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900 W 36th St.
Los Angeles, California 90089

April 28, 2023

Mr. E. Joaquin Esquivel
Chair
State Water Resources Control Board
1001 I Street
Sacramento, California 95814

Dear Mr. Esquivel:

California has been suffering from droughts for several decades and the impacts are expected to get worse due to climate change and overpopulation. Based on the water available, this volume will not be enough to sustain the predicted population by 2050. The consequences will include environmental damage to marine life and vegetation, increased erosion and wildfires, increased cost of water and for industries, difficulty maintaining sanitation in cities, and effects on agricultural output.

We currently have several mitigation tactics in place to remediate these impacts. Water managers are modifying reservoir operations to meet the changing supply and demand. There are turf replacement rebate programs in metropolitan areas such as Los Angeles that help reduce residential utilization of water and help replenish groundwater. There have also been many efforts by non-profit and non-governmental organizations to raise awareness for overpopulation and water use. Individuals have also taken action by using water-efficient appliances, fixing leaks, and taking shorter showers. Many farms use genetically modified (GM) plants that increase the yield of products using the same amount of water. We also utilize facilities to reclaim wastewater for various purposes. The state also funds the construction of recharge basins in order to replenish groundwater.

We suggest using data to determine the water inflows to manage water at a more accurate rate instead of referring to the fixed usage rates we have in place. Water managers should modify water rights agreements to discourage overuse and incorporate better communication between the government and cities for water plans. The state should observe and follow the successful turf replacement rebate program in Los Angeles and create a similar, state-wide, rebate program. It should also run awareness campaigns for water conservation in times of wet periods as well as campaigns that encourage people to choose less water-intensive foods. Due to the benefits of GM plants, funding should be increased to research GM plants as well as increase education about the harmlessness of GM foods. The state should also fund rebate programs for the installation of gray water systems in residential and industrial properties. Water recharge basins should be funded more aggressively in order to take advantage of floods and precipitation.

Our team has a great interest in this water problem and would appreciate your consideration in implementing our solutions. Please let us know of your thoughts and concerns.

Sincerely,

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Water Shortages in the Southwestern U.S.

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Proposed to:
University of Southern California
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April 28, 2023

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Abstract

The current drought that has been ongoing for 23 years since 2000 has surpassed the intensity of the mega-drought of 1571–1592. Our population has grown immensely, which will make more people susceptible to drought's negative effects.

There are several mitigation tactics in place to remediate these impacts. These include changes to reservoir operations, water transfers, turf replacement rebate programs, awareness campaigns for overpopulation and water use, individuals taking action by conserving more water at home, farms using genetically modified (GM) plants that increase the yield of produce, facilities to reclaim wastewater, and also the construction of recharge basins in order to replenish groundwater.

It is crucial to use more accurate and live data to determine the water inflows to manage water at a more accurate rate instead of referring to the fixed usage rates currently in place. The successful turf replacement rebate program in Los Angeles would have a large impact if implemented at the state level. If awareness campaigns for water conservation continue to run in times of wet periods, water demand can be alleviated when transitioning to dry periods. Campaigns that encourage people to choose less water-intensive foods would help our cultural overconsumption of meat and other water-intensive foods. Funding for GM plants should be increased to research and produce more water-efficient crops, and increase funding for education on the harmlessness of GM foods. As gray water systems are efficient in reusing water, they should be installed in more residential and industrial properties. More water recharge basins should be constructed in order to take advantage of floods and precipitation to replenish groundwater.

Executive Summary

The southwestern region of the U.S. has been and still is susceptible to heavy droughts. Droughts are a major hurdle for the people living in the region, causing widespread harm to multiple areas such as agriculture, industrial and individual consumption. The effects of the recent mega-drought are still ongoing. We must take into consideration all of the multiple aspects of drought, meteorological, agricultural, hydrological, and socioeconomic, so that we may deal with its effects which also span multiple areas of society more effectively.

Agriculture accounts for approximately 80 percent of all the water used in California. There are certain key crops such as almonds and other tree nuts that consume large volumes of water while not being able to contribute a corresponding amount to the state's economy. Further, dairy farms take a great toll on the quality of surrounding groundwater and increase the volume of salts found in these freshwater reservoirs. When this happens, it can impair crops, degrade drinking water, damage industrial equipment and even lead to the retirement of land. Therefore, it would be shrewd to reduce the number and volume of these almond and dairy farms.

More than 40% of the world's population suffers from water scarcity. A person needs a minimum of 20 to 50 liters of clean water per day for drinking, cooking, and personal hygiene, according to the World Health Organization. Individuals can protect water quality by acting responsibly and by conserving water. The average American uses about 300L of water each day, with up to 30% of that amount going to outdoor uses. They can be responsible by using environmentally friendly products and properly disposing of hazardous household items. They can also conserve water by making small changes to their daily routines, such as fixing leaky faucets, taking shorter showers, and using less water outdoors. They can also upgrade older, inefficient appliances with water-efficient models can significantly cut down on water usage. Reducing meat consumption and eating a more plant-based diet can significantly reduce an individual's water footprint. Additionally, choosing produce that is in season and locally sourced can cut down on the amount of water used for storage and transportation.

In the West, the primary doctrine governing water rights is prior appropriation which focuses on assigning rights on a "first come first serve" basis which contrasts with riparian water rights which emphasizes the importance of using water without harming neighboring communities that use from the same source. In the West, this system of water rights has led to the overuse of water, especially during droughts since conservation is not encouraged. Instead, the responsibility can be put on the junior water rights holders to work with less water or find other means. While the current system has many disadvantages, it was implemented in the past to ensure the security of farmers and urban centers due to the scarcity of water. It also incentivized them to spend money to develop infrastructure to make use of the resources available. In the West, the biggest state agreement is the Colorado River Basin Compact which splits the states into the upper and lower basin such that the lower basin is promised 7.5 MAF of water per year. However, this is no longer appropriate due to the fluctuating changes in water inflows each year and should be modified.

The drought has led to many current and foreseeable impacts on both the environment and the economy. Environmentally, the drought has resulted in 100 million forest tree deaths due to insufficient precipitation, dry soil, and rising temperatures. The dead trees and plants lead to a high fire risk which negatively affects the health and safety of nearby communities. The drought has also led to damage to the aquatic system which has resulted in many species of fish that are endangered or becoming endangered which leads to an expansion of invasive species. Economically, agriculture yield and livestock have been affected by insufficient water. The drought has also affected other industries such as hydropower and recreation. Overall, the drought is expected to exacerbate both environmental and economic problems.

To work with the drought in the West, the water rights appropriations should be modified similarly to Australia after their severe drought. The system should be overhauled such that the government is the sole owner of water rights and provides licenses to use water to better control its distribution and have better accounting. It can also use that power to decide on allowed agricultural crops during the drought. In addition to modifying water rights, there should be a better use of technology to manage water using modeled future water conditions and real-time data. These should be incorporated in water management plans where the government and cities need to work together closely to manage the watershed rather than city boundaries more effectively. Lastly, in the water plans agriculture should be included in water plans since it accounts for most of the water usage.

Planting native or drought-resistant plants along with the installation of drip watering devices has proven to increase the efficiency of water use in all residential applications. As seen with the success of Los Angeles' turf replacement rebate program, the state should adopt similar rebate programs that can be applied to all residents after meeting their own set of conditions. On this note, it has been found that media presence surrounding the importance of conserving water is correlated with habitual differences by residents. Since this behavioral habit reverts back to wasteful ways, it would be influential to continue running water conservation campaigns even in wet periods in order to maintain safe water storage levels when transitioning to dry periods.

Groundwater can be a reliable source of water, but it is important to remember that they recharge very slowly. Especially during times of drought, groundwater is vulnerable to being depleted, which would cause irreparable damage to the local environment such as land subsidence and saltwater intrusion. Thus we need to take an active role in managing the groundwater supply with groundwater replenishment. To use both direct and indirect replenishment methods effectively, the government should build new and improve existing water infrastructure projects that can be used for water replenishment.

0. Introduction

California has been suffering from droughts for several decades and the impacts are expected to get worse due to climate change and overpopulation. Our current data on water supply suggests that there will not be enough water to sustain the water demand of the increasing population by 2050. The consequences will include environmental damage to marine life and vegetation, increased erosion and wildfires, increased cost of water for everyday use and industries, difficulty maintaining sanitation in cities, and effects on agricultural output. The current drought that has been ongoing for 23 years since 2000 has surpassed the intensity of the mega-droughts of the past, and our population will only continue to grow, which will make the negative effects of the drought more severe. There have been solutions introduced and implemented in the past, with all of them having varying effects.

1. Background

1.1 History of Droughts in the Southwest

First off, what is the definition of a drought? Merriam-Webster Dictionary defines it as "A period of dryness especially when prolonged." [1]. But how much, exactly, does an area have to have a period of dryness for it to be going through a drought? How much less water than usual counts as 'dryness'? This is a tricky question even for scientists, and there have been more than 150 different definitions for a drought during the 1980s in published papers [2]. The reason there were so many different ways droughts were defined was because they reflected different water demand and supply situations of different subject regions. Thus, understanding droughts is very complicated and differs by the context and subject region. Nonetheless, it is very important to have a clear definition so that we can use our resources as efficiently as possible when dealing with droughts.

In modern discourse about droughts, four different types of definitions are used [3]. The first is Meteorological, which is a period of reduced rainfall compared to average levels. Since this definition relies on what is a 'normal' amount for a region, an amount that is considered fine in one could be considered a severe drought in another. The timespan that one calculates the average precipitation may also differ based on the purpose of the research and the area of interest. For California, the average annual rainfall is 22.2 inches, where the U.S. statewide average is 30.21 inches [17]. We can see the effects of the drought for years 2021 to 2022 in figure 1 below. Second is the agricultural definition, where there is not enough water available to fully support the cultivation of a certain crop. Some amounts of rainfall might be a drought for growing certain kinds of crops, where it might be the optimal amount for others. Under this definition, what counts as a drought can differ based on cultural, economical, and geographical factors. The agricultural aspect of the drought is discussed in section 1.2.1.2 Water Footprints of

Different Crops. Third is the hydrological definition where status of a drought is determined by the water levels of surface and subsurface water supplies such as lakes and rivers. We can see the drought in the southwestern U.S. from the dropped water levels of Lake Mead, an important source of water for the region, in figure 2 below. Alongside rainfall amount, water levels are an important parameter that the government bases its water management policies on such as deciding when to regulate consumptions in certain areas [18]. Fourth is the socioeconomic definition where a drought is defined by the effects of a water shortage felt by humans. This is a more subjective definition that focuses on human behavior and society. These different definitions of droughts hint to the complexity of dealing with droughts as its effects span multiple layers of human civilization and the environment. It also provides us a good starting point in addressing the harmful effects of droughts. In this paper, we will be looking at these definitions, visiting each when it is appropriate.

As mentioned above, the location that the drought is occurring at is a crucial factor for understanding droughts. It determines whether or not there even is a drought occurring in the first place, and also determines which measures are available and which are the most efficient in dealing with droughts. Thus, in order for there to even be discussion about droughts, it is imperative to define which areas in the globe we are talking about. In this paper, we will be focusing on the south western region of the United States, or more specifically, the colorado basin area and surrounding regions, shown by figure 3 below.

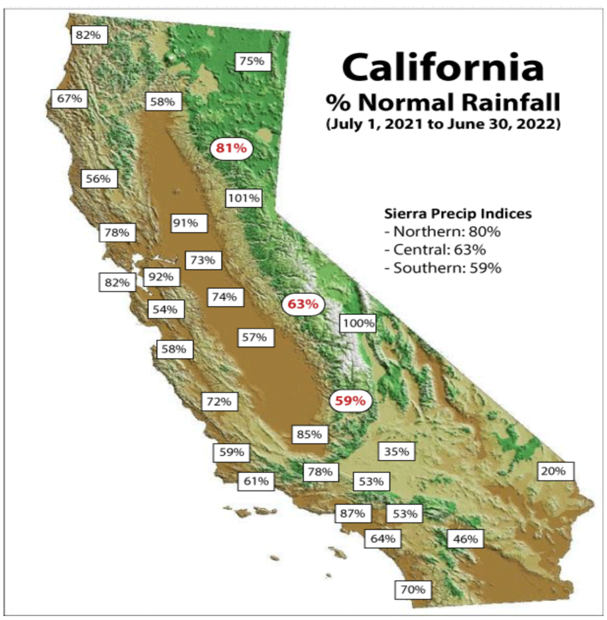

Figure 1: Percentage of rainfall to the average rainfall for regions in California 2021-2022 [18]

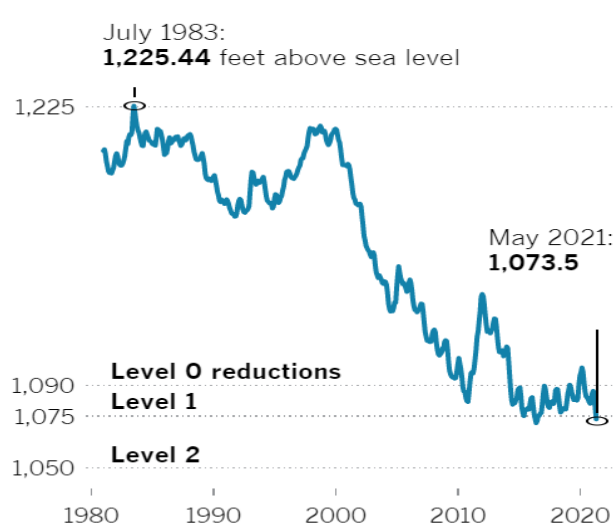

Figure 2: Water surface level of Lake Mead 1980-2020 [19]

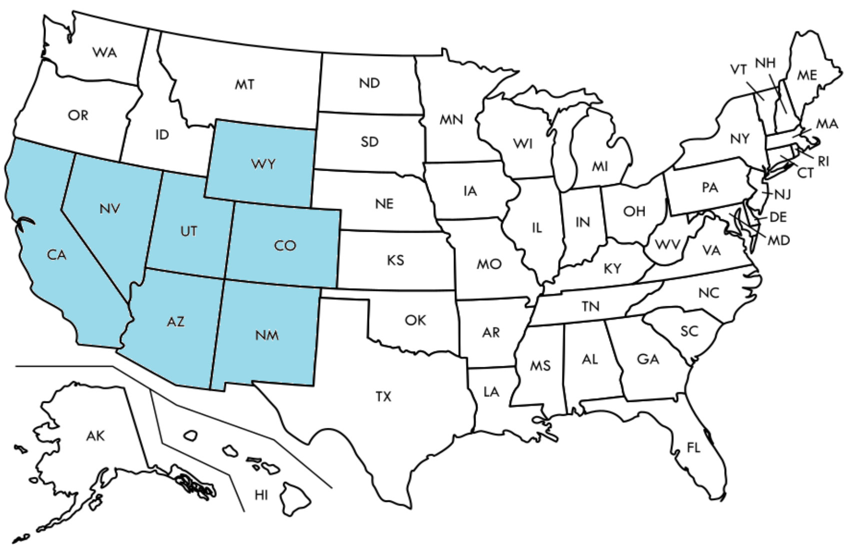

Figure 3: Map of the southwestern US (Edited from [4])

Even centuries before the southwestern region became part of the U.S., droughts were a major threat to survival its inhabitants needed to overcome. Scientists were able to gather data on droughts that happened in the region in the past by studying tree growth rings. Trees grow at different rates depending on the environmental conditions. They grow fast when there's ample resources such as water and ideal temperatures, and grow slow vice versa. Thus, by measuring the tree rings' lengths, we can estimate how the climate was in the past and discover droughts that occurred in premodern times. Out of all of the frequent droughts the region experienced, four mega-droughts stand out for their long duration and extreme dryness. These droughts happened during 863–884, 1130–1151, 1276–1297, and 1571–1592 A.D. These mega-droughts were 0.25 standard deviations more intense in dryness than any droughts recorded in the 20th century [6].

Among the four mega-droughts, it's worth noting the 1276-1297 drought, also called the Great Drought. During the time, one of the major civilizations inhabiting the region was the Ancestral Puebloans. They lived in the areas that are the modern day states of Arizona, New Mexico, Colorado, and Utah [7]. As the Ancestral Puebloans were mostly farmers, the mega-drought had a particularly severe negative effect on their survivability. This, combined with other factors such as increased hostilities with neighboring tribes (which were also caused in part by crop failures from the drought), made them decide that they could no longer inhabit the region, and drove them to abandon their homelands in which they'd lived for generations before [8].

The drought of 1571–1592 was the most severe of the four. It was the worst drought in 1,000 years and it lasted for 40 years [5]. Similar to the Great Drought, this also caused mass migrations and increased hostilities between tribes and European settlers. Records of Spanish settlers in the area show accounts of the suffering of the people in the area [5]. Combined with a deadly epidemic and European conquest, the drought claimed the lives of many living in the southwestern region of the U.S. both indigenous and the new settlers [9].

A modern example of a severe drought striking the southwestern US is what is known as the Dust Bowl. The term Dust Bowl refers both to the drought that hit the region in the 1930s and the region itself [10]. The US government encouraged migration to the west during the late 1800s. Most of these migrants were farmers, thus leading to greatly increased farming in the area. Soon, the soil of the area was being overfarmed. This, combined with a wet period of increased rainfall, led to poor water management and depletion of the soil. Then, the Great Depression hit the region, causing crop prices to plummet. This led to farmers overturning their crop fields in order to harvest a bumper crop and break even. The final blow was a severe drought in the area, leading to plants dying. Without plants holding the soil down with their roots, the ground began to erode, causing the ground to lose its crucial topsoil, leading to massive dust storms all over the US, and worsening the crop failures.This lasted till 1939 when rainfall finally returned and caused the dust to settle [11].

These mega-droughts are not something of the old legends though, as we might be currently living through a historical drought. The current drought that has been ongoing for 23 years since 2000 has surpassed the intensity of the mega-drought of 1571–1592 [12]. Water levels are the lowest ever recorded for important water reservoirs such as Lake Mead as mentioned before, and the moisture deficit in soil is twice as worse than any drought recorded in the 20th century [13]. Although most of the drought is due to the natural characteristics of the region, part of this new historical record is due to human activity. Researchers estimate that 42% of the current drought can be attributed to the increased temperatures caused by human caused climate change [13].

As severe droughts were common in the area, people actively tried various methods to prepare for one and lessen its adverse effects. The most significant of these methods would be the construction of dams. The most well-known of the dams concerning the water supply in the southwestern region would be the Hoover Dam, built in the 1930s. However, in the light of recent mega-droughts of never before seen levels, these measures might not be enough, as water supplies such as Lake Mead are slowly getting depleted to dangerous levels as mentioned before [14].

What is our situation today? Currently, more than 92 percent of Californians rely on public or private water suppliers for their everyday water needs. 82 percent of the water these suppliers utilize is from surface water sources such as rivers and lakes [15]. On the water consumption side, there are three big areas: environmental, urban, and agriculture. Urban and agriculture are self-explanatory, but environmental means the water that is not utilized for the purpose of conserving the environment or scenery. The makeup of these three areas of the total water consumption varies greatly depending on whether it is a wet year or a dry year. In wet years, environmental use makes up 60 percent of total water use, followed by agricultural use at 29 percent, and urban use at 8. On the other hand, during dry years, agricultural use is the most at 61 percent, then environmental at 28, and urban at 11 [16]. This is because in times when water is scarce, environmental water that is protected otherwise is freed up to be used by humans.

With the recent intense rainfall the region received due to the atmospheric rivers, a trail of moisture from the tropical areas to the poles, it may seem as if the region is no longer in drought. Indeed, the increased rainfall in recent years have given hope for the region. However, it is too early for the increased rainfall to undo the effects of the severe drought that hit the region for years before. As one scientist put it, a single paycheck for someone who hasn't gotten it for half a year wouldn't solve their financial problems. By a meteorological definition within the span of a couple recent years, the drought may be no more. However, the damage caused by the drought is not yet undone, as surface water levels such as the crucial Lake Mead and others are still at record low levels. Thus for the current drought to be over fully in all definitions of drought, it would take another couple of years of positive outcomes that undo the effects it had on the region's water situation.

Considering how previous mega-droughts caused widespread turmoil for the communities, premodern or modern, it can be said that we must learn from the past and try our best to come up with ways to effectively deal with the adverse effects of the ongoing mega-drought. The bad news is that our civilization is far more complex and dependent on resources than those of the past. Also, our population has grown immensely, which will make more people susceptible to drought's negative effects. All the negative effects of the mega-droughts mentioned above, such as mass environmental refugees and societal collapse, still remain a very real threat even to our modern advanced societies. The good news, however, is that we have more advanced technology, higher political capacity, and more experience with handling droughts than societies in the past. Thus, by incorporating the knowledge of both past and present, we will be able to deal with droughts more effectively.

1.2 Corporate Impact

Corporations and small businesses consume a majority of used freshwater in both wet and dry seasons. This section will dive into how much freshwater different industries consume.

1.2.1 The Agro-Industry

This section will outline the different aspects of the farming businesses that consume freshwater. These points will include dairy farming's impact on groundwater salinity, the amount of water used to grow food for humans and animals, and what we grow as a commodity to export.

1.2.1.1 Dairy Farming's Impact on Groundwater Salinity

The dairy-salt cycle is one that should be self-sustainable when maintained. The process starts when dairy cows consume salts found in feed and then excrete them in the form of milk and manure (which includes both solids and fluids) [20]. The manure is collected and then applied in the form of both composted and liquid manure fertilizer back to the forage crop lands [20]. These crops remove some of the land salts in the form of macro and micro-minerals and are then cultivated and stored [20]. These stored crops are then used to feed the herd again or sold off[20]. As the salts are also taken from the herd in the form of milk, more forages and concentrated feed are given to replenish their salt [20]. The salts that were not pulled from the land by the crops leach deeper into the soil and become loaded to nearby groundwater basins[20]. When high amounts of salt are introduced into the groundwater, it can impair crops, degrade drinking water, damage industrial equipment and even lead to the retirement of land[20]. From the results from seven different studies, it was found that "the average dairy cow leeches 1.2 tons of salinity to groundwater each year" [20]. To translate this to "a per acre basis, this equates to an average of 3.5 tons of salinity loaded to groundwater per acre of dairy forage field per year" [20].

1.2.1.2 Water Footprints of Different Crops

In order to take a look into how much water each type of crop consumes, it is insightful to also take into consideration the purpose in which this water is being used. Therefore, we will examine water footprint to nutritional value, economic value, and total market value.

It can be argued that nutritional value is the most important figure to examine as that is what is fundamental to all living beings. Some crops that have low water footprints may also have low nutritional value while others may have high water footprints and still provide a highly nutritious food [21]. The figure below depicts a wide range of crops grown in California and the water footprint values on the horizontal axis and average rank of 11 nutrient categories on the vertical axis.

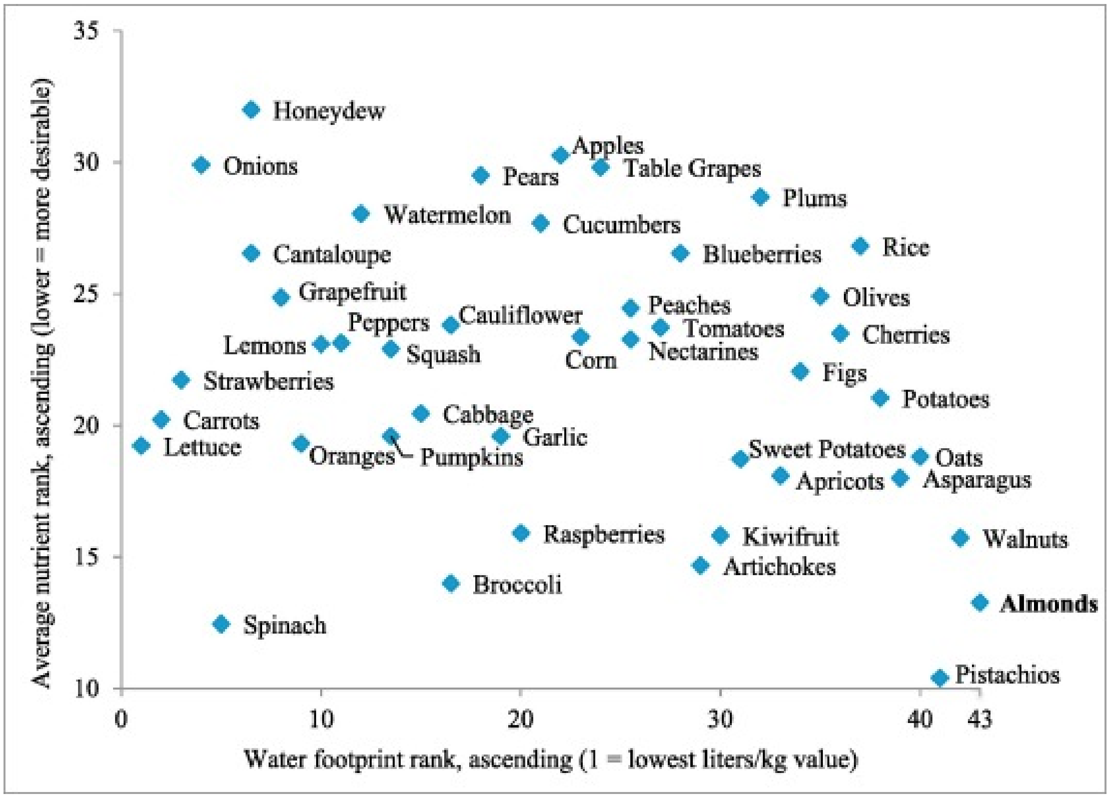

Figure 4: “Major California crops ranked by water footprint values” “and average rank of 11 nutrient categories” from [21]

In the above figure, it is clear to see that almonds, pistachios and other tree nuts have a high water footprint while also producing high nutrient content [21]. In contrast, produce like honeydew and onions do not consume much water while also not producing fruit with high nutrient content [21].

When we compare these crops in a different perspective- from that of economic value, we can see how more context can be shed onto the scene. The figure below depicts crops grown in California and the water footprint values on the horizontal axis in L/kg and ranked by average farm-gate price on the vertical axis in $/kg price [21].

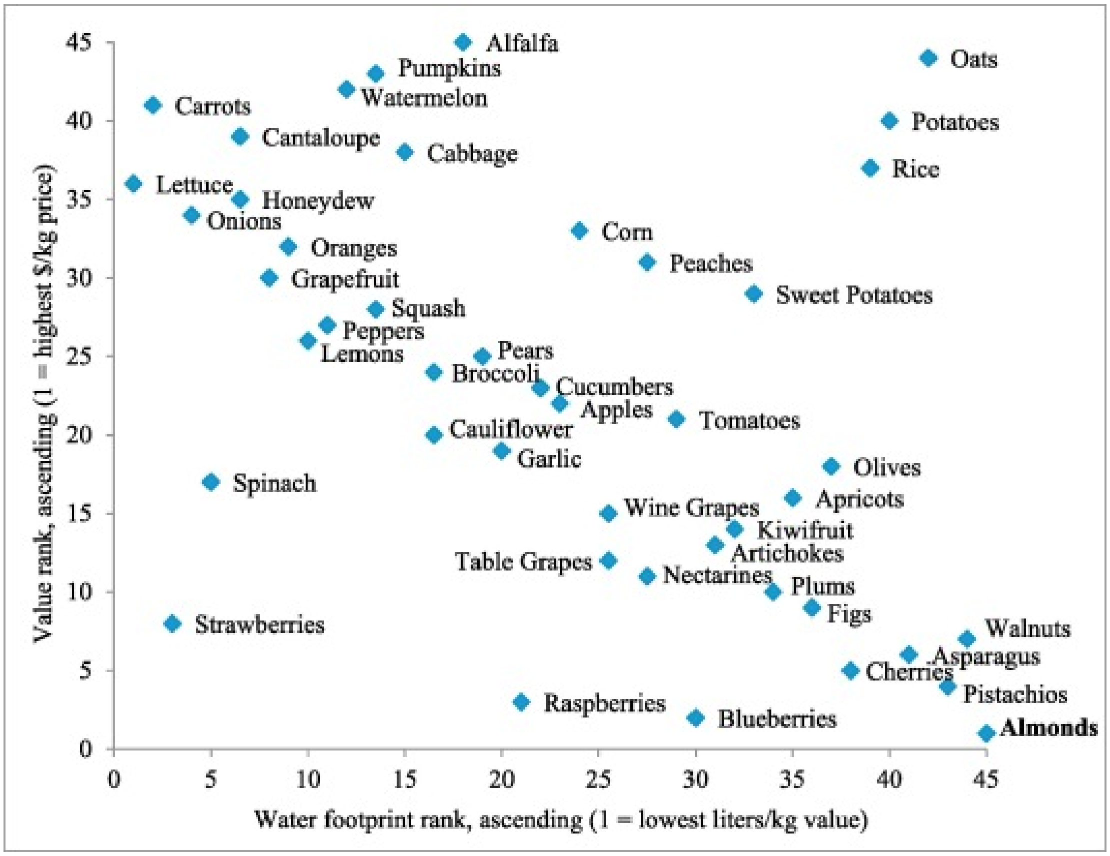

Figure 5: “Major California crops ranked by water footprint values (horizontal axis) and ranked by average (2004–2015) farm-gate price (vertical axis)” [21]

Overall, there seems to be a clear trend from top-left to bottom-right, indicating a linear tradeoff between economic returns and water footprints. This goes for the exception of some crops like spinach, strawberries, raspberries and blueberries which appear to have higher ratios of economic value to water footprint [21]. There are also some staple carbohydrate heavy crops on the top right which are water intensive but do not have a high price ranking [21]; this is due to the heavy subsidization of these crops by the government [22].

Lastly, we can examine the comparison of total crop water footprint to its total market value. This is important because it shows us the absolute position of these crops by its direct total value in the market rather than just by ranks and we can observe the costs and benefits of each crop and contrast them to each other. The figure below shows total water footprint with total market value of each agricultural product within California in 2014.

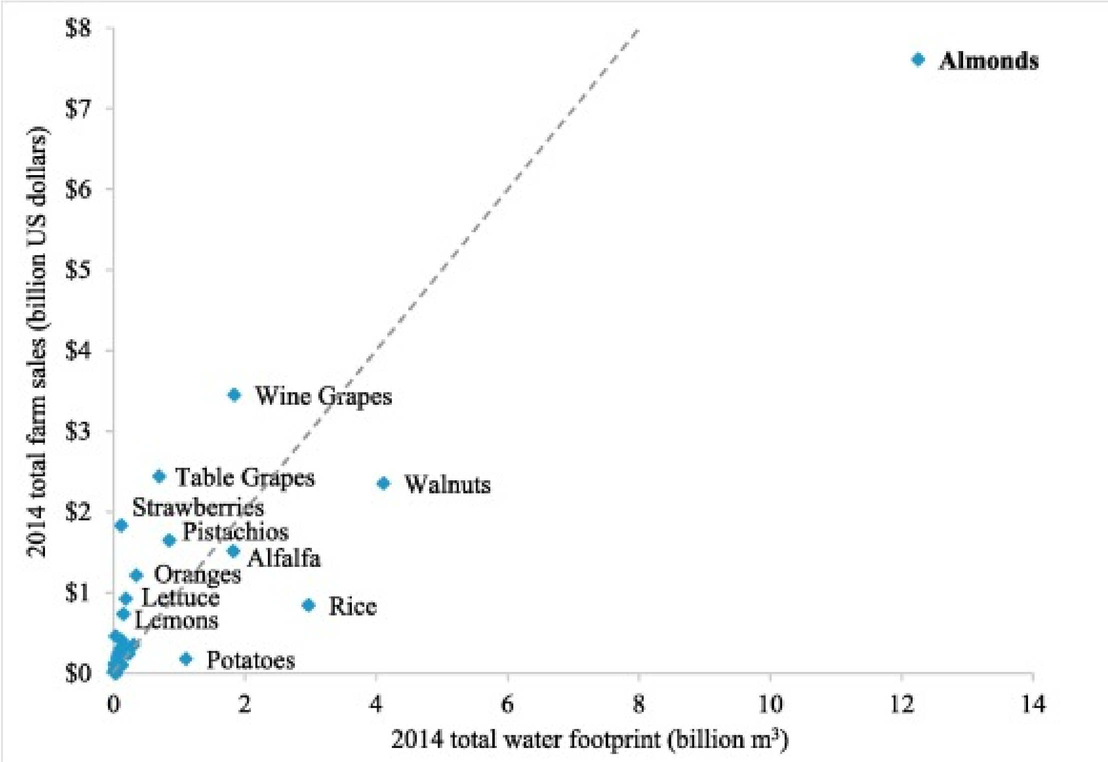

Figure 6: "Comparison of 2014 total water footprint with 2014 total market value of each agricultural product within California. The dashed line corresponds to $1/[cubic meter] water footprint" [21]

In this figure, the dashed line represents a contextual average ratio of one dollar market value to one cubic meter of water consumed and most of these crops fall above this line, meaning that they perform "efficiently" in this metric of market capitalization.

The study that found these numbers found that five crops – wine grapes, table grapes, strawberries, pistachios, and oranges – accounted for 35% of total sales but only 13% of the total water footprint [21]. On the other hand, four major crops fell below the dashed line – almonds, walnuts, alfalfa, and rice – and accounted for only 41% of total sales but 73% of the total water footprint [21]. Just almonds accounted for 25% of total sales and 42% of the total water footprint.

1.3 Individual Impact

Water is an essential resource for human survival, yet water scarcity has become a significant problem in many parts of the world. It is a finite resource, and its availability is crucial for human survival. However, water scarcity has become a significant problem in many parts of the world, affecting millions of people. Water shortage occurs when there is a lack of sufficient water resources to meet the needs of a particular region. This essay will discuss the issue of water shortage and its impact on individuals and their consumption habits.

People can contribute to the preservation of water quality by acting responsibly and by conserving water. By properly disposing of hazardous household items like batteries and pesticides, as well as by using environmentally friendly products, people, according to the National Environmental Education Foundation, can reduce the amount of pollutants that enter waterways [23]. Water conservation can also help maintain the quality of the water because it can reduce the amount of wastewater that needs to be treated before being discharged into waterways [24].

Individuals can protect water quality by acting responsibly and by conserving water. According to the National Environmental Education Foundation, people can lessen the amount of pollutants that enter waterways by using environmentally friendly products and properly disposing of hazardous household items like batteries and pesticides [23]. Because less water is used overall, less wastewater needs to be treated before being released into waterways, which can help protect water quality [24].

More than 40% of the world's population suffers from water scarcity, and this percentage is anticipated to rise in the coming years [N4]. People can fight this problem by making small changes to their daily routines, such as fixing leaky faucets, taking shorter showers, and using less water outdoors. The efforts to conserve water can be significantly impacted by these modest changes. Individuals can support the larger effort to combat water scarcity and ensure the availability of this crucial resource for future generations by being aware of how much water they use and taking measures to conserve it.

Individual water use has a big impact on the global water crisis. More than 40% of the world's population, according to the United Nations, are impacted by water scarcity, and this percentage is projected to rise over the next few years. For instance, the average American uses about 100 gallons of water each day, with up to 30% of that amount going to outdoor uses like watering gardens and lawns. People can fight this problem by making small changes to their daily routines, such as fixing leaky faucets, taking shorter showers, and using less water outdoors. The efforts to conserve water can be significantly impacted by these modest changes.

In conclusion, the lack of clean water is a serious issue that millions of people worldwide must contend with. Although there are many factors that contribute to water scarcity, one important factor that people can control is their own consumption habits. Individuals can lessen their impact on the issue of water scarcity by being aware of their water usage and taking action to conserve water. This essay has outlined some strategies people can use to cut back on their water usage, including being more mindful of their daily routines, eating less meat, and conserving water outside of their homes. Individuals can contribute to the larger effort to combat water scarcity and guarantee the availability of this crucial resource for future generations by making these changes.

1.4 Water Management

1.4.1 Water Rights

Having access to water is considered a human right according to the UN since water is a basic requirement for life [27]. Water is needed for drinking and sanitation as well as for food production which relies on irrigation. Because of this, the state has an obligation to ensure people's minimum requirements are met to not violate any human rights [28]. Insufficient water resources also commonly fuel geopolitical conflict when states have to fight over a precious resource [29]. California and the US West in general is known as the "Great American Desert" which is considered an arid region that is biologically unsuitable for agriculture due to a lack of water [30]. Therefore, the region without making any changes has scarce water resources so the people and the state have conducted projects to bring water from the river sources to where they are needed for urban centers or agriculture.

Since water resources are being diverted and shared, questions arise over which entity owns it. In the West, the rights of water legally fall under the prior appropriations doctrine which is based on the principle of "first come first serve [31]." Under this legal framework, being first to redirect or use a source ensures rights of ownership to perpetuity. The original owners would be given seniority over later claimants given a junior title. Following this system, senior water rights holders maintain priority over the water available such that during water scarcity times they have no obligation to share water with junior water rights holders leaving them to find another source of water [32].

This system of prior appropriations contrasts with riparian water rights used in the East and commonly around the world. Under the riparian doctrine, owners of land bordering a water body gain access to the water but do not own the full rights to all the water available to them [33]. Instead, users must ensure they limit the amount of water they use such at other nearby parties are not harmed. Compared to prior appropriation, during times when water is scarce, claimants need to share the water available, so no groups are left out.

Riparian water rights are more common as shown in the Figure below and appear to be more beneficial since the water is shared equally. However, due to the geographical aridity of the West region, prior appropriation provides benefits in the security of water access to claimants due to water scarcity [31]. This security is important since farmers want to ensure they will be able to irrigate their crops and water access ensures the continual growth of urban centers [32]. For farmers, having different levels of seniority affects their planting decisions and profitability [34]. Additionally, the perpetuity claims encouraged owners to spend money on water infrastructure such as canals to divert water which increases the available land for agriculture. In California, ⅔ of its water supply is governed by prior appropriation [35].

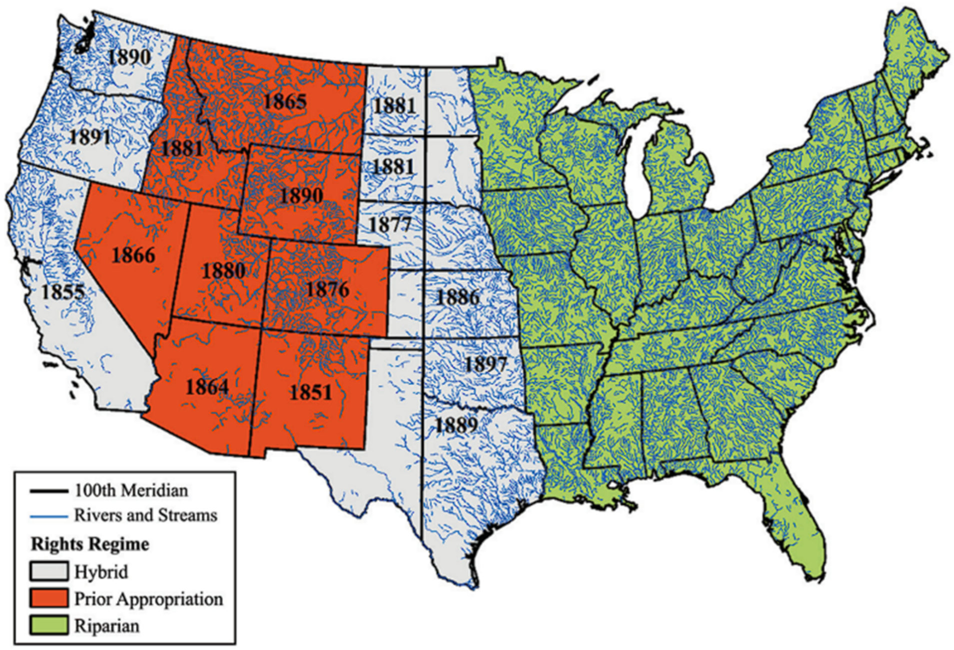

Figure 7: Comparison of prior appropriation and riparian water rights [32]

In addition to the benefits of prior appropriation, the type of agreement was also a result of the California Gold Rush. In 1851, California adopted a law to recognize land claiming by miners to own the land they mine on [33]. Different mining districts dictated the size of the plots of land and the number of claims per person, but it also followed the idea of "first come first serve." Naturally, miners needed access to water for mining, so they adopted a similar type of claim system. While this system of land claims was enforced by the local government, water claims were only enforceable in the courts [33]. However, resolving disputes through courts was slow and a costly litigation process which resulted in the complicated system of water claims that currently exists which is impossible to enforce.

However, over the years due to overuse and misuse of water resources that had led to environmental damage, the government was given the power to modify the prior appropriation rights despite its perpetuity. Under the Public Trust Doctrine of 1983 passed in California, the state gained the power to protect Mono Lake by restricting the outflows [33]. Regardless, navigating water rights remains complex and costly due to the litigation process. In addition to the individual water rights, the states in the West have a major water agreement.

1.4.2 State Agreements

In the West, the Colorado River is the major river supplying fresh water to many states which it collects from snowmelt. This river forms the Colorado River Basin which spans 7 states. To divide up the water, the states agreed to the Colorado River Basin Compact which splits the states up into the upper and lower basin to prevent future disputes as shown in the Figure below. Under this agreement, the upper basin consists of Colorado, New Mexico, Utah, and Wyoming while the lower basin consists of Arizona, California, and Nevada [32].

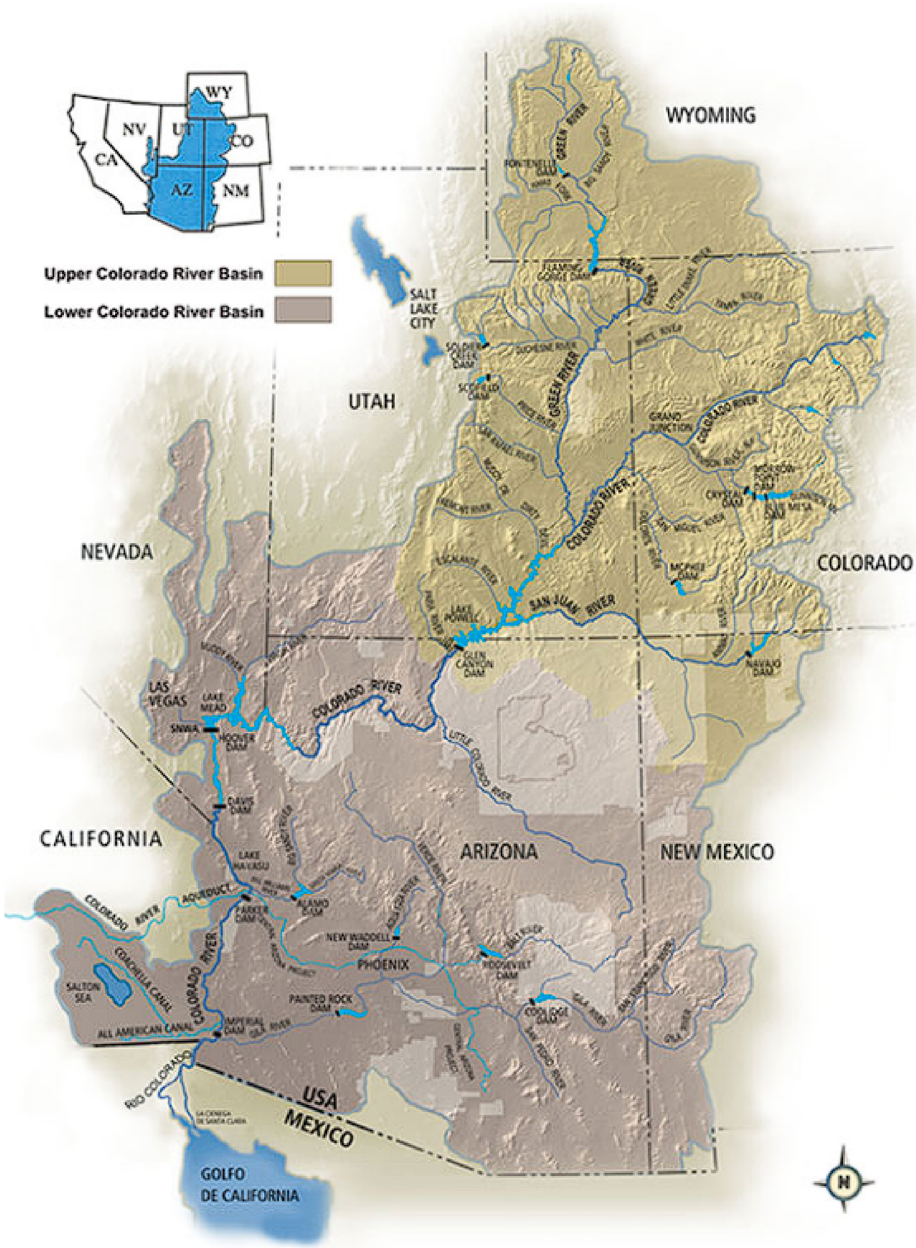

Figure 8: Mapping of the upper and lower river basin [32]

To divide up the regions the Glen Canyon Dam was constructed to create a reservoir that ensures 7.5-million-acre feet of water (MAF) was released from the upper to lower basin each year regardless of the water conditions [32]. However, this agreement is problematic since it was based on a wet year with high stream flow due to more snowpack and rainfall [36]. Due to climate change changing weather patterns, the reservoirs do not receive the same amount of inflow as predicted leading to depletion of reservoir resources. In fact, during the 20-year drought period, the level is getting low to where it affected the power generation of the dam [37].

Aside from the issues with the water usage agreement, both the upper and lower basins had competing objectives. The lower basin wanted to preserve water for the future growth of their states while the lower basin states wanted to keep up their growth by ensuring a steady stream of water [32]. Additionally, under the agreements, the lower basin is promised the 7.5 MAF such that if the rainfall is low the upper basin is still required to deliver the water at their expense. This system of water rights means states may not work together to reduce consumption to ensure their own growth since there is no obligation either through prior appropriations or the Colorado River Basin Compact.

1.4.3 Water Infrastructure

In the past, water management meant focusing on developing water infrastructure to bring more water through dams or canals to meet the current demand since there were a lot of untapped potential water sources. For example, from 1900 to 1990 the reservoir capacity infrastructure increased by more than 800 MAF as shown in the Figure below. Additionally, during this time, the Gold Rush of 1849 in California led to a population boom from 1000 to 34000 people by 1900 [32]. Due to this growth in population in the West, urban centers like San Francisco needed more water and built a reservoir in Hetch Hetchy Valley which was controversial at the time since it was in Yosemite National Park.

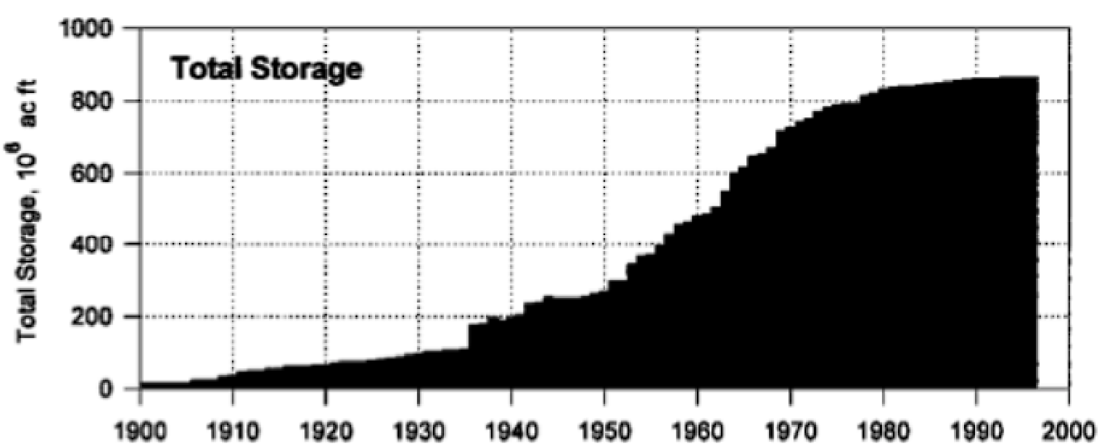

Figure 9: Increase in reservoir storage [30]

This reservoir like many others was extremely detrimental to the local environment since a habitable valley turned into a lake for water storage. While environmentalists were able to hold off the construction initially, Congress approved Public Act 100-563 which allowed reservoirs in national parks which was a major loss at the time [32]. At other locations, the demand for water led to the formation of the US Bureau of Reclamation which funded water projects in the West such as the construction of Hoover Dam which borders Arizona and Nevada in 1928 [38]. Hoover Dam is the largest man-made reservoir in the US which generates 1344800 kW of hydropower.

In another urban center in California, demand for water in Los Angeles funded canal infrastructure to bring water from Owen's Valley to Los Angeles. William Mulholland was appointed to bring water to LA and constructed the Mullholand aqueduct which drained Owen's Lake [39]. To gain access to water resources, he purchased and annexed land around the lake to hold the water rights. Initially, there was little resistance but the water level began to go down and affected the ranchers in Owen's Valley devastating their farms. When it began to affect the locals, they protested and blew up sections of the aqueduct to prevent the stealing of their water. In response, Mulholland and Los Angeles sent guards with shotguns to protect the aqueduct [39]. The end result is environmental devastation that left Owen's lake dry to meet the water needs of Los Angeles.

Water rights are a contentious subject and there are many other examples of conflict over obtaining new water sources. For example, when California began tapping into the Colorado River to meet its water needs, Arizona sent the national guard to stop the construction of the Parker Dam [32]. They were concerned California would take water from the Arizona side but this was eventually resolved by the federal government. Since water is a precious resource in the West, conflicts would be expected as governments try to meet the demand for dwindling water supplies.

Presently, traditional water sources from rivers and lakes are either allocated or overallocated so new methods or conservation would be required. In addition, in the middle of the 20th century, environmental groups regained the attention of the public due to a reinterest in environmental protection and successfully blocked further infrastructure development of reservoirs on protected lands to maintain the natural environment [32]. This adds additional pressure on water managers to find ways to meet the water demands. Beyond the 20th century, there has been a greater focus on water quality through the Clean Water Act and managing current water resources. Since the sources of water from past projects will not change during the drought, effective management and conservation will be needed to sustain water demands from users.

Since water demand continued to grow despite traditional sources being overallocated, cities have attempted to find other methods to obtain water such as through groundwater pumping [32]. The rights to this groundwater are less established since there was not a good understanding of how the water system works. Since then water managers now understand groundwater is linked with the surface water which replenishes these sources. To meet the demands, cities began using more groundwater to meet their needs by excessively pumping. However, this has led to groundwater depletion in many regions as shown in the Figure below. Since there are no limits provided by the government, groundwater pumping led to the ground sinking 30 feet in In San Joaquin in California [32].

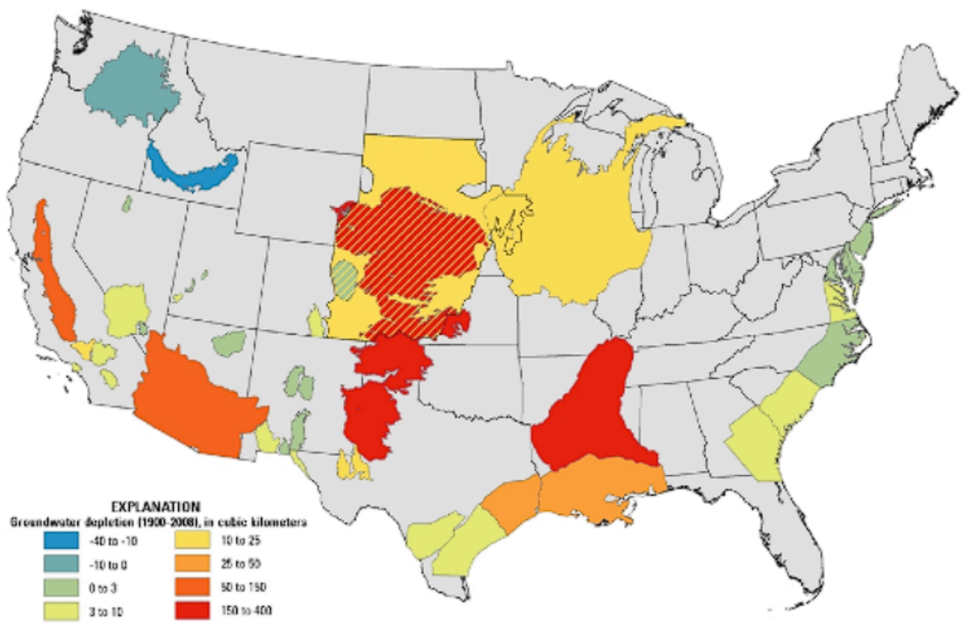

Figure 10: Groundwater depletion [32].

Overall, infrastructure projects dominated the solutions selected at the detriment of the environment in early water management. Since those sources have already been allocated, current water managers will need to look for other solutions to alleviate the increasing water demand while the drought reduces the currently available water.

1.5 Future Impacts

This section details the environmental and economic impacts of the California Drought. The drought has caused a wide array of long term consequences throughout the state that must be analyzed with scrutiny in order to be able to devise proper and effective solutions to these rapidly developing issues. Only after these issues have been carefully studied can strategies to mitigate the problems be properly identified so that they may be carried out in a competent and successful manner.

1.5.1 Impacts on Environment

The California Drought has had severe negative effects on the environment. Water is essential for all living these, therefore a shortage of water causes severe detrimental effects on natural ecosystems. These effects are most noticeable in forestation and marine life.

More than one hundred million forest trees have died during the drought. These deaths have been caused by insufficient precipitation and dry soil, which has been exacerbated by rising temperatures [40]. These dead trees put California at high risk for wildfires. These trees are also unable to reduce erosion of soil into nearby areas. These risks to health and safety will remain long after the drought ends.

The Drought has also affected aquatic ecosystems. California is endemic to many species of fish that are either endangered or are at risk of becoming endangered [40]. The drought has caused low flows and increased temperatures which have significantly reduced the feasibility of their natural habitats. These changes have also supported the expansion of invasive species into their environments [40].

1.5.2 Impacts on Industry

The California Drought has negatively impacted various industries throughout the state. Because these industries require access to water in order to function properly, the water shortages that were caused by this drought have caused these businesses to decline.

This is most apparent in agriculture. Limited access to water had resulted in insufficient crop yields in farms across the state, as well as losses in dairy and livestock [40].

Description	Base year	Drought change	% change
Surface water supply (10^9 m^3)	22.2	10.7 loss	–48%
Groundwater use (10^9 m^3)	10.4	8.0 increase	72%
Net water use (10^9 m^3)	32.6	3.3 reduction	–10%
Drought-related idle land (hectares)	500,000[a]	225,000 more	45%
Crop revenue ($)	$35 billion	$900 million loss	–2.6%
Dairy and livestock revenue ($)	$12.4 billion	$350 million loss	–2.8%
Groundwater pumping cost ($)	$780 million	$590 million rise	75.5%
Direct costs ($)	N/A	$1.8 billion loss	N/A
Total economic impact ($)	N/A	$2.7 billion loss	N/A
Direct farm jobs	200,000[b]	10,100 loss	5.1%
Total job losses	N/A	21,000 loss	N/A

Figure 11: Agricultural Impacts of the drought in 2015. Adapted from [40]

Economic losses caused by the drought have also been noted in other industries in the state, including hydropower, recreation, and maintenance.

Access to clean water is essential for maintaining the health and cleanliness of the citizens of California. Water shortages caused by drought will prevent citizens from having access to the resources they need. Without running water, people will not be able to use the toilets, sinks, and showers in their homes. Consequently, their health and sanitation will deteriorate significantly.

2. Solutions

2.1 Water Management Solutions

2.1.1 Water Rights

The prior appropriations doctrine has been found to be problematic due to its focus on “first come first serve” which does not incentivize conservation since senior water rights holders get to take all the water [31]. Riparian water rights which are used in the East and around the world were found to be less suitable due to the scarcity of water in the arid West which does not have as many sources available [33]. Additionally, since prior appropriation claims are not tracked by the government due to the complexity of the claims, courts are the method to resolve disputes over the water right ownership which often leads to long and costly litigation.

An example of a similar situation regarding the complexity of prior appropriation of water rights can be found in Australia. In 1877-1881, there was a severe drought that forced the government to act to control the river water to ensure the population retained access to agriculture [33]. The government abolished the existing water rights system and instead made the government the sole owner of water. This allowed the Australian government to control exactly how entities used water and how much to allocate for specific agricultural uses. In the new system, access to water required licenses which the government could issue for specific types of uses [33].

For the US, a similar plan could be enacted since the drought pressure pushes the government to reform the system to sustain the future population. It would be difficult since actions against water rights holders are negative, revamping the water system would allow more sophisticated plans to manage the entire watershed and have an accounting of where water should be used. For example in corporate solutions, almonds use the most water for low yield so licenses could be restricted during times of drought [21]. Also similar to Australia, water infrastructure is heavily funded by the government so it would be appropriate for the government to control the entire system and assign costs fairly.

2.1.2 Modeling

Historically, modeling the river flows and available water is extremely challenging due to the multitude of factors such as snowpack, rain, and soil so active management using data was not possible. Instead, reservoirs were used to ensure the 7.5 MAF of water was delivered to the lower basin states regardless of the conditions upstream [36]. Nowadays, research has been able to improve analytical methods to estimate and predict river flows.

One of the methods that can be used for water management is hydrometeorological forecasting which predicts the physics of watershed runoff [41]. Initially, it was difficult to predict water flows since winter precipitation and snowpack vary each year. Also, during dry years snowmelt goes into recharging the soil moisture and aquifers which have nonlinearity and during wet years the lower temperature reduces evapotranspiration. With everything accounted for, water managers can use this prediction tool to plan ahead and allocate water resources based on the water inflows.

In addition to using models to predict water inflows, water managers have access to more live data from satellites to account for the water that is currently available. For example, the Grace satellite allows water managers to view groundwater availability which was not well understood in the past [42]. Also, due to the water crisis, NASA has gathered water data on an OpenET tool which allows farmers, water managers, and conservation groups to determine real-time water availability to better plan their operations [43]. The OpenET database provides farmers with information about evapotranspiration to determine their water use and water loss more effectively to plan for the crops and watering schedules. It also allows water managers to more precisely control the evapotranspiration of agriculture to limit water overuse during droughts.

Overall, new technologies can help augment the tools available to farmers and water managers to more effectively control water resources using both real-time data and model predictions to make short and long-term decisions about the West's watershed.

2.1.3 Management Plans

Water managers have many methods they can take to alleviate the drought which includes: using underground storage, increasing water transfers, encouraging conservation, and recycling [44]. However, the first step is understanding the effects of the results of climate change and drought. The higher temperatures are expected to reduce snowpack and soot from urban activities making the snow melt faster which would change when the water arrives. Additionally, higher temperatures are expected to warm the water leading to algae growth and chemical reactions [44].

To take into consideration the effects, California created the CALVIN engineering model to view the economic costs of changing policies across the state. This macro tool currently enabled helps local agencies plan and diversify water supply [44]. It also helps manage watersheds with multiple stakeholders such as the Sacramento-San Joaquin Delta where local water rights holders are next to federal and state wildlife protection zones [44]. However, regardless of the development of the tool, the management of the city and government is fragmented which limits the effectiveness of tackling flood management and drought.

To determine how California is doing with the water management plan, the regional plans were evaluated for different categories such as water supply, environmental impacts, social impacts, scientific rationale, management tools, and implementation as shown in the Figure below [45]. The study found 88% had good detail in accounting for the water supply in the region but only 47% took into account any social impacts due to the drought. Most concerning, agriculture was only briefly mentioned in the plans if mentioned at all which is extremely problematic considering agriculture accounts for approximately 80% of the water usage.

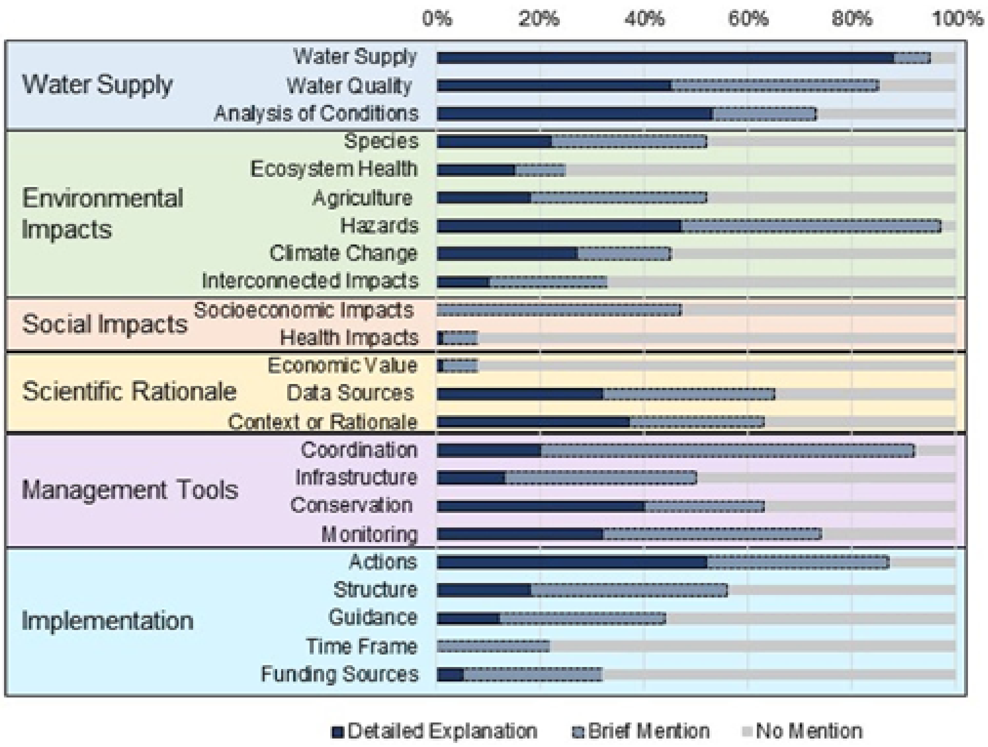

Figure 12: Summary of water management plans in California [45]

Regarding areas of improvement, the plans understood the regions have to better work together to have more effective solutions but there was no plan to implement it. Also, to mitigate issues such as floods, plans cited the creation of facilities but then mentioned it was not feasible due to funding. The plans also did not include any information on public awareness of the water issue or take into account decreasing snowpack.

Overall, the plans still need major work in working together as a single entity since watersheds do not end at city boundaries. Also, it must take into account agricultural water usage since it is such a major part of California's water system it should not be neglected in solutions to the drought problem. Due to funding constraints, the California government should evaluate the impact of the lack of water and ensure sufficient funding is provided for any necessary programs or infrastructure.

2.2 Societal-based Solutions

As opposed to solutions that rely on legal competency, it must be recognized that the responsibility for a more sustainable future also relies on communal-based solutions.

2.2.1 Replanting Greenery

Studies have found three prominent ways to support a green future while consuming less water: replacing plants with indigenous plants and trees, relandscaping residential properties, and introducing more genetically modified plants.

2.2.1.1 Indigenous Plants and Trees

A famous landscaping architect and author, Bob Perry, brings to light with a book at least 360 native or introduced plants that have survived on the West Coast or in Mediterranean, Southwestern, subtropical, woodland, Asian, and coastal ecosystems [46]. In his publications, he describes how native plants in the drier regions of the West Coast and others from similar habitats have survived with ease due to their efficient use and protection of their moisture from the harsh heat. One common argument against the sowing of native plants is the negative reaction to their visual appeal. The book mentioned above includes a section that helps readers arrange aesthetically looking plants that could look better than a grass lawn [46]. This has allowed property caretakers to expend less water throughout the year without having to get rid of plants completely. The federal government has even sown many of these plants on the side of highways since 1965, using mostly reclaimed water and rarely using purified water except in the driest of regions [47]. Although it hasn't been impactful, there have been movements to spread awareness to the general population about the efficacy of these plants and their practicality in replacing brown lawns.

The California Native Plant Society is a non-profit organization that aims to conserve California native plants and emphasizes the need for homeowners to incorporate these plants into their properties [48]. This organization also takes the time to educate California residents on how to maintain a garden of native plants and even how to efficiently sow certain plants in specific positions in order to maximize water conservation [48].

2.2.1.2 Landscape Conversions

Instead of the straightforward replacement of traditional lawns with those that have drought-resistant traits, many property owners have decided to completely change the structure under and around the landscape of their lawns [50]. With records dating back to the 1970's homeowners and businesses have implemented xeriscapes, a "form of adaptive [landscapes] in dry climates that strongly promotes efficient irrigation technology and uses drought-tolerant plants"[50]. This generic term includes implementations found in both (i) and (ii) but more recent research has shown that 66 percent of the efficiency found in xeriscapes comes in its irrigation efficiency [50]. This can be found in the form of drip tubes, hand-watering, or the installation of water-efficient “micro-spray systems” or rotating nozzles [49]. As the emphasis on conserving outdoor uses of water rose over the next few years, the Metropolitan Water District of Southern California (MWD) and the Los Angeles Department of Water and Power (LADWP) created the California Friendly landscaping program in which homeowners would get rebates that correlated to the amount of land they refitted [50].

These landscapes in the, now, Turf Replacement Program must include the following features: 3 plants per 100 square feet of area transformed, a stormwater retention feature, no hardscape within the transformed area - except permeable hardscape, and replacement or modification of overhead spray sprinklers [49]. If the homeowner were to complete the renovation within 180 days of receiving approval for the funds, they will receive 2 dollars per square foot up to 5,000 square feet of converted lawn per year; there have also been instances in which water agencies have included additional rebates [49]. Since the launch of this program, the funding for these rebates has consistently run out [50].

Soon after the launch, one company, Turf Terminators, became notorious for replacing entire landscapes with just gravel and rocks or artificial grass and profiting off of the rest of the rebate [50]. The company was criticized for increasing plastic waste by using artificial turf, reducing biodiversity, and exacerbating urban heat island effects [50]. Today, the program prohibits artificial turf in these renovations and even offers some potential landscape structure formats which include the following: rain garden, rock garden, vegetated swale, dry river bed or dry stream, and berm [49]. A rain garden is a planted depression with permeable soil that allows rainwater to be absorbed [49]. Rainwater collects in the soil and depression area and eventually seeps deeper into the ground over time [49]. A rock garden is a shallow depression with pieces of gravel that are 1-3 inches in diameter [49]. Rainwater rests in between the stones and eventually trickles into the soil - there is no ponding area and, thus people may walk on it [49]. A vegetated swale is a shallow ditch that has gently sloping sides with native perennial grasses planted along the bottom and sides to slow runoff, filter sediments, and remove excess nutrients[49]. The purpose of this landscape is to direct rainwater to where you want it to go on your property, i.e. a flower or vegetable garden [49]. A dry river bed is a landscape made to slow heavy flows of water from rainfall and correct erosion problems [49]. This is done by using large stones in the swale to slow water and prevent erosion [49]. Berms are mounds of earth with sides that are positioned between areas of approximately the same height [49]. These are designed to direct water from flowing off the property to encourage groundwater retention [49].

Figure 13: (Left to right, top to bottom) rain garden, rock garden, vegetated swale, and dry river bed derived from [49]

After investing 350 million dollars in these programs, and only replacing around 3 percent of the landscapes in the district's service area, water managers have shifted towards the goal of marketing and educating the public about these kinds of landscapes [50].

2.2.2 Awareness Campaigns for Water Conservation

As brought out by [51], studies using media volume "as an explanatory variable in water demand modeling" is quite a contemporary and new idea and, thus, there is a large potential for future work exploring the intersection of water use and mass media. Conducting more studies on peripheral variables such as the timing of media coverage over a week or a month, other types of media - social media, and the number of people in these residences - whether they be multifamily, commercial, industrial, etc., could uncover more information about the points discussed in (2.2.2).

With the objective to spend the least amount of money for the most decrease in water use, governmental organizations have transitioned from active rebate programs to more passive awareness campaigns as discussed in (2.2.1.2). A 2017 study that looked at the impact of media volume on consumer action found that regular media exposure to the drought in 2011-2015 had been associated with an 11–18% reduction in water use [51]. This was particularly compared to the water shortages around 2007-2009 with which the news coverage was mostly overshadowed by the economic recession and presidential election making it easier to refine the data and make such a conclusion [51].

During the time period in focus(2011-2015) for this study, many broader influences could have impacted the public's response to these media factors. For example, (1) in June 2008, Governor Schwarzenegger released an emergency proclamation for selected Central Valley counties, (2) in February 2009, Governor Schwarzenegger declared a Drought State of Emergency, (3) in January 2014, Governor Brown declared a Drought State of Emergency, (4) in July 2014, outdoor water conservation regulations were imposed, and (6) on April 2015, a mandatory statewide water use restriction was placed [51]. Governor Schwarzenegger's public influence could be considered an extra factor and other government warnings could have caused more people to action than normal. All of these events can be tracked in Fig. FDS2 below.

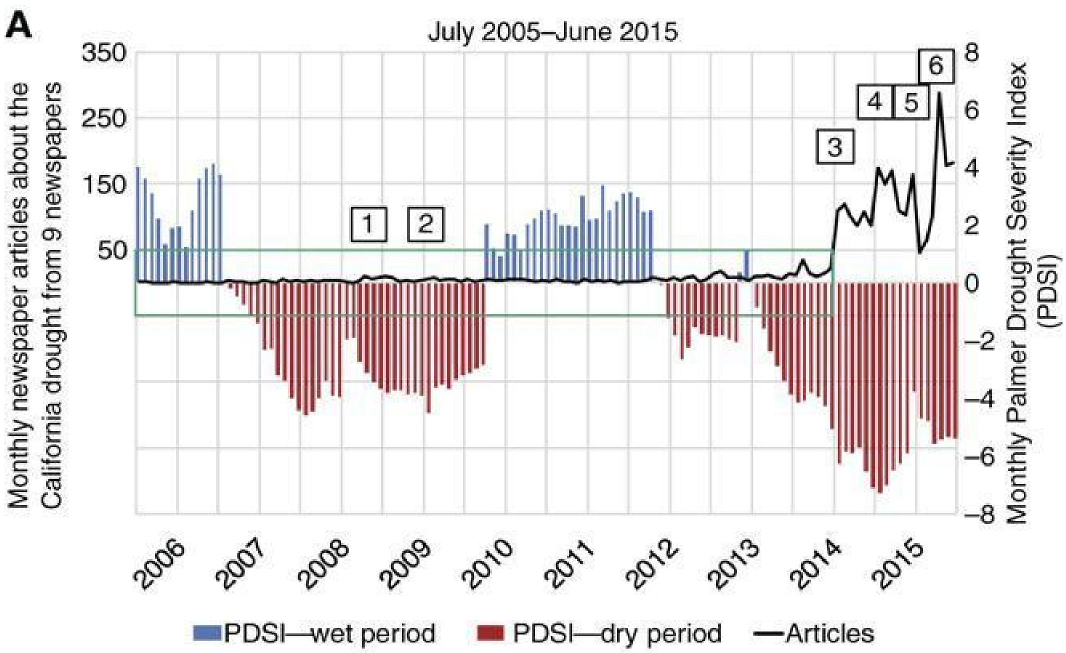

Figure 14: "(A) Media coverage for the entire study period, highlighting heavy coverage of the later drought." Modified from [51]

Although Figure FDS2 depicts a correlation between media coverage and dry/wet seasons, this does not imply a causational relationship. To make conclusions that are based on more stable and causal data, this study also found correlations between Google searches that were relevant to the drought in California and how much news coverage there was about the drought [51]. The positive correlation is shown in Figure FDS3 below.

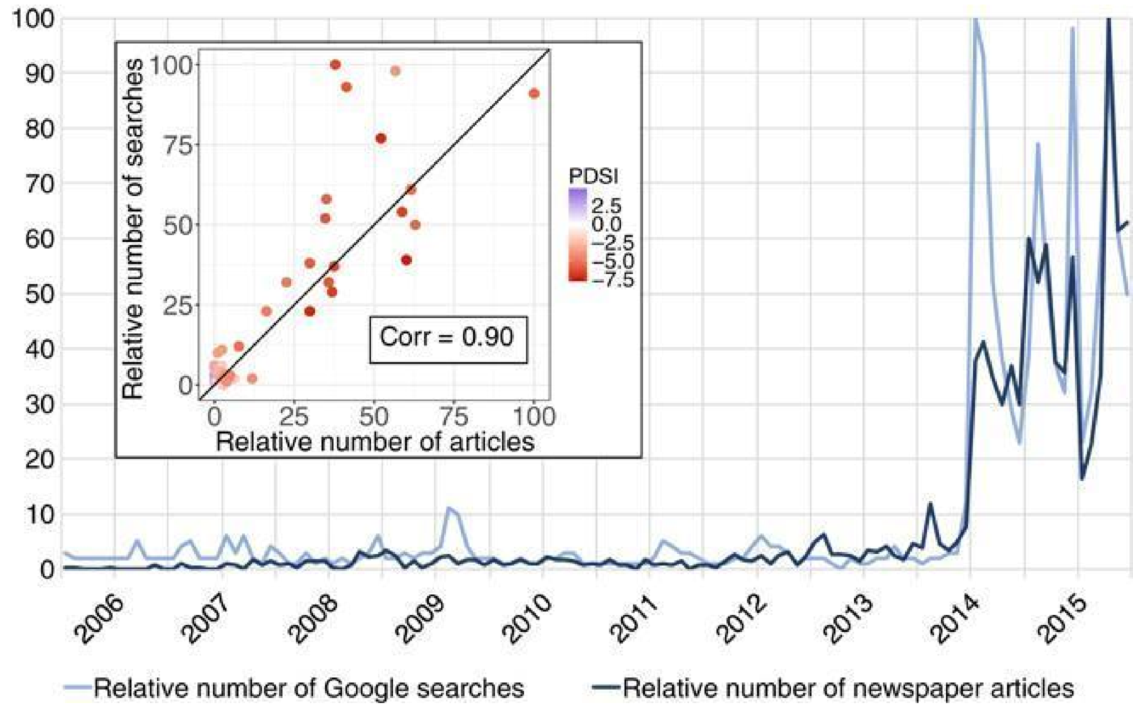

Figure 15: "Public interest as measured by Google searches for the term California drought and news media coverage of water- and drought-related issues in California." [51]

This is a key factor because this demonstrates that the public actually committed some behavioral change and was affected by this news coverage. A study in 2018 found that this impact was not only temporary but the decline in the usage of water became "sticky" after these campaigns [52]. This means that public habits of conserving water stay persistent for even years after the exposure to drought-related problems has ended.

Another study in Spain that focused on this topic found in survey responses that many residential owners refused to install water-saving devices, relandscape, follow governmental regulations on water usage, and reduce their overall use of water because they simply believed their water usage was not high enough to make an impact on the overall state of the drought [53]. This goes to show the impact of regular education and more widespread information about how much power change in a whole community can be.

2.2.3 Awareness for Overpopulation

As found in the results of [63], our food production systems have to expand by at least 70 percent to sustain a population that we are predicted to reach by 2050. Our options to prevent disaster include creating a more unified effort to conserve water, creating more efficient sources of nutrients, and finding ways to slow overpopulation.

A scientific journal concerning the depletion of freshwater around the globe states that the greenhouse gas emitted from farm animals and glacier water lost due to the increase in temperature due to the gasses from the animals and black carbon(soot) is even more than the impact of freshwater lost from industrial production and transport [54]. In its research, the paper found that around 60 percent of the Himalayan recession is due to black carbon and has more uncertain effects around the globe [54]. The research goes on and finds that 19 to 29 percent of greenhouse emissions come from food and agriculture, which could be greater than the estimated amount of greenhouse emissions resulting from industrial production and transport [54]. The journal concludes that, as the population only increases, it will become even harder to reduce the negative impacts, especially since the consequences of the agro-industrial complex will grow even faster than those of the similarly looming production complex [54].

Another journal emphasizes specific effects and flaws of capitalism as one of the primary causes of this global warming. Here, the author finds that the greed of corporations only exists because of the capitalist institution and allows for the careless destruction of the Earth [55]. This greed is the reason that the world and its beings are being exploited environmentally and sociologically [55]. They state that “this is why the persistent positing of population control as a solution to climate change is a distraction and moral dead end” and that “the most significant cause of rising emissions is not the reproductive behavior of the poor but the consumer behavior of the rich” [55]. Although this is a problem that we cannot tackle at our scale, it is even more not something to be ignored nor left out of the picture.

In response to the rise in population and the fear of collapse, many solutions have been implemented by numerous entities. Billboards have been posted with the lines, "We Chose One!" or "We Chose Childfree!" and non-profits spend much time creating public campaigns for awareness concerning overpopulation [56]. They also try to reach the public in the form of podcasts and public advertisements [56].

2.3 Individual Consumption

Water is a precious natural resource, but factors like population growth, pollution, and climate change are threatening its quality and availability. A person needs a minimum of 20 to 50 liters of clean water per day for drinking, cooking, and personal hygiene, according to the World Health Organization [57, 58]. But compared to the global average of 173 liters, the daily water consumption of the average American is about 300 liters [59]. Showering, flushing toilets, and watering lawns are the main causes of this high level of water consumption.

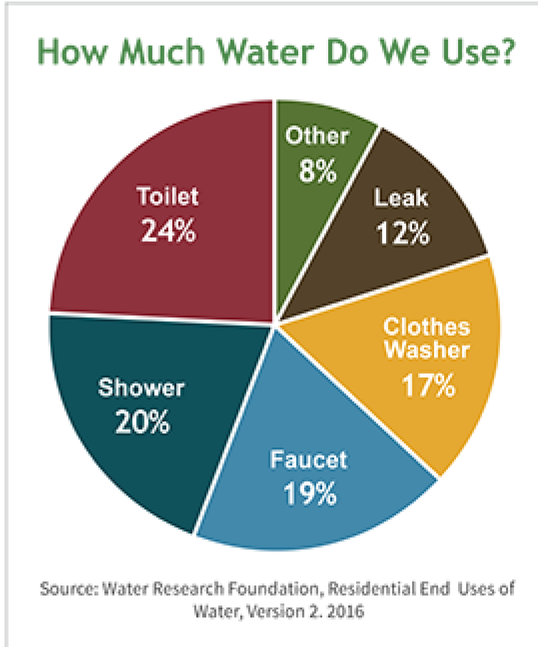

Figure 16: Water in Daily Life [25]

Individuals have a sizable influence on water use, and their consumption patterns may exacerbate the issue of water scarcity. While the average person in Africa only uses 5 to 15 gallons per day, the average person in the United States uses about 80 to 100 gallons daily [62]. This disparity in water consumption emphasizes the need for people to be aware of how much water they use and to do their part to conserve it.

The United States Environmental Protection Agency (EPA) estimates that household water use makes up about 70% of all water use in the country [24]. Daily water conservation can make a big difference in lowering overall water usage and protecting this priceless resource. Fixing leaks, taking shorter showers, and cleaning outdoor spaces with a broom instead of a hose are a few easy ways for people to save water [24]. Furthermore, upgrading older, inefficient appliances with water-efficient models can significantly cut down on water usage [24].

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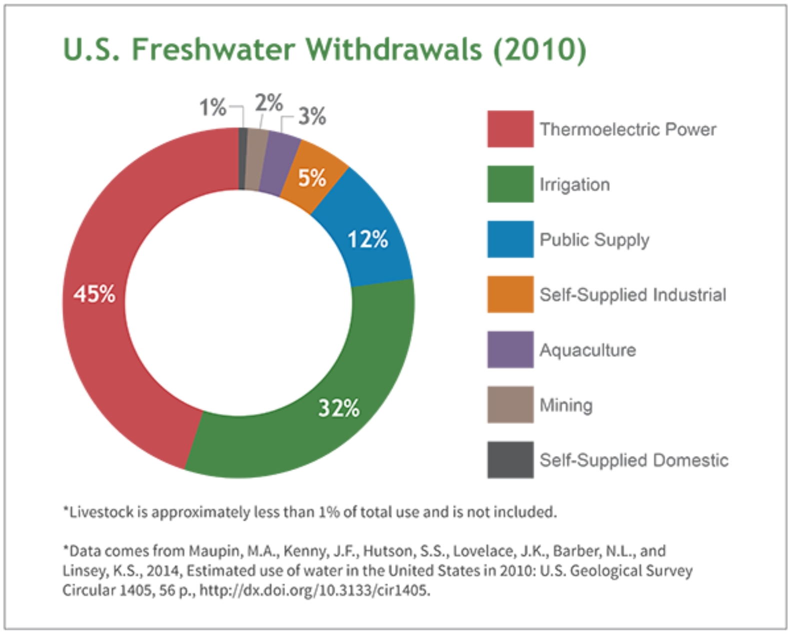

Figure 17: Commercial, Industrial, Agricultural & Electricity Water Use [25]

Reusing and recycling water, in addition to conservation efforts, can aid in addressing the water shortage. Recycled water can be used for industrial processes and other non-potable uses, reducing the need for freshwater resources. Participating in water recycling programs in their communities, using recycled water outdoors, and advocating for greater investment in infrastructure for water reuse are all ways that individuals can support these efforts. It is crucial to remember that recycled water is not appropriate for all applications, and that proper treatment and disinfection are required to ensure safety.

Being aware of how much water is used during daily activities is one of the best ways to reduce water use. For instance, you can save up to four gallons of water per minute by turning off the faucet while shaving or brushing your teeth. Similar to this, repairing leaky faucets and pipes can stop hundreds of gallons of water from being wasted each month. Additionally, installing low-flow showerheads and taking shorter showers both significantly lower water usage.

Another way individuals can reduce their water consumption is by being mindful of the food they eat. Agriculture is another significant contributor to water scarcity, with irrigation accounting for around 70% of global freshwater withdrawals. In many parts of the world, water is diverted from natural sources such as rivers and lakes to irrigate crops, which can lead to depletion of these water sources and exacerbate water scarcity. Irrigation is the main reason for this, with crops requiring large amounts of water to grow. However, there are several innovative approaches to water management in agriculture that can help to reduce water consumption. For example, precision irrigation uses sensors to monitor soil moisture levels and delivers water only where it is needed, resulting in significant water savings [59]. Additionally, drip irrigation systems can reduce water consumption by up to 50% by delivering water directly to the roots of plants [60]. These and other water-saving techniques are essential to ensure the sustainable use of water resources in agriculture and other sectors.While individuals may not be directly involved in agricultural practices, they can still have an impact by supporting sustainable farming practices and reducing their consumption of water-intensive foods. For example, eating a plant-based diet can significantly reduce an individual's water footprint, as it takes much less water to produce crops than to raise livestock. Therefore, reducing meat consumption and eating a more plant-based diet can significantly reduce an individual's water footprint.

Additionally, choosing produce that is in season and locally sourced can cut down on the amount of water used for storage and transportation. Outside of their homes, people can also take action to save water. For instance, hundreds of gallons of water can be saved by cleaning driveways and sidewalks with a broom rather than a hose. In a similar vein, drip irrigation systems and landscaping with drought-tolerant plants can drastically cut back on outdoor water use.

Individual water conservation efforts have an impact that goes beyond consumption patterns. Individuals can help the overall effort to combat water scarcity by consuming less water.

For instance, every gallon of water conserved through personal efforts enables the use of another gallon to meet the needs of others. Furthermore, water conservation efforts may result in lower water bills, which may free up funds for other necessities.

Water consumption is undoubtedly a pressing problem in the world today, where there is a limited supply of clean, fresh water and a rising global demand for it. For current and future generations to have access to clean, sufficient water, water consumption must be managed. To address the global water crisis, efforts must be made to cut down on water waste and implement sustainable water management techniques. According to the World Wildlife Fund, agriculture, which accounts for roughly 70% of all freshwater withdrawals globally, is one of the main factors influencing water consumption [61]. This number is significantly influenced by the use of irrigation systems and the expansion of crops that require a lot of water, particularly in regions where water is scarce.

Moreover, high water consumption is also a result of industrial processes. Around 22% of the world's water withdrawals in 2020 came from the industrial sector, primarily for cooling and energy production [62]. Since thermal power plants need large amounts of water for cooling, the rising demand for energy has resulted in an increase in the use of water for power generation. This demand for water will most likely rise in the coming years as the energy sector is expected to keep growing.

Individual water consumption also has a significant impact on total water usage. Water use is frequently taken for granted in developed nations, where people frequently use large amounts of water for activities like showering, washing dishes, and watering lawns [24]. Contrarily, a large number of people in developing nations lack access to clean water sources and are forced to make do with meager supplies for their daily needs. The global water crisis can be solved in part by reducing individual water consumption in developed nations and increasing access to clean water in developing nations.

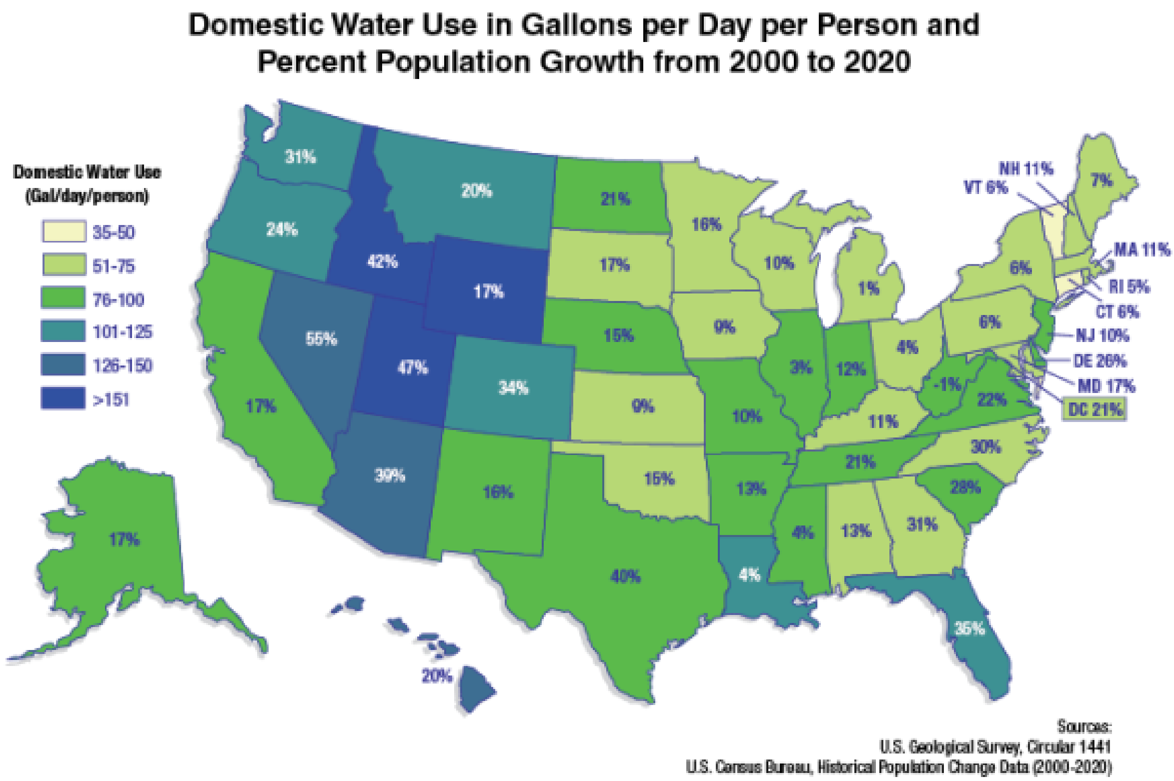

Figure 18: Domestic water use in gallons

In conclusion, water scarcity is a critical global issue that affects millions of people around the world. While individual consumption habits are not the only contributing factor, they are a crucial factor that individuals can control. By being mindful of their water usage and taking steps to conserve water, individuals can reduce their impact on the problem of water scarcity. This essay has highlighted some of the ways individuals can reduce their water consumption, including fixing leaks, taking shorter showers, and using water-efficient appliances. Furthermore, recycling and reusing water can also help address water scarcity. Individuals can participate in water recycling programs in their communities, use recycled water for outdoor purposes, and advocate for increased investment in water reuse infrastructure. By taking action to conserve water and supporting water reuse efforts, individuals can contribute to the larger effort to combat water scarcity and ensure the availability of this essential resource for future generations.

2.4 Corporate Solutions

As corporations in agribusiness and others take a majority of water in both wet and dry periods, it is imperative that we take a look into existing and potential solutions in this sector. Further, as the agricultural sector consumes up to 90 percent of used water in California, section 2.4 will only consider this domain.

2.4.1 Genetically Modified Plants

To sustain a population that we are predicted to reach by 2050, our food production systems have to expand by at least 70 percent [63]. With this impending deadline in mind, scientists have continued to develop genetic engineering technology to breed species of plants that are more fruitful, more resistant to pests and diseases, and can grow fully with less water [63]. One experiment found that, if they were able to send signals to inhibit stomata from constantly opening in the leaves during photosynthesis, less water vapor can be lost while maintaining a similar amount of produce [63]. In this study, tobacco was the target crop and the researchers were able to cut water usage by 25 percent just by injecting multiple copies of a key gene [64].

There have since been many debates on whether GM foods are safe to eat consistently. Some scientists agree that, since there is nothing inherently strange with the engineering process, there is not much to be worried about concerning the health of those who consume many GM foods[65]. To successfully create a new crop strain, a scientist must find a donor organism "containing the characteristics they want to transfer to the plant host" [65]. After the strain is complete and can be reproduced, the crops are regularly "molecularly identical" [65].

Other scientists have opposing opinions, stating that there are many red flags in pushing this process. For example, inserted genes can be transformed in many ways and only show up in future generations [65]. There have also been various studies pointing toward organ damage and threats to pregnant women [65].

In 2017, the Census of Agriculture showed that 58 million acres in the U.S. were irrigated cropland [66]. Further, "much of [that] irrigated land is concentrated in the western U.S. where the production of many crops requires irrigation" [66]. When there is a wet year like that of 2006, 8 percent of water in California is distributed for urban use while 29 percent is dedicated to agricultural use [67]. If the state experiences a dry year, agricultural use is raised to 61 percent while residents are urged to conserve water and are stressed into following strict conservation policies [67]. This goes to show the impact that the continued or greater use of drought-resistant GM crops has or would have on the conservation of freshwater on the West Coast.

In order for the public to fully adopt GMOs in our primary food system, more should be done to communicate what exactly happens in the genetic modification process in order for people to be more open to adopting it into their regular diets. Further, the government should consider sponsoring funding for research related to the experiment with tobacco plants.

2.4.2 The Reduction of Farming Water-Intensive Crops

As mentioned in section 1.2.1.2, there are certain crops that require less water and yet produce more nutrients and are more sustainable in capital markets. However, there were five very common crops that consumed more water than they were able to benefit markets. Namely, these included almonds, walnuts, alfalfa, and rice [21].

These crops accounted for 73% of total water footprint and yet only contributed to 41% of total sales [21]. Importantly, almonds alone accounted for 42% of the total water footprint and contributed to 25% of total sales [21]. In California, it does not seem strategic to continue farming these water-intensive crops when the state suffers from severe droughts and should aim to replace the farming of these crops with other staple foods like potatoes, lettuce, and oats.

2.4.3 The Reduction of Dairy Farming

Cows themselves consume large amounts of water due to the amount of plants and feed that they have to consume. The amount of salinity leaching described in section 1.2.1.1 is another large point of concern. To recall, the study found that every single dairy cow leeches 1.2 tons of salinity into the groundwater each year [20].

This is a crucial problem because farmers constantly use groundwater when there isn't enough water from their contracts. When these high amounts of salts exist in the groundwater, it can impair crops, degrade drinking water, damage industrial equipment and even lead to the retirement of land [20]. Therefore, the amount and size of dairy farms should be restricted in regions surrounding like Davis and the Central Valley where these farms are abundant.

2.5 Wastewater Reclamation

The water shortage caused by the drought will require numerous engineering solutions in order to be fully mitigated. One such solution is the implementation of water reclamation systems into affected regions.

Wastewater reclamation, also known as water reuse or water recycling, is the process of treating wastewater to a standard where it can be reused for beneficial purposes. This process not only helps to conserve precious water resources but also provides a cost-effective solution to water scarcity in areas where fresh water is limited [68].

Wastewater reclamation involves several treatment stages, which include physical, chemical, and biological processes. The first step in the process is to remove large solids and debris through physical screening. This is followed by primary treatment, which involves the removal of suspended solids and organic matter through sedimentation and flotation. Secondary treatment then takes place, which involves the use of biological processes to remove dissolved organic matter, nitrogen, and phosphorus. Finally, the tertiary treatment stage is used to remove any remaining impurities, such as pathogens and dissolved solids [68].

The treated wastewater can be reused for a variety of purposes, including agricultural irrigation, industrial processes, and municipal water supply. In agriculture, reclaimed water is used to irrigate crops, providing a reliable source of water that is not affected by drought or water shortages. In industry, reclaimed water is used for cooling, cleaning, and other processes that require large quantities of water. In urban areas, reclaimed water can be used to supplement municipal water supplies, reducing the strain on local water resources [68].

Wastewater reclamation is an effective tool for the conservation of water resources. As the world's population grows and demand for water increases, it is becoming increasingly important to find ways to conserve this precious resource. Wastewater reclamation helps to reduce the amount of water that is withdrawn from rivers, lakes, and groundwater sources, thus ensuring that these resources are available for future generations.

2.6 Importance of Groundwater

Groundwater is a crucial water supply for a lot of people in the U.S. It makes up 30 percent of the total freshwater supply on earth, second to water locked in ice and glaciers which are very hard to utilize. The remainder of the water, lakes, rivers, and such, account only for slightly more than 1 percent of total freshwater supply [71]. Thus effectively, one can say that groundwater is the number one in volume if accounted for accessibility. Thanks to its quantity and distribution that isn't limited to areas with lakes and rivers, a lot of people rely on groundwater for their water uses. 51% of the total U.S. population depend on groundwater for their drinking [69]. In California, 85% of the population depends on groundwater for some of their water needs [70]. Thus, managing groundwater supplies is a crucial part for preparing and dealing with the effects of droughts.

Groundwater is stored in small cracks and pores in the rocks and soil underground. It is similar to how sponges hold water in their pores. Groundwater is formed from the water from rain, irrigation, and melting ice seeping through the soil and gathering in underground aquifers. Because this seeping process takes a long time, flows into groundwater aquifers are very slow. This can be seen where the unit of measurement of groundwater flow is done in feet per day (for fast ones) or feet per year or decade (for slow ones), whereas surface water flow is measured in feet per second [72]. As the water goes through the topsoil into underground aquifers, the water is filtered through them and makes them generally cleaner than surface water. Additionally, since the water is not exposed to air, it evaporates less than surface water supplies, making it ideal for use in droughts. However, this means that groundwater is especially vulnerable to overuse and depletion in times of drought, as both natural recharge of water and human use is increased. This is an issue for the Colorado River Basin, where during the ongoing drought, reduction in water supply in groundwater accounted for 50.1 km3 of the total 64.8 km3 of its total freshwater loss [78]. The slow rate of natural recharge makes it crucial for us to carefully manage our use of the aquifers since the adverse effects of long term overuse are very difficult to heal. Thus groundwater sources need to be carefully managed both in a drought and not

Depletion of groundwater can have various negative effects. First, its societal and economic impacts. As mentioned earlier, a large portion of the population of the U.S. and the agriculture sector depends on groundwater for their water needs. If groundwater is depleted either by droughts or overuse, the people who depend on them will lose access to the critical resource to survival. This will cause unrest in society as people will have difficulties to tend to their basic human needs such as drinking and hygiene, and could possibly have to relocate as the Ancestral Puebloans did during the 1200s, or import water from elsewhere which would be financially burdening. Additionally, a lot of farms in the south western region rely on groundwater to irrigate their heavy water consuming crops. If groundwater fails to steadily supply water for the farms, productivity of farms would diminish, leading to scarcity of agricultural products. Not only that, a plethora of products that rely on agricultural products such as animal products and such would also receive a hit to production efficiency. Thus, groundwater depletion can have negative economics and social consequences.

Second is the environmental damage caused by the change of water pressure underground. As everything else in nature, water tends to move in a way that reaches equilibrium in water pressures. Because of this, if more water is drawn from underground aquifers, there will be more pressure for water to move underground from lakes and rivers. This will lead to a drop in the water levels of surface storages, making access to fresh water more difficult and damaging the local ecosystem [77]. This pulling of water is especially a problem for coastal areas. In coastal areas, this pull is satisfied from the seawater, making the soil saltier and in turn causing environmental damage to the local plants and animals. This phenomenon is called Saltwater intrusion [74]. Saltwater intrusion is particularly concerning since it can make the groundwater reservoirs go into a positive loop since the aquifers being contaminated by saltwater puts even more strain on groundwater. Other consequences include lower water quality and increased energy use that comes with drawing up water from further underground [75].

Third is land subsidence. When large amounts of groundwater is depleted from underground storages, the soil and clay that makes up the aquifer dries and contracts, leading to a reduction in the ground's elevation. These subsidences have almost permanent effects, as the ground is usually inelastic, meaning even if we put the water back in the aquifer, the ground wouldn't go back to its original elevation [75]. The most common consequence of this is the destruction of buildings and public infrastructure such as roads and bridges. This is an ongoing issue in the southwestern region. A report about land subsidence in California found that the rates of decreasing elevation levels are a historically high one foot per year and this is causing billions of dollars worth of infrastructure damage [76]. Thus, we can see that managing groundwater levels is crucial and failing to do so effectively can lead to both short and long term damage in many ways. As groundwater is especially vulnerable to depletion during times of drought, we need to utilize efficient ways to manage it properly.

2.5.1 Water Replenishment

A major part in managing this important water supply is water replenishment. The definition of water replenishment is the "intentional replacement of groundwater back into the aquifer after it has been pumped" [71]. Basically, it is the various methods to maintain sustainable groundwater levels. As mentioned before, the natural rate in which groundwater is recharged into aquifers is very slow. Although the quantity of groundwater makes it a reliable source of water, with evermore increasing populations and more intense agricultural practices in our modern civilization, the rate of consumption of groundwater is becoming dangerously high and stored groundwater levels dangerously low, as shown in figure 1 below. Combined with the severe drought the southwestern region is going through right now, the loss of groundwater supply levels is only about to get accelerated. That is why water replenishment is important for dealing with droughts although it isn't a direct solution to increasing the overall water supply.

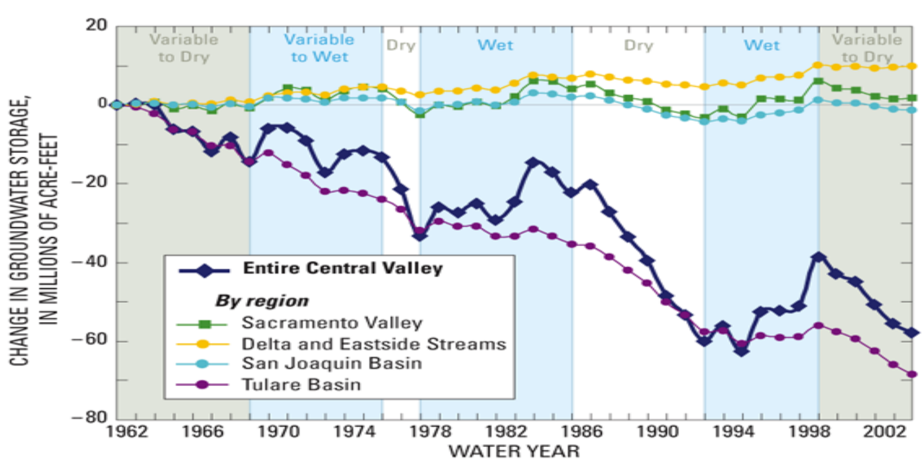

Figure 19: Change in groundwater storage in millions of acre-feet [73]

Water replenishment can be done in two ways: direct and indirect. These two methods deal with the input and output of water from groundwater supplies. Direct recharge is the process of increasing the input of water. It tries to increase the input of water into the aquifers artificially, which naturally would be very slow and minimal. The other groundwater replenishment method is indirect recharge. Indirect recharge is also known as in-lieu recharge. In-lieu, meaning 'instead of,' are methods that deal with the output of groundwater, or try to lower the amount of extraction from the aquifers by supplying its users with alternative sources of water. Indirect recharge comes with the difficulties that one faces when trying to change human behavior on a large scale. In order to manage groundwater in a sustainable manner, it is important to utilize both ways of groundwater replenishment appropriately.

Direct recharge is the quicker and more effective solution to increase groundwater levels. However, the issue is where do we draw the water from? If such large amounts of fresh clean water was readily available in the area, groundwater depletion wouldn't be such a critical problem as more water would flow into it while there's less extraction from people who would just use the easily accessible surface water. Additionally, if we were to draw water from other areas to inject into groundwater reservoirs, the residents of the location that water is drawn from may feel like their water rights are not protected, which would especially be a source of conflict during severe droughts. Thus, one may use alternatives from drawing water from another location such as desalination plants and water recycling plants as discussed in the previous section about water reclamation, where water that is otherwise unusable is processed to be acceptable for human use. Especially in the West, the rainfall is concentrated into short periods of time, resulting in floods and a large part of the water supply from the rain being lost. We can acquire water that could be used for groundwater injection by building more infrastructure to store these flood water and processing them [79]. Finally, if none is available, water can be imported from other regions.

How we get the water into the aquifers is another challenge. There exists a variety of different methods for direct recharge that are used in different situations depending on the characteristics of the region and the purpose of the water replenishment. The first method is through simply distributing water on the surface above the aquifer. This method is basically emulating the process of how aquifers form and are refilled naturally: by water from precipitation seeping through the soil and into the aquifers. Only here, we use various technologies to make the process more consistent and on a large scale. One specific example is the construction of recharge basins. Also called infiltration basins, these are basically artificial water reservoirs that collect floodwater and stormwater. The water is left in the basin to slowly seep into the ground and thus into the aquifers. These basins serve as a buffer to store temporarily increased water supply due to storms and floods that would otherwise be wasted. An example of this being used in real life is the Kern Water Bank [80]. Another method this can be achieved is through using less concrete for urban infrastructure. Concrete allows for less water to seep through, so by having more soil instead of concrete in urban areas, we can increase the natural flow of water from rainfall to groundwater storages.

The second method is using wells to actually pump water into the aquifers directly. This is called water injections, and the concept is similar to what is used in oil extractions. The wells used for this purpose are called ASR wells which stands for Aquifer Storage and Recovery wells. Injection is especially effective when natural recharge of aquifers is very difficult due to the aquifer being very deep underground or there being a layer in the ground that reduces water movement. Injection is also very effective for urban areas where limited space makes it difficult to construct and maintain recharge basins [81]. The downside, though, is that ASR wells are much more expensive to build and operate than the previous methods. Thus, although it allows for fast replenishment of groundwater supplies, ASR isn't a reliable source of groundwater that could have widespread use. A use case of ASR wells is those used by the Monterey Peninsula Water Management District. They use multiple ASR wells to inject water into nearby aquifers when there is excess water during winter [82].

Direct injection is fast and effective, but it is difficult to use the method in times of extreme drought, as water to inject into aquifers is hard to come by. Additionally, it is not a fundamental solution to the problem as it can only be used after groundwater levels have gone down. Because of this, direct injection has been found to not be effective in solving the problem of land subsidence, and it decreases the quality of groundwater [83]. That is why indirect replenishment methods are also important, as they address the problem of over extracting water from the aquifers.

Indirect, or in-lieu recharge tries to lower the output of water from the aquifer, contrary to how direct recharge tries to increase the input of water into it. As the meaning of in-lieu suggests, it tries to do this by providing groundwater users with alternative sources of water. The issue of finding the source of such alternative water is also present like for direct recharge. Similar to direct recharge, the alternative sources of water for indirect recharge can be gathered through infrastructure projects such as recharge basins. Structures such as the recharge basin could allow for better collection and storage of temporary spikes of water surplus such as stormwater. During times of drought, people could use these stored water supplies instead of groundwater to prevent its depletion. An important concept for indirect recharge is what is called conjunctive management. Conjunctive management is simply the efforts of trying to optimize our water uses by choosing which water source to use depending on their availability. For example, the community could collectively decide to use mainly surface water during periods when surface water is abundant, and leave groundwater to recharge itself both naturally and artificially. By using conjunctive management in combination with direct recharge methods and better infrastructure to better make use of temporary surplus from stormwater, we will be able to better manage our groundwater supply in times of drought.

3. Conclusion

Water management is a complex topic due to the historic water right agreements that have lead to oversuse since the "first come first serve" system does not incentivize conservation during droughts and instead transfers the responsibility onto junior water rights holders that are left without water. But since water is a human right, the state has an obligation to ensure their rights are met in this drought problem. A solution to this is to follow the model in Australia and overhaul the water rights system so that the government becomes the sole owner of water and controls its distribution. While this may be difficult, a systemic problem with the water problem needs to be addressed systematically as Australia did during the drought crisis.

Additionally, in the West, the water supply from the Colorado River is governed by the Colorado River Compact which ensures 7.5 MAF of water is delivered to the lower basin states regardless of the water inflows. Due to climate change, the previous projection during a wet year would not be appropriate and should be revised to use real-time data or models to better manage the Colorado River water. For California, the water management plans are more substantial than other states however it lacks several aspects that can make it more effective. For example, there should be better coordination between cities and states to have a cohesive plan that manages the watershed rather than city boundaries. Also, the plans must address agricultural water usage and incorporate climate effects to plan for the future.

An increase in funding for landscape conversions and awareness campaigns for water conservation as well as overpopulation should be implemented. As seen with the success of Los Angeles' turf replacement rebate program, the state should adopt similar rebate programs that can be applied to all residents after meeting their own set of conditions. These landscape conversion programs should continue to deny applicants intending to use artificial turf and should amplify the efficacy of native and drought-resistant plants. The awareness campaigns for water conservation should continue running past the time of drought to a) keep the public ready for consecutive droughts and b) ingrain into people the benefits of communal efforts to save water. This campaign should make the extra effort to convey the fact that each person in the community and their water consumption does have a meaningful impact.

As GM plants are sure to become more and more incorporated into the future, it is necessary for the state to be prepared for any resistance to or fear of the existence of genetically modified foods. On that note, the state should also fight for the reduction of almond and dairy farms due to both of their intensive consumptions of water.

Although the severity of the drought may make some increased consumption inevitable, it is crucial that we manage our groundwater supplies in a sustainable manner. Depletion of groundwater does not only mean that we have less water to use, but also it means that the physical and chemical properties of the ground will change. This causes issues such as land subsidence and saltwater intrusion. The negative effects of such changes could put the sustainability of the ground into a positive feedback loop, causing more harm in the long run. Thus, instead of viewing groundwater as a renewable resource, we need to approach it with caution and try to balance the consumption rates with recharge rates. To do this, we first need to gather data of the input and output amounts into aquifers in the region. Then, we need to implement ways of conjunctive management where we try to optimize our water use by allocating consumption to either groundwater or surface water depending on their availability at the moment. Lastly, we need to use water replenishment methods to further manage the groundwater supply levels. In order to do this, we need to construct more infrastructure that can act as a buffer for temporary spikes in water levels from heavy rainfall.

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