33] (United States Geological Survey, 2017)
[34] (GRACE Water Footprint Calculator, 2019)
[35] (GRACE Water Footprint Calculator, 2019)

Data	**Description**	**Access**
Food and Agriculture Organization of the United Nations (AQUASTAT Main Database)	Renewable Water Per Capita	http://www.fao.org/nr/water/aquastat/data/query/index.html
USGS	Water Usage Data (2010, 2015)	https://water.usgs.gov/watuse/data/
USBR	Shortage Odds in Lower Basin	https://www.usbr.gov/lc/region/g4000/riverops/crss-5year-projections.html
USGS	Live flooding map	https://waterwatch.usgs.gov/index.php?id=flood&sid=w__map
Leonard F. Konikow (USGS)	Groundwater Depletion in the United States (1900–2008)	https://pubs.usgs.gov/sir/2013/5079/
EPA	Drinking Water Infrastructure Needs Survey and Assessment (6th Report to Congress)	https://www.epa.gov/sites/production/files/2018-10/documents/corrected_sixth_drinking_water_infrastructure_needs_survey_and_assessment.pdf
ASCE (American Society of Civil Engineers)	Failure to Act infrastructure report card	https://www.infrastructurereportcard.org/wp-content/uploads/2016/10/ASCE-Failure-to-Act-2016-FINAL.pdf
USDA	Irrigation & Water Use	https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/#private
Eric Celeste	Geojson State and County	http://eric.clst.org/tech/usgeojson/
USGS	Various Shapefiles for mapping aquifers, the Colorado River Basin, and Rivers	https://www.usgs.gov/products/data-and-tools/gis-data
EPA	2017 Snapshot of aggregated various climate change research	https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-water-resource

		s_.html#Overview
Water Research Foundation	Residential Water Usage	https://www.circleofblue.org/wp-content/uploads/2016/04/WRF_REU2016.pdf

I will dive deeper into the narrative structure in the following section, but my approach consisted of summarizing the (mostly) USGS and EPA data a high level on water usage, climate change, groundwater, and infrastructure repairs followed by a small model that visualizes the difference in impact that behavioral changes vs. investments can have on annual water conservation.

The visual essay was built with Vue CLI 3, D3, Mapbox Studio, and QGIS. I also used the help of the graph-scroll.js library for scroll events and vue-slider-component for the slider components.

Narrative Structure

Heavily inspired by the explainer genre of storytelling in the web-based visual essay format, this project was crafted to fit within that paradigm. Because the water crisis is such a large and nuanced topic, a narrative journey which includes many scroll based animations and other time-based presentation methods allows a dense and long topic to feel smoother and digestible to a general audience. Following the same form as the historical background outlined in prior sections and influenced by the three-act structure of a screenplay, the narrative arc addresses the following:

1. Background
    a. Why Are We Running Out of Water?
    b. Where Does Our Freshwater Come From?
    c. How is Our Water Used? (both including and excluding thermoelectric water)
2. Water Stress
    a. Freshwater Withdrawals Per Capita
    b. Current Water Stress in the United States
    c. Case Studies
        i. Climate & Surface Water
            1. Extended Drought Affecting the Colorado River
            2. Flooding Across the Nation
        ii. Groundwater Depletion & Over-Abstraction
        iii. Drinking Water Infrastructure
3. Water Action
    a. Behavioral Changes vs. Direct Investments

In each of the sections above, a scroll based transition animation guides the user to the next point while the data simultaneously updates to a different view or subset of the data. This hand-holding approach can enable more complex storytelling and hold readers attention for longer. An animated approach allows for more control over where a reader's eyes should be at any given moment.

Storytelling & Design Decisions

I also found it necessary to move the arc along an additional cadence: from wide to narrow and back to wide through the three sections. Prose paragraphs connect the three sections and acting as a transition mechanism to introduce the next section and set of visuals. The following paragraphs will explain those decisions in greater detail.

1. Background

I open with a problem—we are running out of water per capita—but then instead of diving right into the stressed areas of the country, I provide some needed context around sources of water (surface vs. fresh) and usage of water over time (irrigation, municipal, thermoelectric, industrial, and other). This helps to paint a broad picture of freshwater usage, and let the reader adjust to the voice and most importantly, the vocabulary used throughout the piece.

By sticking to simple line and area charts in the first section, I reduce the cognitive load of the reader and enhance their ability to understand the information given to them over the course of the first section. This is because standard mapping techniques (bar charts, line graphs, etc.) don't require as much time to process the language of the chart as other more extrinsic and artistic mappings might. I found this technique useful, especially at the beginning of a long-form essay to not scare the reader away (but provides enough urgency to be interesting and engaging).

2. Water Stress

Second, I transition to the water stress section which incorporates a geospatial paradigm (built with mapbox studio, EPA and USGS datasets, and shapefiles). By moving from an overview of water told through charts to a lone map of the United States, it's clear we are about to look at water in a different, regional-specific way.

After learning about freshwater usage per capita by county, the next scroll trigger inverts the colors on the map from light to dark as we enter the water stress section. This transition, when seen for the first time can be startling, but it's meant to be a bit uncomfortable to show we are about to enter a potentially uncomfortable reality.

After using markers on a map to show water stress locations, the following map-based visualizations are split into three subsections. In the first, **climate**, both drought in the Colorado River Basin and flooding across the country. In the second section, **groundwater**, I show a national level view of the entire US, with aquifers mapped as shapefiles provided by the USGS. The aquifers are painted with color on a diverging scale in order to best map the data from the USGS groundwater study referenced in the previous section. The study compares depletion intensity from 2000-2008 compared to the entire 20th century. I calculated the percentage increase or decrease for each aquifer and mapped them accordingly. If depletion intensity is decreasing, it's mapped on a blue scale and if depletion intensity is increasing, aquifers on mapped a brown scale—the same brown hues I use throughout the piece to represent both drought and overall lack of water. Finally, in the third subsection, **infrastructure**, I use the EPA research on drinking water repair needs and display (one at a time, in rapid succession) the amount of dollars, in billions, needed to repair each state's infrastructure. This adds elements of drama and suspense as each state adds to this enormous total—ultimately ending in "$472.6 Billion" displayed on the center of the viewport.

Additionally, in the Colorado River Basin and drinking water repairs views, a panel on the right-hand side of the screen overlaying the map helps provide more context and additional organization of data—through line charts, data tables, and text—where solely geospatial data cannot communicate the entire idea.

3. Water Action

In the final section, I provide a small model to compare behavioral changes vs. direct investments in order to communicate, at a high level, what actions we can take that may have the biggest impacts. Using the water usage data from the USGS 2015 study, the Residential End Uses of Water report, and the Water Footprint Calculator, and the United States population, I made some simple calculations to convert users inputs, in percentage changes, to billions of gallons of water conserved per year. I determined that our direct water usage (drinking water, cooking water, cleaning water at home) is about 14.6 trillion gallons a year for the entire US population and that our virtual water usage (water used in production phases and as an ingredient in our food, products, and energy) to be 102.8 trillion gallons / year for the entire US population.

Additionally, there are two investment categories to compare and contrast. The first consists of drinking water infrastructure repairs for which I compared the data from the EPA study on drinking water investments needed and the Failure to Act report by the American Society of Civil Engineers data on water loss (six billion gallons / day)[36] to determine that for every dollar spent on infrastructure repairs over the next 20 years (as the EPA assessment recommends), we yield 92.68 gallons per year saved. The second investment category is smarter irrigation—specifically

[36] (American Society Of Civil Engineers, 2016)

farms converting to efficient drip irrigation from more wasteful irrigation techniques. Based on USDA research, there are 56 million acres of irrigated cropland in the United States.[37] If accounting for conversion pricing to determine the spending input and USGS water usage data on irrigation, I determined the factor for drip irrigation conversion to be 135. For every dollar spent on drip irrigation, 135 gallons of water are saved per year.

[37] (United States Department of Agriculture, 2019)

Conclusion

This project aims to educate readers on the water crisis in the United States and hopefully question their relationship with water. After learning how fragile our water cycle has become, the possibility that we could dry up groundwater aquifers, and the billions of dollars needed to repair infrastructure, my hope is that readers will consider putting pressure on elected officials to act with greater urgency, but also to consider their virtual water footprint when buying products and choosing their diet.

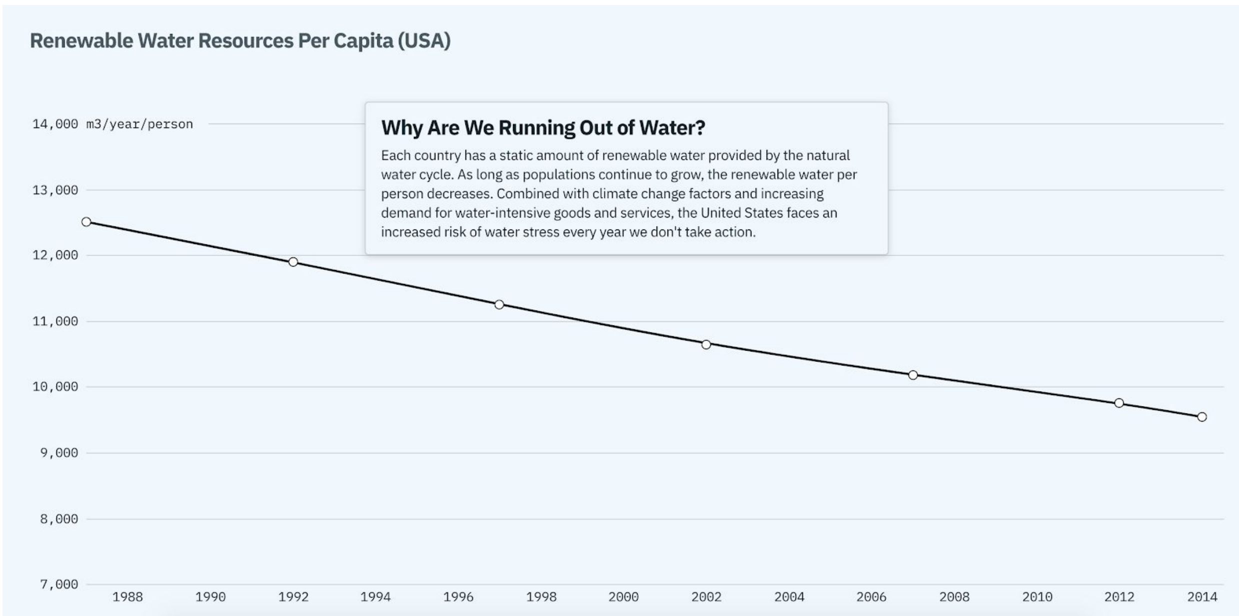
Although the first version of this project has been published, the project still has room for additional exploration. From a technical perspective, it would be impactful to the narrative if the visualizations—specifically the USGS climate related data mapping—pulled from live sources as opposed to static files pulled at the time of creation. This would maintain relevance as the web-based visual essay ages over time.

Additionally, there is room to expand the third section of this project. By breaking down behavioral changes in to smaller subsets, and by providing additional investment categories, the power of the model can reach its potential. This would enable readers to make specific lifestyle decisions based on the project, whereas currently it simply encourages them to continue research on diet, energy, and product consumption on their own.

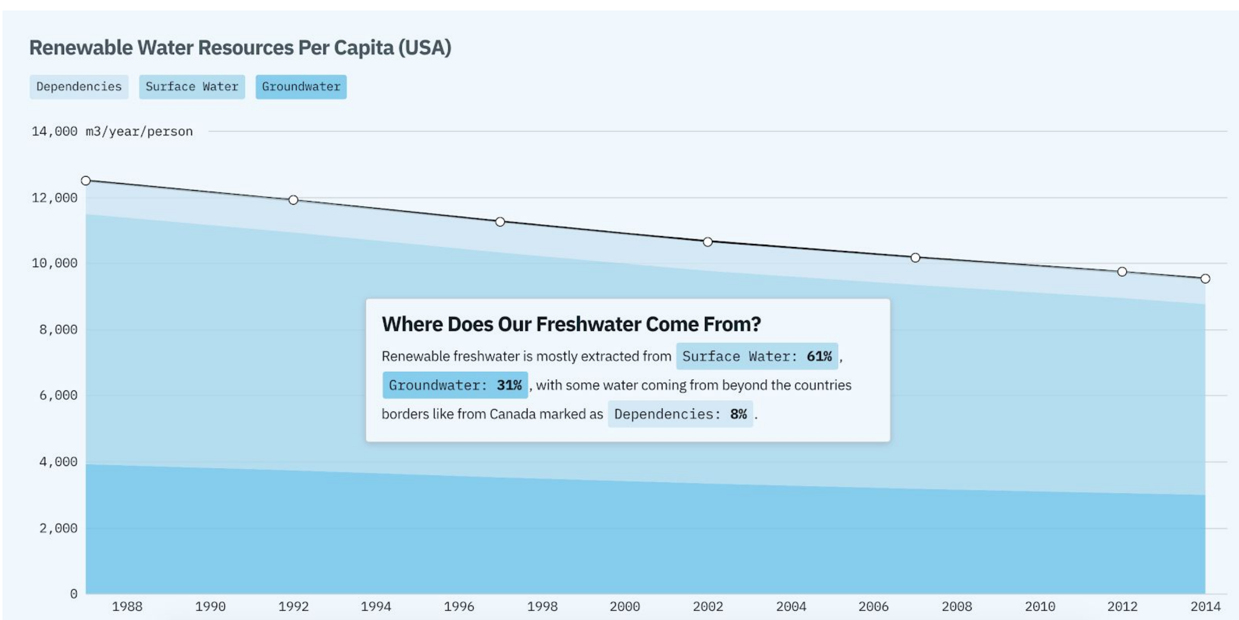
I hope this work will enable those to be mindful of water usage in their daily lives and conveys with critical importance that we must change our relationship with the most valuable natural resource on Earth.

Appendix

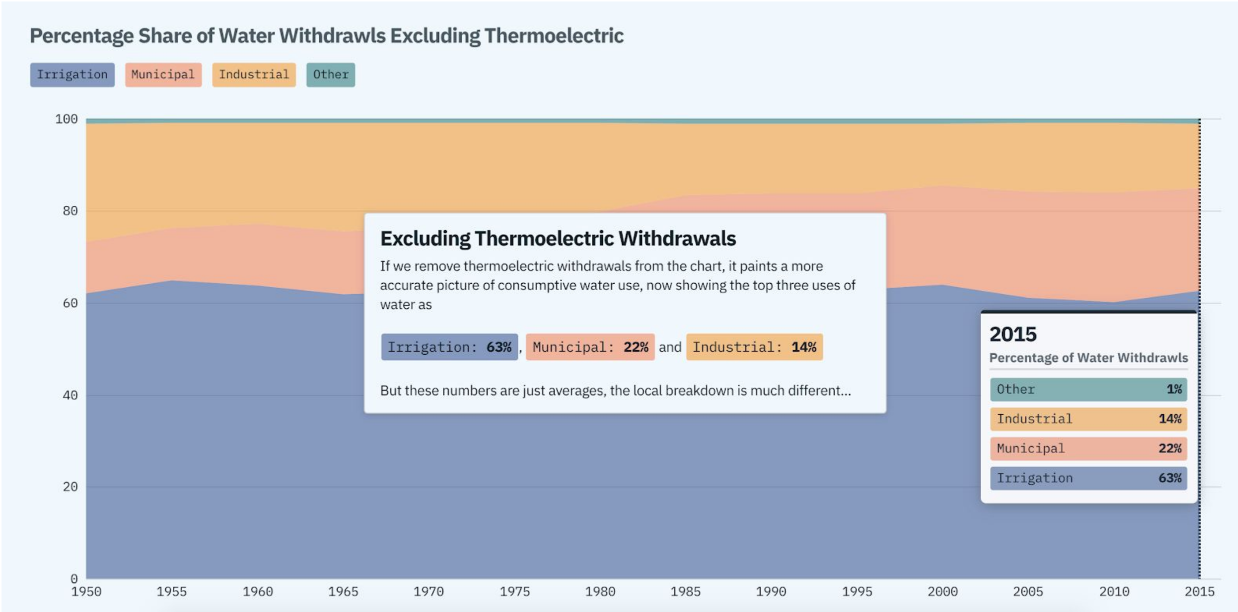
Below are images from my project in the order presented in the visual essay.



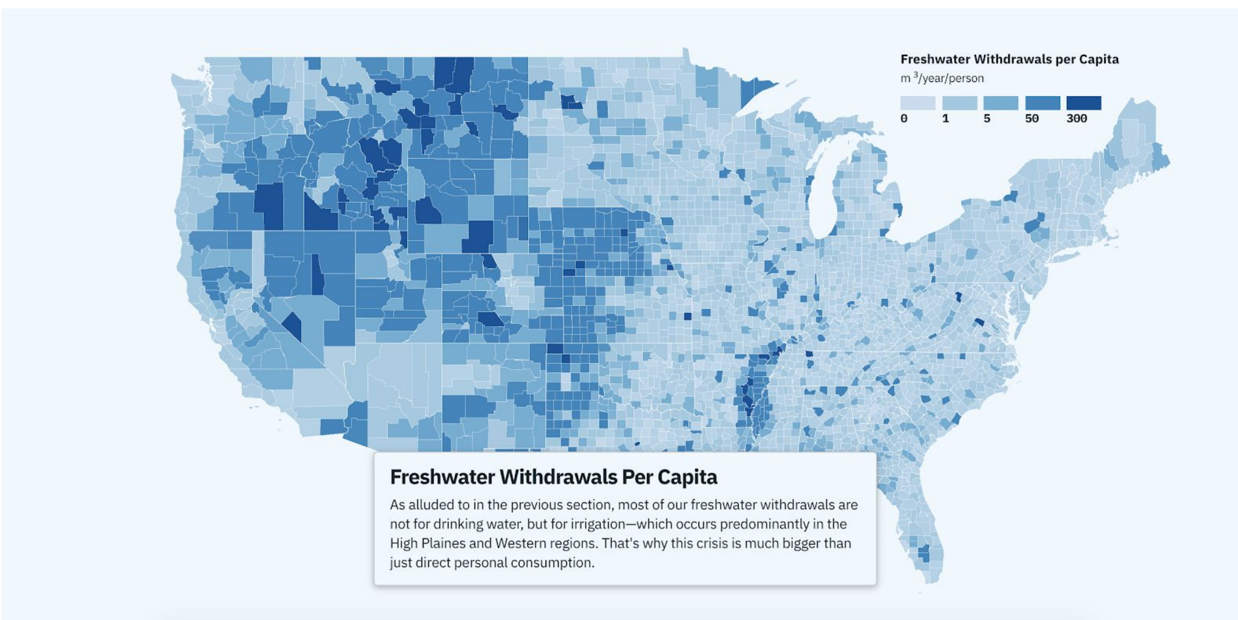
Why Are We Running Out of Water?



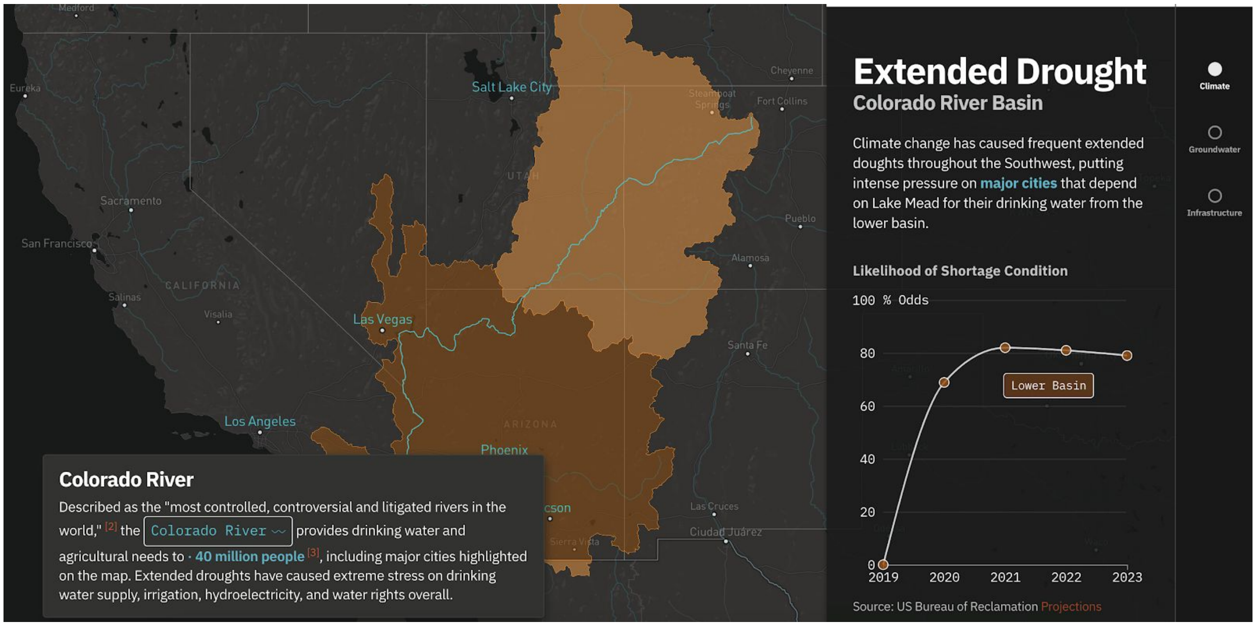
Where Does Our Freshwater Come From?



How is Our Water Used? (both including and excluding thermoelectric water)

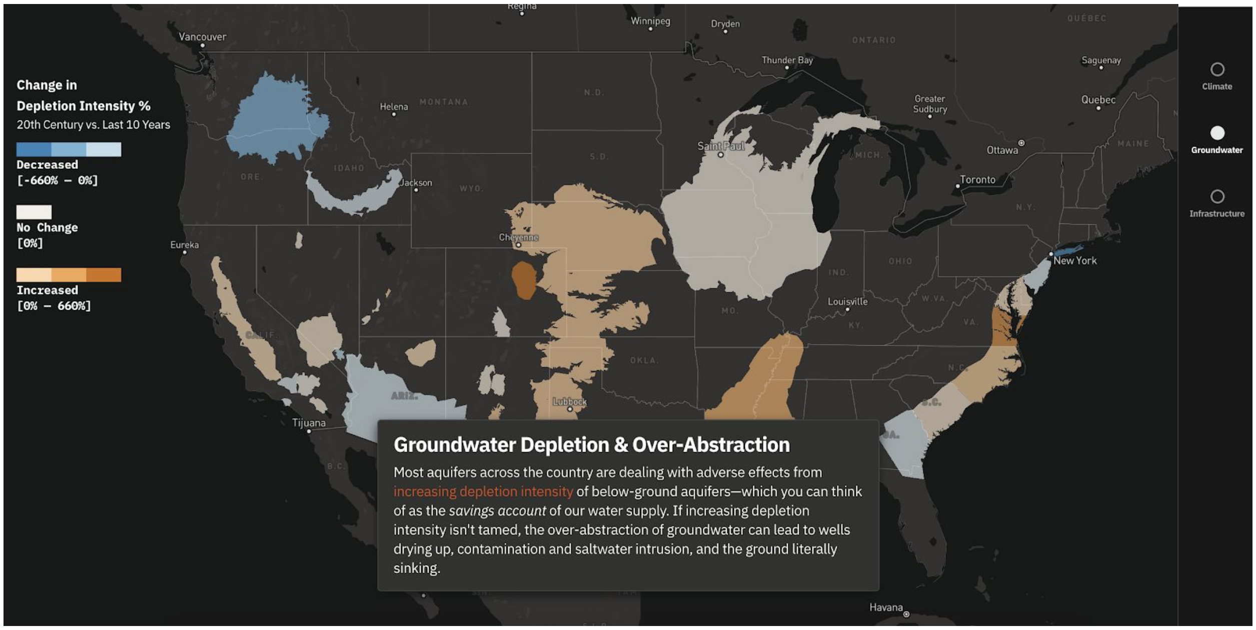


Freshwater Withdrawals Per Capita

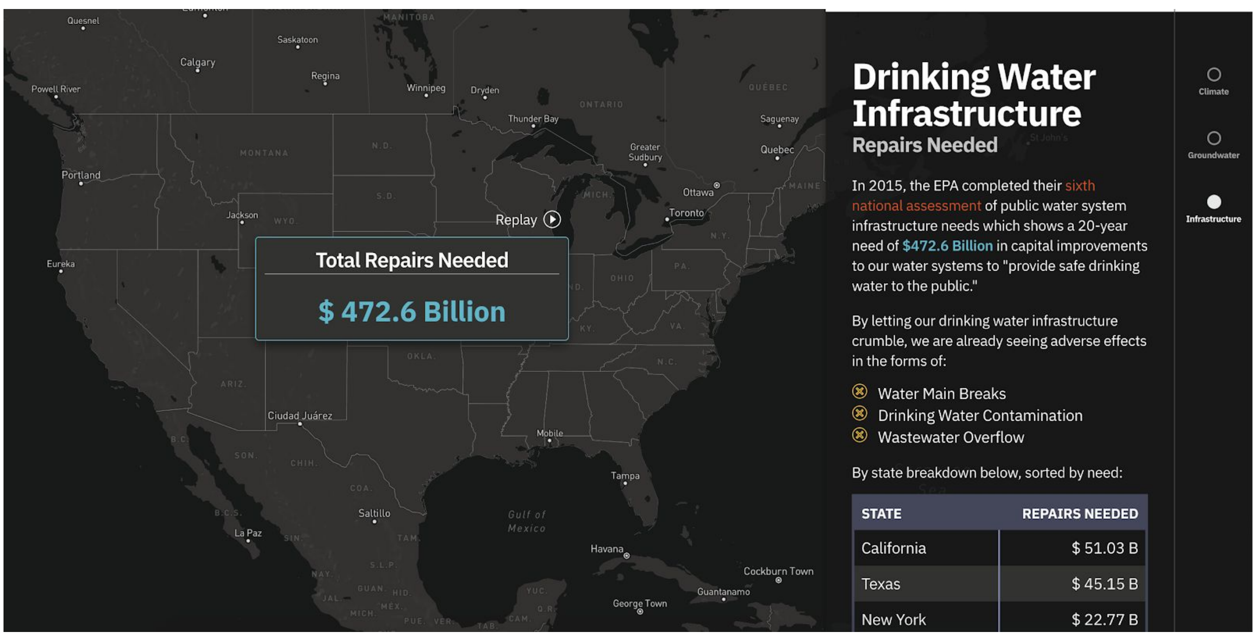


Extended Drought Affecting the Colorado River

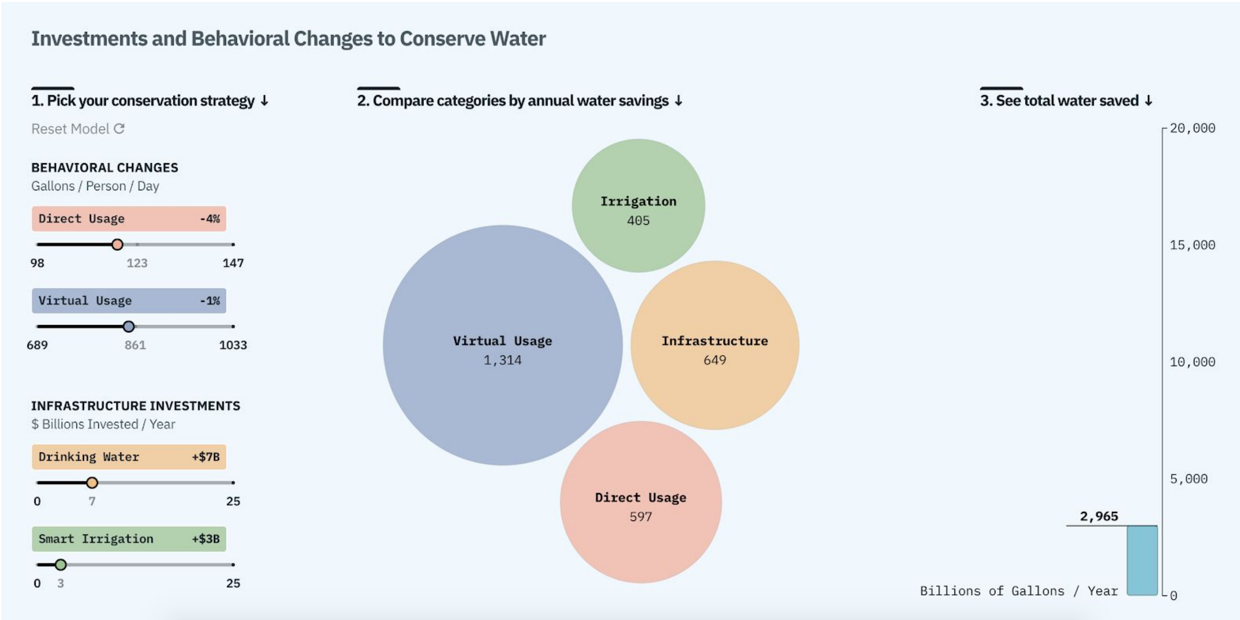
Flooding Across the Nation



Groundwater Depletion & Over-Abstraction



Drinking Water Infrastructure



Water Action: Behavioral Changes vs. Direct Investments

Bibliography

American Society of Civil Engineers. 2016. Failure to Act: Closing the Infrastructure Investment Gap for America’s Economic Future. Washington, DC.

Brichieri-Colombi, Stephen. _The World Water Crisis: The Failures of Resource Management: International Library of Human Geography_. New York, NY: I.B.Tauris & Co, 2009.

Costa, Albert B. 1981. "Water Crisis." Journal of College Science Teaching 11 (2): 120-121. http://www.jstor.org/stable/42988380

Durenberger, David. 1985. "VIEWPOINT: Is there a National Water Crisis?" Journal (American Water Works Association) 77 (2): 11. http://www.jstor.org/stable/41272304.

Feldman, David Lewis. _Water Policy for Sustainable Development_. Baltimore, MD: Johns Hopkins University Press, 2007.

Food and Agriculture Organization of the United Nations. "AQUASTAT Main Database." http://www.fao.org/nr/water/aquastat/data/query/index.html.2019.

Gaskin, Jamie. 2016. United Way Estimates Cost of Helping Children $100M Meredith Corporation.

Gibbons, Diana C. _The Economic Value of Water_. Washington, D.C.: Resources for the Future, 1986.

Glennon, Robert Jerome. _Unquenchable: America's Water Crisis and What to Do about It_. Washington: Island Press, 2009.

GRACE Communications Foundation. "Water Footprint Calculator." https://www.watercalculator.org/.2019.

Leonard F. Konikow. 2013. Groundwater Depletion in the United States (1900−2008): U.S. Geological Survey Scientific
Investigations Report 2013−5079,. Reston, Virginia.

Leonard, Liam. 2007. "The Galway Water Crisis." Studies: An Irish Quarterly Review 96 (384): 379-389. http://www.jstor.org/stable/25660510.

Mohai, Paul. 2018. "Environmental Justice and the Flint Water Crisis." Michigan Sociological Review 32: 1-41. https://www.jstor.org/stable/26528595.

PPIC Water Policy Center. 2015. California: Water for Farms. San Francisco, California.

Schwartz, Eric. 2019. "Roughly 2,500 Lead Service Lines Left to Replace in Flint." .

Service, Robert F. 2009. "California's Water Crisis: Worse to Come?" Science 323 (5922): 1665. http://www.jstor.org/stable/25471762.

Shamus, Kristen Jordan. 2018. "State: McLaren Flint was Primary Source of Legionnaires' Outbreak." Detroit Free Press. https://www.freep.com/story/news/local/michigan/2018/05/30/flint-water-crisis-legionnaires-disease-mclaren-hospital/653042002/.

Solanes, Miguel, Pablo Solón, and Denisse Rodríguez. _Water and Free Trade: A Social Vision of Water_. Bolivia: Agua Sustentable, 2007.

Stauffer, Julie. 2013. The Water Crisis : Constructing Solutions to Freshwater Pollution. Hoboken: Taylor and Francis.

The Economist. 2008. "Running Dry." The Economist.

U.S. Environmental Protection Agency Office of Water Office of Ground Water and Drinking Water Drinking Water Protection Division. Drinking Water Infrastructure Needs Survey and Assessment: Sixth Report to Congress. Washington, D.C.

United States Bureau of Reclamation. "Colorado River System 5-Year Projected Future Conditions;" https://www.usbr.gov/lc/region/g4000/riverops/crss-5year-projections.html.2019.

United States Department of Agriculture Economic Research Service. "Irrigation & Water Use." https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/#private.2019.

United States Environmental Protection Agency. "Climate Impacts on Water Resources." https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-water-resources_.html. 2019.

———. "How the Drinking Water State Revolving Fund Works." https://www.epa.gov/drinkingwatersrf/how-drinking-water-state-revolving-fund-works#tab-1.2019.

———. "United States Environmental Protection Agency." https://www.epa.gov/.2019.

United States Geological Survey. " Map of Flood and High Flow Condition (United States)." https://waterwatch.usgs.gov/index.php?id=flood&sid=w__map.2019.

———. "Data and Tools: GIS Data." https://www.usgs.gov/products/data-and-tools/gis-data.

———. "Water-use Data Available from USGS." https://water.usgs.gov/watuse/data/.2019.

UN-WATER and Richard Connor. 2015. The United Nations World Water Development Report 2015: Water for a Sustainable World: United Nations.

Water Footprint Calculator. GRACE's Water Footprint Calculator (WFC). New York, New York.

Water Research Foundation. 2016. Residential End Uses of Water, Version 2: Executive Report. Denver, Colorado.