An Analysis of Water Scarcity in California and Recommendations for Management in Coalinga

A Major Qualifying Project submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the degree of Bachelor of Science.

March 18, 2024

Authors:

Duncan D'Olimpio

Neilie Fromhein

Kayleigh George

Chloe Harrison

Ricky Healey

Submitted to:

Professor Jeanine Dudle Ph.D, P.E.

Worcester Polytechnic Institute

Worcester, MA

Abstract

Water scarcity and insecurity caused by climate change and anthropological resource depletion has significantly impacted water costs and quality of life in California. The city of Coalinga in Fresno County was identified as an area of concern due to their ongoing issues with water scarcity. Our team conducted research on California's water availability, water use, conservation efforts, public perception of water strategies, and costs associated with alternative water sources. Potable water management recommendations were then created for Coalinga which includes water conservation incentives and wastewater reuse to decrease both import costs and reliance on stressed fresh water sources.

Executive Summary

Since the 1990s, California has been experiencing more intense and prolonged periods of drought, which has led to the depletion of natural water sources and ongoing water scarcity. This project evaluated water availability, water supply and use, conservation efforts, public opinion, and costs associated with alternative water sources in California. The goal was to create water resources management recommendations for the City of Coalinga which has experienced reductions in water allotments and a lack of viable freshwater sources.

During dry years, California uses approximately 167,000 acre-feet of water daily (61 million acre-feet/year). Significant water sources are groundwater, including 35,000 wells and 515 other groundwater sources, and surface water, including 1,300 reservoirs and over 3,000 lakes. Of these reservoirs, 36 are considered large and provide most reservoir water use. Both sources are impacted by intense droughts, with more than half of the 4,800 municipal wells projected to decrease in available water in the next 20 years and lakes such as Trinity Lake experiencing a 62% decrease in volume from 2019 to 2022. Alternative water sources include desalination, wastewater reuse, and imported water. California has twelve coastal desalination plants, including a Carlsbad, CA plant that produces 150 acre-feet per day, with six more planned as of 2023. As of 2024, desalination contributes 330 acre-feet of water per day (0.2% of the daily demand), wastewater reuse contributes 1,830 acre-feet per day (1.1% of the daily demand), and imported water contributes 3,070 acre-feet per day (1.8% of the daily demand). Generally, freshwater sources (groundwater and surface water) cost less than alternative sources.

Of the water used within California, 50% is used by the environmental sector, the agricultural sector uses 40%, and 10% is for urban uses. In the urban sector, water use fell from 231 gallons (0.0007 acre-feet) per capita per day in 1990 to 180 gallons (0.00055 acre-feet) per capita per day in 2010. This decreased use can be attributed to efforts such as the mandatory installation of water-saving appliances and monetary incentives. During periods of drought, water policies and laws are enforced across the state, which mandate water restrictions. In the industry sector, repairs and replacements are required to prevent losses. Water plans must be made in the agricultural sector, including plans for efficient irrigation practices.

The city of Coalinga in Fresno County is a primary example of the large-scale water scarcity issue faced in California. Historically, Coalinga has used 7,125 acre-feet of water during its wettest years. They were historically allocated 10,000 acre-feet of water a year from their only water source, the Central Valley Project. However, at the height of the drought in 2022, their allocations were reduced to 2,000 acre-feet, predicted to disappear by December of that year. This forced the purchase of an additional 600 acre-feet of water to meet their needs. The groundwater in Coalinga is unusable due to contamination. They also lack usable surface water sources.

To combat this scarcity issue, it is recommended that Coalinga introduce alternative water sources, such as wastewater reuse and rainwater harvesting and reuse. Their current wastewater treatment plant has an influent of 3500 m^3 per day (2.8 acre-feet/day or 1,022 acre-feet per year). However, it does not currently have the infrastructure to produce potable water. While it would be costly to update this, it could contribute 14% of the city's annual needs. Coalinga currently receives 8.25 inches of rainfall yearly. If residential roofs were updated to allow for rainwater collection, the city could capture 151,000 m^3 per year (122 acre-feet/year), contributing 1.7% of their yearly needs. To combat cost issues, it is recommended that the city apply for grants and loans from the California Department of Water Resources or the EPA to allow for a larger budget without increasing the price of water for their citizens. It is also recommended that the city of Coalinga increase conservation efforts. This can include educating homeowners; encouraging water-saving technologies such as low-flush toilets in homes; and enabling industry efforts to reduce water usage through incentives. Finally, to further promote conservation, Coalinga could implement a tiered billing system that charges lower rates for households that use less water than the budgeted amount per household.

Acknowledgments

Our team would like to thank our advisor Jeanine Dudle, Ph.D., P.E. for the continued encouragement and invaluable guidance provided throughout the duration of this project.

Authorship

All team members contributed to the front matter, the research and writing and revisions of Chapter 1 and Section 3.6. Duncan was the primary contributor for Chapter 2 and Chapter 3.3, Kayleigh for 3.1, Chloe for the executive summary and 3.2, Neilie for 3.4, and Ricky for Chapter 4. Neilie, Chloe, and Kayleigh were all primary contributors to Section 3.5.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction and Background

This project focused on identifying problems and potential solutions concerning water management in California through the exploration of its current and future availability, use, conservation efforts, public opinion, and cost of water sources and treatment strategies. This resulted in the creation of a resource management plan that suggests best management practices with a focus on the city of Coalinga as a case study. This chapter provides a background on water use in the United States, water regulations, water scarcity, and the impacts of water overuse. This chapter outlines some prevailing water issues and discusses potential solutions to enhance water availability and ensure the long-term sustainability of water resources.

1.1 Water Use and Water Rights

Water use in different regions of the United States varies based on climate and population. The primary uses of water in the United States are for industry, agriculture, and domestic uses. The majority of water is drawn from fresh surface water and groundwater storage with a small portion taken from brackish or saline waters. Brackish waters are simply natural waters that have an amount of salt above that of freshwater but below that of seawater. The use of water within different sectors is heavily influenced by water rights. This section provides data on water use in different sectors, legal water requirements and regulations related to water.

In the United States, water use can be categorized into public supply, domestic, irrigation, thermoelectric power, industrial, mining, livestock, or aquaculture. In 2015, 39,000 Mgal per day of water was withdrawn for public supply with most from surface water sources (USGS, 2021). Public supply includes 283 million Americans who relied on public water supplies for their household in 2015. This number represents about 87% of the total American population. Domestic water use comes from the public supply and includes drinking, watering, and cleaning. It totaled 23,300 Mgal per day in 2015 (USGS, 2021). In the same year, total irrigation withdrawals were 118,000 Mgal per day with most from freshwater and surface water sources and some groundwater withdrawals (USGS, 2021). Irrigation was needed over 63,500 thousand acres and 55% were irrigated by sprinkler systems, and the rest with surface (flood) and microirrigation systems (USGS, 2021). It is important to note that “the national average application rate for 2015 was 2.09 acre-feet per acre” (USGS, 2021). Thermoelectric power for 2015 used 133,000 Mgal per day of water and all was withdrawn from surface water sources, predominantly freshwater (USGS, 2021). This was 41% of all water withdrawals, 34% of total freshwater withdrawals, and 48% of fresh surface-water withdrawals for all uses (USGS, 2021). Industrial used only 5% of total withdrawals for all categories of use. Nearly all of this water came from surface water sources. Mining, livestock, and aquaculture take less then 5% of the total water withdrawals combined.

Water use in the US has changed significantly over the last 70 years. From 1950 to 1980, water use increased in conjunction with population growth; however, after 1980, advancements in water conserving technologies began to decrease. The population of the United States increased from 158,804,396 in 1950 to 335,893,238 in 2024 (US Department of Commerce, 2024). In comparison, water use has returned to levels equivalent to the mid 60s (USGS, 2018). The decline can primarily be attributed to reductions in thermoelectric power plants and more efficient cooling systems being installed that greatly reduced water usage. Thermoelectric Power plants water usage increased 400% from 1950 to 2005, but with the increase in renewable energy sources and improved cooling systems, water usage dropped 18% from 2005 to 2015 as depicted in Figure 1. Table 1 depicts the allocation of water by sector from 1950 to 2015. The future trends of water consumptive use have been estimated by numerous universities and the USDA and the conclusions they have drawn are relative to the severity of climate change. The USDA has a wide range potential outcome with the best-case scenario where water use will decrease by 8% and worst-case scenario where water use will increase by 235% (AGU, 2021).

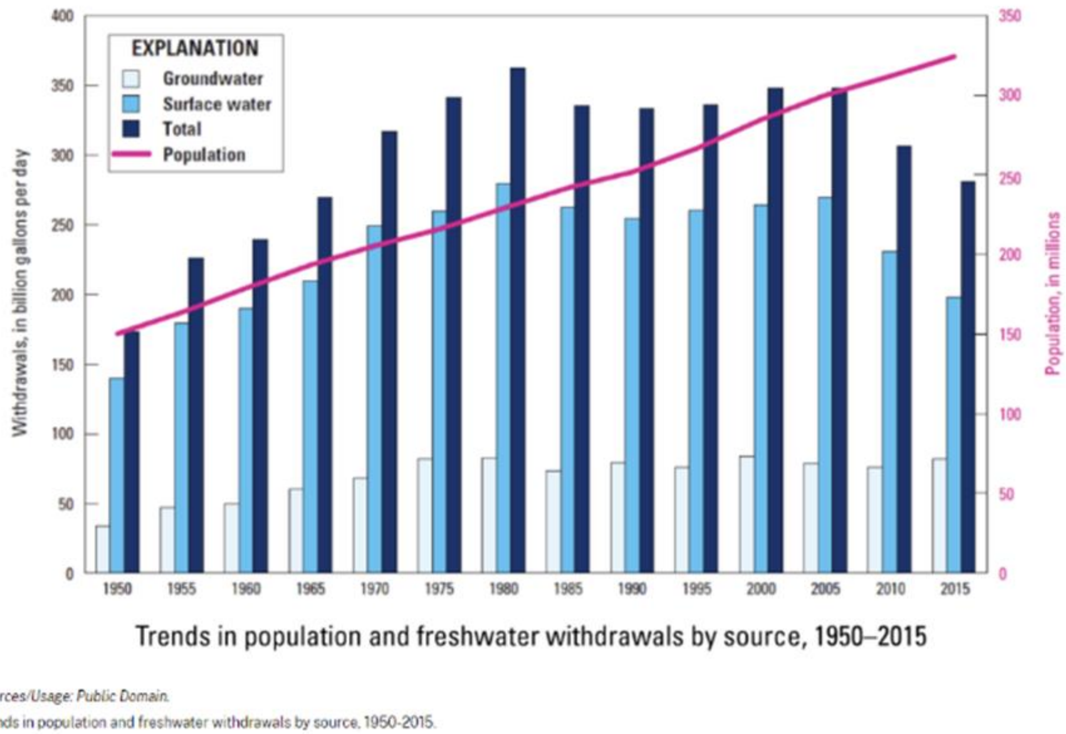


Figure 1: Trends in freshwater and groundwater use from 1950 to 2015 (USGS, 2018, Public Domain)

Table 1: Allocation of water use over recent decades. Broken down by water use sector (USGS, 2018, Public Domain).

	Year														Percent change, 2010–15
	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015	
Population, in millions	150.7	164.0	179.3	193.8	205.9	216.4	229.6	242.4	252.3	267.1	285.3	300.7	312.6	325.0	4
Total withdrawals	180	240	270	310	370	420	430	397	404	398	413	410[a]	354[a]	322	–9
Public supply	14	17	21	24	27	29	33	36.6	38.7	40.2	43.3	44.4[a]	42.0	39.0	–7
Rural domestic and livestock															
Self-supplied domestic	2.1	2.1	2.0	2.3	2.6	2.8	3.4	3.32	3.39	3.39	3.58	3.73[a]	3.53[a]	3.26	–8
Livestock	1.5	1.5	1.6	1.7	1.9	2.1	2.2	2.23	2.25	2.28	2.37[a]	2.15	2.00	2.00	0
Irrigation	89	110	110	120	130	140	150	135	134	130	139	127	116[a]	118	2
Thermoelectric power	40	72	100	130	170	200	210	187	194	190	195	201	162[a]	133	–18
Other															
Self-supplied industrial	37	39	38	46	47	45	45	25.8	22.4[a]	21.6	19.5[a]	18.1	16.2[a]	14.8	–9
Mining	(b)	(b)	(b)	(b)	(b)	(b)	(b)	3.44	4.93	3.59	4.13[a]	3.83	3.97[a]	4.00	1
Commercial	(b)	(b)	(b)	(b)	(b)	(b)	(b)	1.23	2.39	2.89	(c)	(c)	(c)	(c)	
Aquaculture	(b)	(b)	(b)	(b)	(b)	(b)	(b)	2.24	2.24	3.27[a]	5.79[a]	8.83[a]	8.96[a]	7.55	–16
Source of water															
Groundwater															
Fresh	34	47	50	60	68	82	83	73.4	79.4	76.4[a]	84.3[a]	78.9	75.9[a]	82.3	8
Saline	(c)	0.6	0.4	0.5	1.0	1.0	0.93	0.66	1.30[a]	1.11	2.47[a]	1.51	2.22[a]	2.34	5
Surface water															
Fresh	140	180	190	210	250	260	280	263	255[a]	261	265	270	231[a]	198	–14
Saline	10	18	31	43	53	69	71	59.6	68.7[a]	59.7	61.0	59.8[a]	45.0	38.6	–14

[a]Data revised from Maupin and others (2014) because of revisions to individual State data during interim years.

[b]Included in self-supplied industrial.

[c]Data not available.

Sources/Usage: Public Domain.

Source: Estimated Water Use in the United States in 2015

1.1.1 Water Rights

Water rights refers to the legal permission of property owners to access a reasonable amount of water from sources on or adjacent to their properties. There are several different types of water rights, with the major ones being riparian and littoral rights. Riparian rights refer to the rights of a landowner whose property lies along a flowing body of water such as a river or stream. In such cases, the landowner is allowed to use said water body provided that any use does not cause any harm to the upstream or downstream neighbors. If the water body is non-navigable, the landowner owns the land under it to the middle (Water Education Foundation, n.d.). Littoral rights refer to the rights of landowners whose property borders navigable lakes, oceans, or other water bodies with tides and currents that affect them but do not flow in the same manner as rivers or streams. Landowners have complete access to the water body but only own the land up to the median high-water mark. Water rights are appurtenant, which means they accompany the property instead of the owner, suggesting that the owner gives up rights when the property is sold (American Land Title Association, 2001).

Generally, water rights are regulated by individual states rather than the federal government. However, federal law may come into play under acts such as the Endangered Species Act and other similar acts that protect certain bodies of water. The U.S. Bureau of Reclamation can also have some influence on water rights due to their role in the distribution of water (Water Education Foundation, 2020). Water rights differ across the US, with the laws in eastern states greatly differentiating from those in the west. In the west, states follow the riparian system, with the government imposing regulations under the system that requires individuals and companies to apply for a permit and provide an estimate of water use. Some states also implement Appropriative Water Rights. This refers to the removal of water for use in non-riparian areas. These appropriative rights can be sold or transferred and stored for future use (California Land and Ranch n.d.).

1.1.2 Water Regulations

Water regulations are essential for safeguarding public health, ensuring the sustainable use of freshwater resources, and protecting the environment. They establish standards and guidelines that govern the quality and end location of water. These regulations serve as a framework to mitigate contamination, promote responsible water management, and maintain the balance between human needs and the ecosystem.

The Safe Drinking Water Act (SDWA) was created to ensure that all Americans have safe drinking water. Under the SDWA, the EPA sets and enforces standards for drinking water quality and monitors states, local authorities, and water suppliers. The EPA sets maximum contaminant levels and treatment requirements for over 90 contaminants in public drinking waters through the National Primary Drinking Water Regulations (NPDWR) and the National Secondary Drinking Water Regulations (NSDWR). The primary standards focus on legally enforceable standards for the public water systems, limiting the levels of specific contaminants that can affect the public health and setting treatment technique rules. The secondary standards focus on non-enforceable guidelines for contamination that may cause cosmetic and aesthetic effects, such as taste, color, and smell of drinking water. The EPA also publishes a list of unregulated contaminants called the Contaminant Candidate List which is updated every five years (USEPA, 2000). The EPA sets maximum contaminant level goals (MCLGs) based on data about the health effects of the specific contaminants. The EPA considers people at high health risk when setting the MCLGs; this includes infants, children, pregnant people, and the elderly (USEPA, 2000). The EPA requires all water systems to provide a Consumer Confidence Report (CCR) to all customers which is based on the quality of the public water system required by the EPA. This report offered detailed information about the quality of the drinking water, where the water comes from, contaminants found in the water, and how customers can protect their drinking water.

Wastewater regulations can be based on technology or water quality. Both come from the Clean Water Act (CWA). Technology based permits are enforced through NPDES permits to set a minimum standard for the quality of water being discharged for point discharges. A point source defined by the EPA is “any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel, conduit, discrete fissure, or container” (EPA, n.d.). This permit is designed to ensure that the state's water resources remain free from pollution and that the treatment of wastewater aligns with the most advanced technologies and environmental best practices. One strategy that is used for water quality is Total Maximum Daily Limits. Total Maximum Daily Loads (TMDLs) play a crucial role in California's water management and environmental protection efforts. TMDLs provide a systematic approach to addressing water quality impairments (CA, 2018). When water bodies, such as rivers or lakes, are found to be falling short of established water quality standards, TMDLs are developed to outline the maximum amount of a specific pollutant that can be introduced into the water body while still maintaining the desired water quality. TMDLs take into account both point source pollution and nonpoint source pollution that may contribute to the impairment. These plans are comprehensive, covering all aspects of the watershed's drainage system and pollution sources. By addressing the full range of pollution sources and developing strategies for their reduction, TMDLs are an essential tool for safeguarding and restoring water quality in California's diverse ecosystems. They aim to ensure that all waters within the state meet the standards set to protect human health, aquatic life, and recreational and industrial uses. The development and implementation of TMDLs are critical in the ongoing efforts to maintain and improve water quality, especially in the face of increasing environmental challenges (CA, 2018).

The NPDES permit program initiated by the EPA regulates point sources and stormwater runoff that would pollute the environments it flows into. The permit allows runoff to be approved for discharge into receiving waters only if it meets specific water quality standards and environmental protection criteria. These standards include limits on the concentration of pollutants such as sediment, nutrients, heavy metals, and various contaminants of concern. To obtain and maintain an NPDES permit, facilities and municipalities must implement pollution control measures, conduct regular monitoring and reporting, and, where applicable, implement best management practices to ensure that the stormwater runoff discharged into the environment is appropriately treated and does not pose a threat to water quality, aquatic ecosystems, or public health (EPA, n.d.).

The Municipal Separate Storm Sewer System (MS4) program under the National Pollutant Discharge Elimination System (NPDES) permit is a critical component of urban stormwater management. MS4 permits are needed for regulating stormwater discharges from municipalities with separate storm sewer systems. Separate systems means stormwater and wastewater are conveyed to their final locations in different sets of pipes. This entails one system for managing stormwater, directing water through pipes and catch basins downgrade until a water source is reached (Bradford, 2023). A completely different set of pipes will move just wastewater. These permits like MS4 are effective in reducing the adverse impacts of stormwater runoff on water quality and the environment by limiting contaminants. Under the MS4 NPDES permit program, municipalities must develop and implement comprehensive stormwater management programs and have separate systems as discussed. These programs typically encompass various strategies and practices aimed at minimizing the quantity of stormwater runoff and improving its quality. Key components include public education and outreach, implementing best management practices to control stormwater pollution, and establishing measures to control construction site runoff.

The California State Water Resources Control Board (CA SWRCB), the Regional Water Quality Control Boards, and the USEPA have made continuous efforts to mitigate runoff and explore treatment plans. This prevents a certain level of pollutants being allowed to wash into water bodies in industrial, municipal, and residential areas (California Water Board, n.d.). Along with this initial quality regulation, California is widely seeking to expand into stormwater capture and reuse. The State Water board has proposed a plan that maximizes the amount of stormwater captured and puts it to use in the agricultural sector, as well as groundwater well and aquifer recharging. This plan includes two major ideas and techniques. The first is Low Impact Development (LID), which uses the initial site design and existing stormwater management of an area and sustainably enhances it to ensure that the pre-development runoff rates and volume remains the same. The second technique is the installation of green technology in already developed areas with minimal green spaces to filter out pollutants (California Water Board, n.d.).

1.2 Water Overuse

Water overuse and the depletion of aquifers is an issue with implications for freshwater resources. Aquifers store a significant portion of the world's freshwater and play a crucial role in agriculture, industry, and drinking water. Extraction of groundwater from aquifers is causing the water table to drop faster than the natural recharge rate leading to other problems such as saltwater intrusion and sinkholes. Continuing this unsustainable extraction will cause a threat to the ability to meet current and future water needs, as well as environmental consequences from the intrusion of saltwater into freshwater sources, lands subsidence, and to the formation of sinkholes. There is a need for responsible water management and conservation practices to reduce the negative effects from water overuse.

Surface water depletion refers to the decreased availability of water in rivers, lakes, and other freshwater sources. Approximately 70% of the freshwater used in the United States comes from surface water sources (USDA, 2020) When these sources of water decrease, it is usually because of human uses like irrigation, industrial use, and urbanization. As populations grow and economies expand, the demand for water intensifies, leading to the over-extraction of surface water. The US Department of Agriculture claims that this drainage negatively impacts wildlife habitat functions which, in turn, affects public health and safety (USDA, 2020). Sustainable water management practices and conservation efforts are crucial to mitigate the impacts of surface water depletion and ensure the long-term availability of this vital resource for both human and environmental well-being.

Aquifer depletion is a critical environmental issue that occurs when groundwater, stored in underground reservoirs known as aquifers, is being withdrawn at a faster rate than it can naturally recharge. This overuse of groundwater resources creates significant challenges for both the environment and humans. Some of the effects of groundwater depletion are lowering the water table causing wells to no longer be able to reach groundwater (USGS, 2023). As the water table lowers, the water must be pumped from a different point, or the well must be drilled deeper into the ground to reach the groundwater. This uses more energy and will be more expensive. Groundwater and surface water are connected; when groundwater is overused, lakes, streams, and rivers supply diminish as well (Groundwater Foundation, 2023). This can be seen in Figure 2 below.

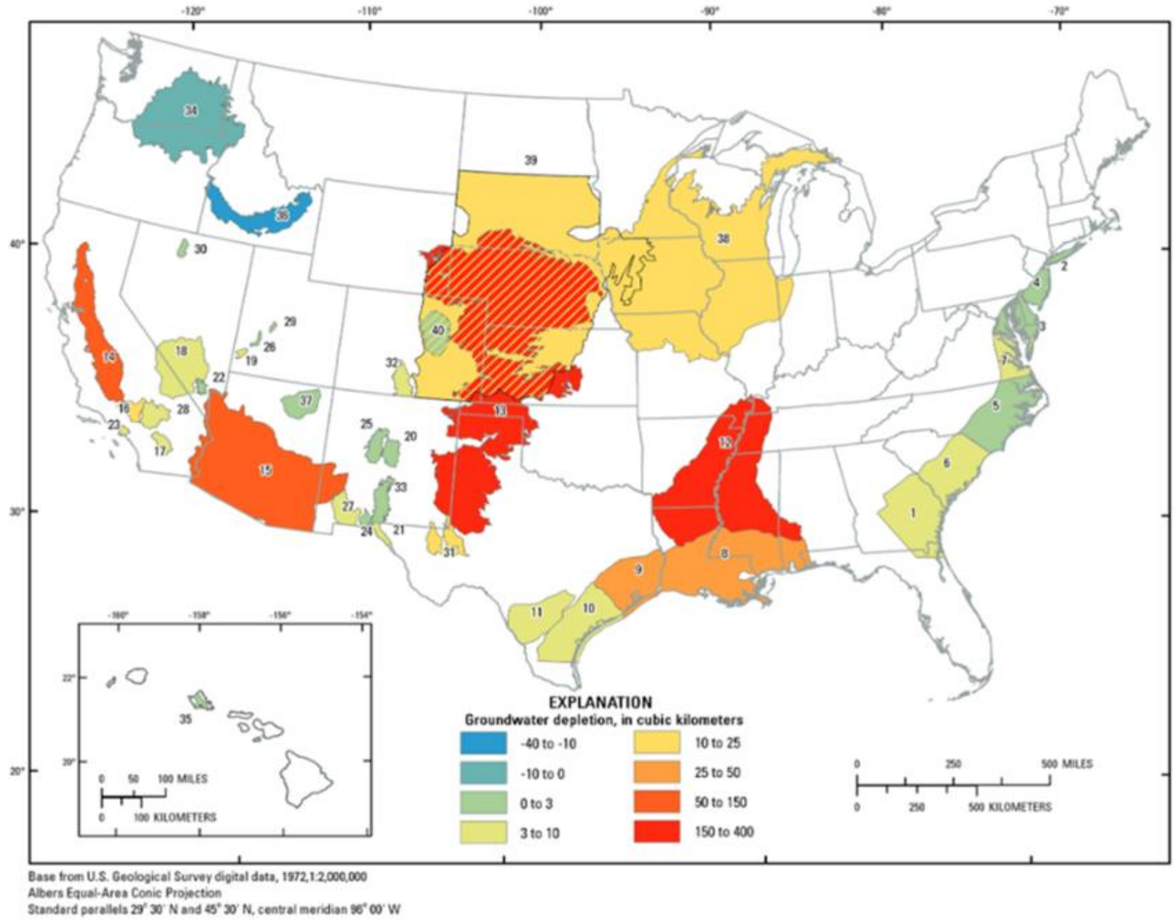


Figure 2: Map of the United States from 1900 to 2008 assess aquifer systems. (USGS, 2023, Public Domain).

Groundwater pumping in coastal regions induces the inland and upward movement of saltwater, resulting in the contamination of water supplies. The prevalence of saltwater intrusion is escalating with rising sea levels, particularly in low-elevation areas. This issue is accentuated by the fact that saltwater adversely affects water quality, rendering it unsuitable for agricultural use and human consumption (USGS, 2023). The EPA has established an upper advisory level for drinking water salt content at 30-60 parts per million. Water with a salt concentration of 250 ppm can exhibit a salty taste and cloudy appearance, with the perception of saltiness by the average person occurring at 400 ppm. Florida, situated on the coast with lower elevation, has grappled with saltwater intrusion in groundwater since the early 1900s, with some aquifers in the state reaching a significant saltiness level of 1000 ppm (Richter, 2023).

When groundwater levels drop, support from soft rock material weakens and can lead to collapse. Sinkholes are dangerous results ranging in diameter from less than 1 foot to more than 100 feet (USGS, 2018). Sinkholes can be a natural occurrence, but humans most often cause them (EPA, 2023). These causes include too much groundwater pumping from aquifers, petroleum drilling, or mining (PennDEP, n.d.). Aquifers can be depleted from excess pumping. In such a case, pumping can cause subsidence and even collapse in significant cases. When water is extracted from an aquifer, a void or cavity in the underground space is created and the overlong soil and rock can gradually settle into the void created from pumping. This can result in the formation of sinkholes. Sinkholes can be prevented and mitigated by managing the water extraction from aquifers and finding sustainability (USGS, 2023).

In the United States, water shortages are becoming commonplace. These predicted water shortages will impact most of western and central United States. Water overuse plays a big role in water scarcity as well. Places such as Los Angeles, where the residents see the water shortages first-hand, have strict water restrictions in addition to high water prices. Los Angeles uses a tiered system for water pricing, with people using more water falling into tiers 3 and 4. For tier 3, in 2022 water prices increased from $9.192 to $10.436 per HCF and for tier 4, prices increased from $9.192 to $12.794 (LADWP, 2021). These prices have maintained the amount of water used even when Los Angeles' population increased significantly. Los Angeles also has strict water use restrictions due to their water scarcity that help them to manage their water resources. For example, vehicles cannot be washed with a hose unless fitted with a self-closing nozzle, decorative water features cannot be operated unless the water is recirculated, and at restaurants patrons do not get water unless it is upon request (LACWD, n.d.). There can also be development restrictions due to water scarcity. In Phoenix, Arizona, although many housing developments have been approved, they are now being reconsidered given the water insecurity in the area. The state has not revoked building permits; however, state officials are requiring developers to find alternative water sources other than groundwater because the current groundwater supply would not be enough for the projected population (Flavelle & Healy, 2023). Going forward, officials will be less likely to approve building permits due to the water shortage that is occurring. Situations like this are happening more frequently as water supplies dwindle rapidly.

1.2.1 Climate Change

Beyond flooding and droughts, the increase in temperatures worldwide is causing a multitude of environmental problems causing a lack of water in general. Earth's average surface air temperature has increased by about 1 °C (1.8 °F) (The Royal Society, 2020). As a result, terrestrial water storage is projected to decrease at a rate of 1 cm per year (UN, n.d.) from the dehydration of soil in addition to snow/ice melting. Much of the snow on mountains is projected to melt due to an increase in global temperatures. The increase in global temperatures also leads to less snowfall in general. This will cause water shortages and dry periods. According to the United States Geological Survey in 2023, climate change has caused droughts to be more frequent, longer, and more severe. Water sources are becoming obsolete over time due to the added pressure of climate change.

1.3 Water Development Options

With the growing challenges posed by climate change and population expansion, management of our water resources has become crucial. Through stormwater capturing, aquifer storage and recovery (ASR), and water reuse, these challenges contributing to water scarcity can be minimized if successful.

Stormwater is suggested as a potential solution in areas like Southern California that heavily rely on imported water and unsustainable groundwater practices. Another benefit is the positive impact the process can have on sewer systems. CSOs are combined sewer overflows resulting from a combined sewer and stormwater systems in a flood (Tibbetts, 2023). Stormwater capture can reduce the severity of CSOs by separating the sewage runoff from stormwater and reducing overall stress on these systems, preventing any possible damage and mitigating potential costs associated with the collection of excess water due to extreme levels of precipitation (Parker et al., 2022). Stormwater capture can effectively reduce the environmental toll from municipal separate storm sewer systems (MS4s) when captured separately from sewer runoffs. MS4s can often move water at a very high velocity after increased precipitation, leading to excessive chemicals being washed into the system and potentially causing erosion. Stormwater control methods can reduce the volume entering the system and mimic the speed and volume of water entering the system before rain, even after a large amount of precipitation. It has been suggested that MS4s be altered to allow the treatment of greywater (relatively clean waste water from things such as baths) and storage of runoff from places such as streets and rooftops (Parker et al., 2022; Filali, 2023). This treated water can then be used between storms or continuous precipitation for non-potable activities, including irrigation and toilet flushing.

Along with the benefits mentioned earlier, stormwater capture is a relatively inexpensive alternative water source as the treatment processes and water capture are less intensive. Stormwater treatment can cost between $0.48 and $1.23 per cubic meter, while wastewater treatment can cost between $1.72 and $2.29 per cubic meter (Chemtech, 2022). Stormwater capture also has major environmental benefits. Stormwater entering drains can often carry harmful chemicals and pollutants into the water sources to which these systems are connected. However, the capture and treatment of this water prevents these harmful substances from entering the water system. The captured water, once treated, can also be used in wetland restoration and injected into aquifers to prevent issues related to low water levels, such as sinkholes. With the rise of severe weather systems, such as prolonged periods of rain or high-category hurricanes, there has been a significant increase in the average precipitation rate, and significant flooding issues have occurred. The capture of stormwater can help reduce the effects of extreme storms on urban areas with minimal drainage by reducing the strain on storm drainage systems and, when used concurrently with other green infrastructure practices, provide a greener urban environment (EPA, 2022).

Managed aquifer recharge, or MAR, replenishes water levels through spreading methods, in-channel modifications, well boreholes, bank filtration, and runoff harvesting. Spreading methods like ponds control flood waters and move water into the ground through infiltration. In-channel modifications store water from streams through dams, so water has a longer time to travel vertically. Well, shaft, and borehole recharge may use the same well that was used to extract groundwater in the first place and sources may come from recycled water or even other wells which has been proven to improve quality. Induced bank infiltration indirectly recharges as water is slowly taken from underneath a lake where the water has had time to infiltrate and become much cleaner. Finally, runoff harvesting from stormwater can be stored in a large pit over a groundwater aquifer for natural recycling (Zhang, 2020).

AR and ARS projects are examples of the well, shaft and/or borehole recharge systems. They are more prevalent in areas with high population density, proximity to intensive agriculture, petroleum drilling, and mining. These are the same areas where there is a higher risk of sinkholes. AR replenishes water within aquifers through the injection of water in designated AR wells. The process benefits communities near saltwater by preventing saltwater intrusion into the freshwater aquifers. ASR stores freshwater underground that can be retrieved for needs such as drinking water, irrigation, industrial use, or ecosystem restoration projects. Approval and permits are needed prior to AR injections, along with regulations on the quality of water (EPA, 2022). There are 204 ASR sites in the United States and approximately 7% of the sites are operational, 24% are under various stages of testing, 26% were abandoned, and 12% were test sites only (Bloetscher, 2014). However, the abandoned 26% of the 204 total abandoned sites consist of 3 abandoned sites that were reused for potable supply wells.

Water reuse, which is also termed water recycling or water reclamation, involves the treatment and subsequent repurposing of water for alternative use rather than discharging it back into the environment. This approach addresses water scarcity by adopting a cradle-to-cradle method, regenerating water sources as opposed to a cradle-to-grave approach. Annually in the United States, approximately 2500 acre-feet of reclaimed water find various beneficial applications (WateReuse, 2023). Moreover, resources such as nutrients, phosphorous, and nitrogen can be salvaged and reused from wastewater.

The process of water reuse may occur either deliberately or incidentally. Planned reuse examples include agricultural and landscape irrigation, industrial process water, potable water supplies, and groundwater management (EPA, 2023). Alternatively, some communities draw water from rivers where neighboring communities upstream discharge wastewater. This is unintentional recycling of wastewater, also called unplanned reuse. The multitude of applications for water reuse highlight the importance of tailoring water treatment according to its intended purpose. Water reclaimed for crop irrigation must meet certain quality standards to protect plant health, soil fertility, and human well-being (EPA, 2023). Conversely, if reclaimed water is destined for domestic use, a more rigorous and thorough treatment process becomes necessary to meet regulation standards. The latter describes the idea of potable water; water treated to meet drinking water standards. Direct potable reuse signifies a planned introduction of recycled water to a drinking water system or water supply directly upstream from a drinking water plant (State Water Resources Control Board, 2016). Specific geographical features make water reuse more advantageous in some areas over others. Geographically, water reuse facilities tend to be in the southern United States, including Florida, Texas, and California, as seen in Table 2 below.

Table 2: Number of reclaimed water suppliers per state (Data adapted from The United States Federal Energy Management Program, 2023).

State	**# of Reclaimed Water Suppliers**
AZ	18
CA	117
CO	12
FL	329
NV	4
TX	36

Surface water augmentation consists of a reservoir that holds onto wastewater before further treatment provides multiple benefits. For one, a reservoir provides dilution of wastewater so treatment would be much easier. In this approach, highly treated recycled water, which may have originated from wastewater treatment plants or other sources, is intentionally discharged into surface water reservoirs or natural water bodies (EPA, 2023). Doing so supplements the available surface water resources with an additional treated water source, protecting the amount of water usable by the environment. After the reclaimed water is mixed with the natural surface water, it undergoes further dilution and additional natural processes without harming the environment. The environment may be harmed if water discharges have too many nutrients, causing a eutrophic event. Subsequently, the mixed water is drawn from the reservoir and subjected to further treatment to meet drinking water (potable) quality standards.

Chapter 2: Methodology

The goal of this section was to identify the sources of data present in Chapter 3 – Results and Analysis.

2.1 Groundwater and Surface Water Data Collection

Data on groundwater availability spanning the last two decades were sourced primarily from the United States Geological Survey (USGS) website (usgs.gov). Searches were conducted using Google Search engine and WPI Gordon Library database. The USGS website provided comprehensive information on trends in water use. To contextualize these trends, data were compared with demographic information obtained from the Population Statistics article on the US Department of Commerce website. Table 3 shows keywords and websites used for this part of the methodology.

2.2 Wastewater Reuse

Quantitative data pertaining to wastewater reuse and treatment facilities were sourced from various reputable references. Rachael Becker's comprehensive report on the utilization of recycled wastewater in California in 2023 was consulted, accessible through the search "California Plans to Turn Sewage into Drinking Water" on the Google search engine. Adam Olivieri's 2015 publication provided specific insights into household wastewater reuse, complemented by broader data on wastewater reuse in California, retrievable by searching "California Water Reuse – Past, Present, and future perspectives" on Google. Table 3 shows key words and websites used for this part of the methodology.

2.3 Rainfall and Water Imports

Rainfall data were obtained from the National Oceanic and Atmospheric Administration (NOAA). Specifically, rainfall data in California provides data from 2023 on rainfall within California along with the rest of the US. Water imports in California are needed in specific areas, as outlined by the California Department of Water resources. 2023 water import data was also found from The Metropolitan Water District of Southern California and can be found with the Google search engine with the keywords *Securing our Imported Supplies*. Table 3 shows key words and websites used for this part of the methodology.

2.4 Use and Demand of Water in California

Data on water use for industry was mostly from USGS and different water organizations in California, such as CWC, California State Resources Control Board, and California Department of Water Resources. Information from USGS was found on usgs.gov by searching the phrase "industrial water use in California." Data on the water use by sector from CWC was found using the Google search engine and the keywords “California water use by sector.” Information on the urban and agricultural use of water in California was found using the Google search engine and using the keywords “urban and agricultural water use in California.” The NOAA provides data on droughts, which was found using the search keyword “California drought data” on the NOAA website (noaa.gov). Data on environmental water use were found using the Google search engine with the keywords “water use in California’s environment.” Data on desalination were found by searching “desalination plants California” in the Google search engine. Water reuse data were found from Science Direct (sciencedirect.com) by searching the keywords “California water reuse.”

2.5 Conservation Efforts

Regulation and legal data were gathered from the official websites of these agencies: California Department of Water Resources (DWR), State Water Resources Control Board (SWRCB) and the California Environmental Protection Agency (CalEPA). A systematic review of government publications, peer-reviewed articles, and relevant legislation, including contributions from the DWR, SWRCB, and CalEPA, formed the basis of the 1.1.3 background. The Water Education Foundation provided information on the US Bureau of Reclamation. Table 3 shows key words and websites used for this part of the methodology.

2.6 Public Opinion and Marketing

Public opinion data on recycled water were gathered from multiple surveys conducted and compiled by WaterPolls.org. WaterPolls.org is a website compiled of surveys and other data sources about public opinions on water. Another survey conducted by Xylem, a global water technology provider, was used to acquire data on public opinion on recycled water. A paper published by the American Water Works Association titled “Understanding questions and concerns about potable water reuse: An analysis of survey write-in responses” by C. Scruggs et. al. was analyzed to compile further information on the public opinion of water reuse. Another research paper titled “Perception and acceptance towards water reuse in the Southeast United States: A public survey” by W.B. Pathiranage et. al., was read and analyzed to collect data on the opinions of water reuse in the Southeast US. The final source of public opinion data was a press release by the San Diego County Water Authority discussing a poll on the county’s opinion on saving water. These sources were found by searching the keywords “opinions on water reuse”, “public opinion water reuse”, “potable water use survey”, and “water conservation opinions” on Google Scholar and the AWWA website. Table 3 shows key words and websites used for this part of the methodology.

2.7 Cost

Treatment costs for different possible water collection, storage and usage were gathered from county and municipality websites and through private consulting agencies. Treatment costs for surface water came from a 2018 survey conducted by Vincent Tidwell, titled, Mapping Water

Availability, Cost and Projected Consumptive Use in the Eastern United States with Comparisons to the West. Groundwater costs came from the National Ground Water Association. Desalination data was collected through an article titled Reverse Osmosis Desalination: Water Sources, Technology, and Today's Challenges. Written by Lauren Greenlee. Wastewater reuse was taken from an article by Shimabuky Cooley, titled, The Cost of Alternative Urban Water Supply and Efficiency Options in California. Imported water costs were obtained through the Municipal Water District website. Table 3 shows keywords and website used for research.

2.8 Water Resources Plan for Coalinga

The design employed for compiling the information to formulate a comprehensive water resources plan for Coalinga, California involved a systematic approach. Initially, data on various aspects of water management, including groundwater availability, surface water sources, water use patterns, and wastewater treatment, was collected from reputable sources such as the United States Geological Survey (USGS), the California Water Boards, and other relevant governmental and scientific databases. Detailed insights into the historical trends and current status of water resources were obtained by reviewing reports and articles from the US Department of Commerce, Google searches, and pertinent literature. The research incorporated an investigation of existing water conservation strategies implemented in municipalities across California, with a focus on tiered billing systems, wastewater reuse, efficient technology, desalination, artificial aquifer recharge, rainwater harvesting, and water conservation education in schools. Furthermore, the design involved a critical analysis of the feasibility and applicability of each water management strategy to the unique context of Coalinga. Comparative studies with other Californian cities, such as Los Angeles and San Diego, provided valuable insights into the potential benefits and challenges associated with certain approaches.

Table 3: Methods used for finding Section 2.1 through 2.7

Section	Search Terms	Publication(s) and/or Websites Found	Content of Resources
2.1 Groundwater and Surface Water Availability	1. *Domestic Water Use, Industrial Water Use, Irrigation Water Use, and Public Water Supply Use, California Water Science Center* 2. *California population data* 3. *Well data California Water Boards* 4. *California water Trends* 5. *CDEC Lake Reservoir*	1. USGS website (usgs.gov) 2. US Department of Commerce website 3. Waterboards.ca 4. USGS CA GAMA-PBP Public-Supply Well (PSW) Results: Inorganic Data and Trends, 1974 – 2022 5. Cdec.water.ca.gov	1. USGS.com article on groundwater and surface water usage. 2. Population Statistic article for California. 3. Declining water use in the US. 4. Projections of Freshwater Use. 5. California Reservoir data.

Table 3 Continued: Methods used for finding Section 2.1 through 2.7

Section	Search Terms	Publication(s) and/or Websites Found	Content of Resources
2.2 Wastewater Reuse	1. *California Plans to Turn Sewage into Drinking Water* 2. *California Water Reuse – Past, Present, and future perspectives* 3. *The Cost of Alternative Urban Water Supply and Efficiency Options in California* 4. *State Water Resources Control Board Results, Challenges, and Future Approaches to California Municipal Wastewater*	1. Calmatters.org - *California Plans to Turn Sewage into Drinking Water* 2. Sciencedirect.com - *California Water Reuse – Past, Present, and future perspectives* 3. Pacinst.org - *The Cost of Alternative Urban Water Supply and Efficiency Options in California* 4. Waterboards.ca.gov- *Results, Challenges, and Future Approaches to California Municipal Wastewater*	1. Water reuse programs being enacted. 2. The history and outlook for water reuse in California. 3. Reuse in urban water supplies. 4. Wastewater recycling in California.
2.3 Rainfall Data and Water Imports	1. *NOAA California Rainfall* 2. *California Water systems* 3. *Securing our imported supplies California*	1. NOAA website (noaa.gov), 2. Water.ca.gov - *California Water systems* 3. Mwdh2o.com - *Securing our imported supplies – California*	1. California Rainfall data. 2. Where California imports its water from and to. 3. California's imported water.

Table 3 Continued: Methods used for finding Section 2.1 through 2.7

Section	Search Terms	Publication(s) and/or Websites Found	Content of Resources
2.4 Use and Demand in California	1. *Industrial water use in California* 2. *California water use by sector* 3. *Urban and agricultural water use in California* 4. *California drought data* 5. *Water use in California's environment* 6. *Desalination plants California data* 7. *California water reuse*	1. Usgs.gov - California Water Use 2. Cwc.ca.gov - Water Use in California 3. Cwc.ca.gov - Agricultural Water Efficiency 4. Noaa.gov - 5. Ppic.org - Water Use in California 6. Waterboards.ca.gov- Ocean Plan Requirements for Sea Water Desalination Facilities 7. sciencedirect.com	1. Water use by industry in California. 2. California Water Use. 3. Agricultural water use. 4. Recent and past drought data 5. Water use in California 6. Desalination Use in California 7. Reuse in California
2.5 Conservation Efforts	1. *Regulations on water use California* 2. *Water policy in California* 3. *Domestic water regulations*	1. *California Water Service* 2. California Department of water Resources 3. Water Resources Control Board	1. Regulations on 6 stages of drought and restrictions. 2. Regulations on water usage in industry and in agriculture 3. Regulations and fines in Domestic water use.

Table 3 Continued: Methods used for finding Section 2.1 through 2.7

Section	Search Terms	Publication(s) and/or Websites Found	Content of Resources
2.6 Public Opinion and Marketing	1. *Recycled Water Public Opinion* 2. *Potable Water Reuse AWWA* 3. *Water Reuse in Southeast US Survey*	1. Waterpolls.org - Measuring the yuck factor: recycled water and public opinion 2. AWWA.com - Potable Reuse 3. Pubmed.ncbi.org - Perception and acceptance towards water reuse in the Southeast United States: A public survey	1. Survey on recycled water knowledge 2. Potable Water reuse willingness to use survey. 3. Survey conducted in southeast US on possible water reuse facilities.
2.7 Costs	1. *US consumptive costs on surface water US.* 2. *NGWA US costs* 3. *Desalination costs peer reviewed* 4. *Wastewater Reuse costs US* 5. *Imported water costs, California River, Orange County*	1. Doi.org - Mapping Water Availability, Cost and Projected Consumptive Use in the Eastern United States with Comparisons to the West. 2. NWGA.org 3. Doi.org - Reverse Osmosis Desalination: Water Sources, Technology, and Today's Challenges 2009 4. Iopscience.org - The Cost of Alternative Urban Water Supply and Efficiency Options in California. 5. Ocwd.com - How Water works in OC	1. Water costs across the US comparison. 2. Groundwater costs across the US. 3. Desalination costs per size of treatment facility. 4. Wastewater reuse costs per size of treatment facility. 5. Colorado River import costs into Orange County

Chapter 3 – Results and Analysis

The goal of this project was to develop a water resource management plan for Coalinga, California. This chapter provides information on water availability, supply and demand for water, and conservation efforts in the state of CA., public opinion on water sources and water scarcity, and costs of alternative water sources are provided. Then, this information was used to develop a management plan for the city of Coalinga, which has significant water scarcity problems and has very few water management practices in place.

3.1 Geography and Hydrology of California

This section provides information on the state of California, including geography, hydrology (including natural and artificial water systems), and population. Trends over time in population, water availability, and water use are also shown.

3.1.1 Geography and Population

California is home to 39.24 million people. Most of California's population is in only a handful of coastal counties. The most congested areas are the counties in the San Francisco Bay area (Alameda, Contra Costa, Marin, Napa, San Mateo, Santa Clara, Solano, Sonoma) and the coastal counties spanning from Santa Barbara to San Diego (Los Angeles, Orange, San Diego, Santa Barbara, Ventura). Relative to the rest of the state, these counties are small but inhabit the most people by far. Figure 3 shows population densities in the state, demonstrating the contrast between the counties listed above and those not on the coast.

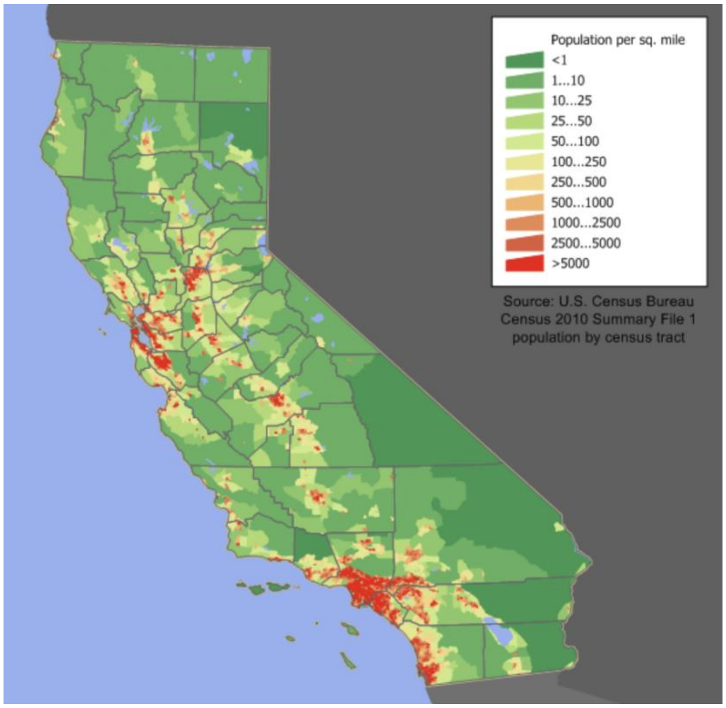


Figure 3: Map of California counties and population densities (CA Census, 2010, Public Domain)

3.1.2 Hydrological Regions

California's water management efforts are greatly aided by the division of the state into ten hydrologic regions: North Coast, Sacramento River, North Lahontan, San Francisco Bay, San Joaquin River, Central Coast, Tulare Lake, South Lahontan, South Coast, and Colorado River. The ten hydrological regions are designed to facilitate the study, management, and control of water resources, as they are based on natural drainage patterns and water flow from precipitation (CWW, n.d.). The regional approach allows for better accounting of water inflow and outflow in different areas of the state. The hydrological regions also aid in determining who has claims to which water sources. Figure 4 shows the ten hydrological regions in California and the three drainage areas. The hydrological regions are referred to with numbers 1-10 in the order listed above. The drainage regions are #11-13: Northern Central Valley, Mid-Central Valley, and Southern Central Valley, respectively.

Figure 4: California's 10 hydrological regions and 3 drainage regions (California Water Watch, n.d., Public Domain)

The northern watersheds, the Sacramento and San Joaquin River systems, are characterized by greater rainfall, which causes the region to have more forests and biodiversity. Snowmelt from the Sierra Nevada mountains also provides water to groundwater aquifers in the region, allowing them to supply millions of people with water. Along the coast are the North Coast, San Francisco Bay, Central Coast, and South Coast Regions. Named for their proximity to the Pacific Ocean, these regions are essential for supporting a variety of ecosystems, which play a crucial role in maintaining water quality and flood control. The North and South Lahontan, as well as the Colorado River regions, are desert watersheds. An arid climate and a lack of vegetation characterize these areas. Water scarcity is a significant issue in these areas, making water conservation practices essential. The southern part of the state usually relies on groundwater and the Colorado River for water (Smith, 2023).

The North Coast region covers 19,400 square miles and all or part of 13 counties. The region also includes the Klamath River Basin and the North Coastal Basin. The Klamath River Basic includes four major tributaries: the Scott, Shasta, Salmon, and Trinity Rivers. The North Coastal River Basin contains the Eel River and its tributaries, which comprise California's third-largest river system. This area contains 63 groundwater basins and subbasins, which underlie 1,600 square miles (8%) of the North Coast region and supplied 32% (364 thousand acre-feet) of the annual water supply for the region from 2005 to 2010 (State of California, 2015). The Sacramento River region is 5,500 square miles and covers all or part of 10 different counties. Its main hydrologic feature is the Sacramento River, which is 250 miles long. The annual outflow of this river is 1/3 of all-natural surface water runoff in California (Sacramento Valley Subregion, n.d.). The North Lahontan Region covers more than 2,100 square miles and sits along the borders of Oregon and Nevada. The North Lahontan region includes the Eagle Lake, Susan River/Honey Lake, Truckee River, Carson River, Walker River watersheds, and Lake Tahoe. During wet years, the primary water source is surface water, mainly from snowmelt from the Sierra Nevada. The San Francisco Bay region is 4,603 square miles, and its main feature is 1,100 square miles of the 1,600 square mile San Francisco Bay Estuary, the largest estuary on the west coast of the United States. The region's waterways form the centerpiece of the fourth-largest metropolitan region in the United States, including Napa, San Francisco, and Santa Clara counties (San Francisco, 2017). The San Joaquin River Region contains about half of the San Joaquin River Delta. The Sierra Nevada and the coastal section of the Diablo Range border it. The region contains the San Joaquin River, one of California's longest rivers, 300 miles long (California Water, 2013). The Central Coast Region covers 11,300 square miles. It contains the following rivers: Salinas, Cuyama, Santa Ynez, Santa Maria, San Antonio, San Lorenzo, San Benito, Pajaro, Nacimiento, Carmel, and Big Sur. The Tulare Lake Region covers about 16,800 square miles and includes all of Tulare and groundwater basins that underlie about half of the area, which contribute about 53% of the annual water supply for the Tulare Kings counties and most of Fresno and Kern Counties. The region contains 19 Lake Region. The major Rivers that drain into the Tulare Lake Region are Kings, Kaweah, Tule, and Kern (State of California, 2013). The South Lahontan Region covers about 26,700 square miles. This region contains the highest and lowest ground elevations in the contiguous United States, Mount Whitney and Death Valley. The most significant waterways of the region are the Mojave, Owens, and Amargosa rivers, in addition to the Mono Lake drainage system. The South Coast region covers 11,000 square miles. It includes all of Orange County and significant portions of Los Angeles, San Bernadino, and San Diego counties. The major rivers in the area are Los Angeles, San Gabriel, San Diego, San Luis Rey, Santa Ana, Santa Clara, Santa Margarita, and Ventura (State of California, 2015). The Colorado River region covers 19,900 square miles and contains numerous valleys. This region contains California's largest body of water, the Salton Sea. The area also includes the Colorado, Alamo, New, and Whitewater Rivers (State of California, 2013).

3.1.3 Precipitation, Floods, and Droughts

Rainfall in California varies considerably depending on the region, leading to inconsistent water availability in different parts of the state. Most rainfall events occur in the northern part of California. In the last century, the county that received the most rain was Del Norte County, the northernmost county in California, receiving a mean of 80.16 inches per year from 1901-2000. The county that received the least amount of rain was Imperial County, the southernmost county, with a mean of 3.38 inches annually from 1901-2000 (NCEI, n.d.). The counties in between vary significantly based on the location, and rain patterns are very inconsistent from year to year. For example, in 2022, Imperial County received 1.26 inches of rain, but in 2020, it received 3 inches of rain (NCEI, n.d.).

California is prone to periodic floods. All 58 counties have experienced at least one significant flood event in the last 25 years (State of California, n.d.). The many valleys of California are more susceptible to river overflow. Lowland coastal flooding occurs when high tide coincides with large storms. In southern California, the deserts are prone to flash floods, especially in areas that have experienced wildfires. Flooding happens in urban areas often due to a lack of permeable surfaces and inadequate drainage systems. The state's growing population and high-value properties create more economic risk and a higher public safety risk in a flood situation. For example, the 2017 Oroville Dam spillway failure led to an emergency evacuation of nearly 200,000 people. This failure occurred due to a lack of maintenance, leading to $500 million in repair costs. It is estimated that California needs to spend about $34 billion on flood management infrastructure to prevent mass evacuations in the future (PPIC, n.d.).

Among the lower 48 states, California is ranked #2 for drought risk (Climate Check, n.d.). Over time, California has experienced many dry periods, with several notable events in the last century, including ten years in the 1920s and 1930s, 1987-1992, 2012-2016, and the ongoing drought declared in 2021. Given the decreasing number of wet years between each drought, the current drought is projected to last for ten years. Not only are droughts becoming more frequent, but they are also getting worse. In the 21st century, consistent drought conditions range from abnormally dry to exceptional drought. Droughts are classified as D0, D1, D2, D3, or D4, with drought conditions worsening as the corresponding number increases. D0 means abnormally dry, characterized by short term dryness, fire risk above average, lingering water deficits, and pastures and crops not fully recovered. D1 is characterized is damage to crops, high fire risk, low water levels in wells, streams, and reservoirs, and an imminent water shortage. D2 has crop loss, very high fire risk, common water shortages, and imposed water restrictions. D3 has significant crop/pasture losses, extreme fire risk, and widespread water shortages and restrictions. D4 is characterized by widespread crop and pasture loss, exceptional fire risk, and water shortages in wells and streams causing water emergencies. As time goes on, the severity of the droughts gets worse as there is a higher percentage in the D4 category, as can be seen in Figure 5, which shows the drought patterns for the entire state of California. The yellow symbolizes D0, the tan symbolizes D1, D2 is the orange, D3 is the red, and D4 is the maroon color. The droughts in the early 2000s were shorter in duration and less severe than those in the 2010s and 2020s. This pattern is projected to continue, and these dry conditions are projected to worsen throughout the state (Brigan, n.d.).

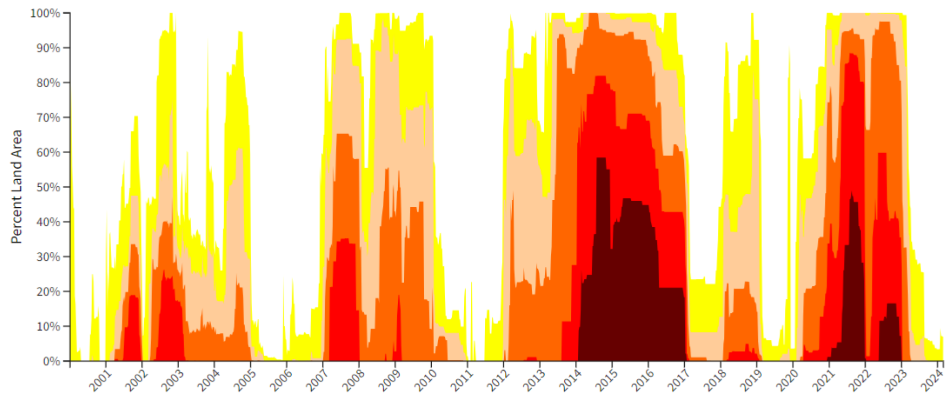


Figure 5: Percent land area in California experiencing various levels of drought (California Drought, n.d. Public Domain).

3.1.4 Surface Waters

California has 1300 reservoirs and over 3000 lakes. Though not equally placed throughout the state, these can be found in each hydrological region. Reservoirs are manufactured lakes that occur when a river is dammed. Seventeen of these reservoirs are monitored at all hours of the day (CDEC, 2023). Figure 6, from the California Department of Water Resources, shows water levels in the 17 monitored reservoirs at midnight on November 11, 2023. Specifically, the figure shows the major California reservoirs and their amounts of water in percentages based on capacity (blue) and their historical average (green). The graphs for the reservoirs have a scale with the amount of water in TAF (thousands of acre-feet) specific to the particular reservoirs, considering that they vary significantly in amounts of water and water capacity. Most of the reservoirs are above their historical average levels. The three reservoirs below average levels (Millerton, Casitas, and Trinity) are in water-stressed areas due to their proximity to extensive agricultural and human use (CDEC, 2023). Millerton Lake is located in the San Joaquin River Valley at 145,000 acre-feet, significantly down from its average of 224,000 acre-feet. Millerton Lake supplies water to the Central Valley projects area, home to numerous agricultural areas and hydro dams. Lake Casitas in the South Coast region has a current level close to the historical average; however, Lake Casitas is experiencing a downward trend in water levels. In 1983, Lake Casita measured 246,000 acre-feet; by 2019, that level was 91,000 acre-feet, and by 2022, that level was its lowest at 71,000 acre-feet. The 2020-2022 prolonged drought that hit California can be best seen at Lake Trinity in the Sacramento River Region. In 2019, Trinity Lake was above the historical average at 1,969,000 acre-feet. By 2022, it was at 534,000 acre-feet, 62% lower than the historical average.

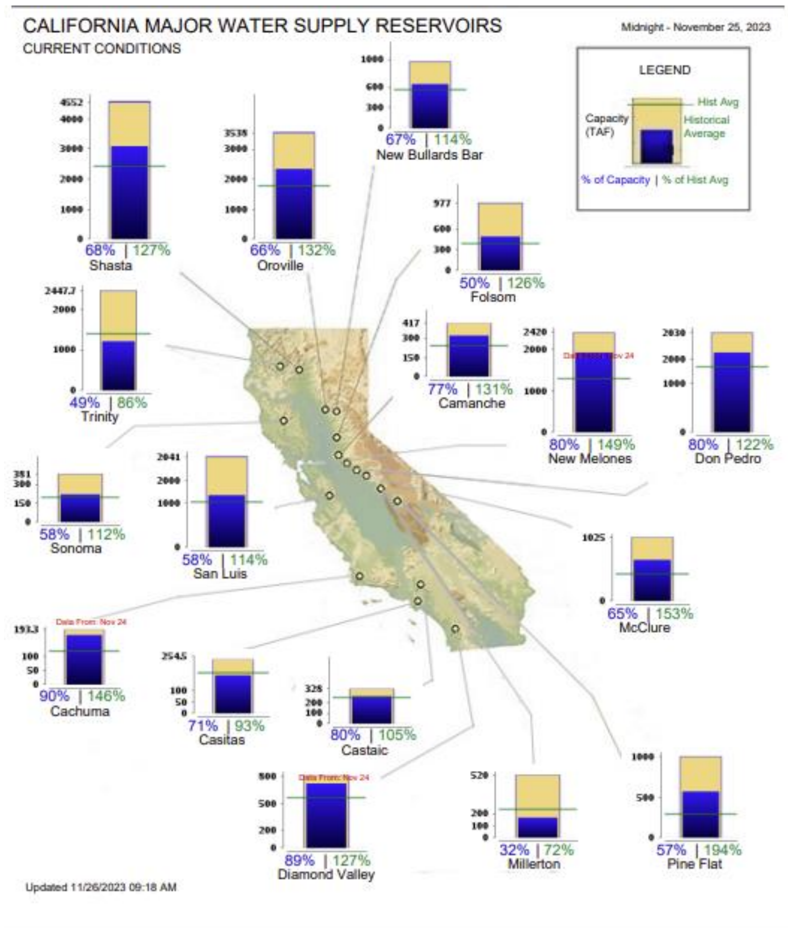


Figure 6: 17 reservoirs in California showing levels on November 25, 2023 (DWR, 2023, Public Domain).

3.1.5 Ground Water

Groundwater plays a crucial role in California, particularly during droughts. As droughts across the western U.S. increase, so does the demand for groundwater. The state's reliance on groundwater during these dry spells underscores the significance of maintaining healthy wells and ensuring the sustainability of this vital resource. California's groundwater management extends to the health of household wells, which are crucial for many residents. In 2022, reports indicated 1,500 dry household wells out of 2 million, reflecting a concerning water scarcity issue (Pineda, 2022). However, in 2023, this number decreased to 400 after a significant decrease in drought conditions, highlighting the state's vulnerability to droughts (James, 2023).

The state monitors over 35,000 wells, although some data are from 2019 (California Department of Water Resources, n.d.). A review of 4,800 municipal wells gave data on current levels and trends. Typically, the depth of a well is influenced by how much water is available. Only 152 wells of the 4,800 extend more than 500 feet beneath the surface, primarily concentrated in water-stressed regions in central and southern California (ArcGIS, 2023). Central and Central Southern California suffers the worst drought issues in the state. As a result, this area has the deepest wells, many exceeding 500 feet. More than half of the 4,800 wells reviewed in the California 20-year water trend map are experiencing a downward trend in available water (James, 2023).

California recognizes 515 groundwater sources across the state. The most prominent is the Central Valley Aquifer system, which extends for more than 20,000 square miles (about twice the area of New Jersey). This trough, roughly 400 miles long and in some parts 70 miles wide, holds the most agricultural diversity in the nation (USGS, 2023). Figure 7 illustrates a continuous downward trend in the Central Valley aquifer in California from 2004 to 2022. While the state may have transitioned away from severe drought conditions, likely experiencing a recharge period, the downward trajectory is expected to persist. It underscores the ongoing need for sustainable groundwater management practices, even in less drought-prone years.

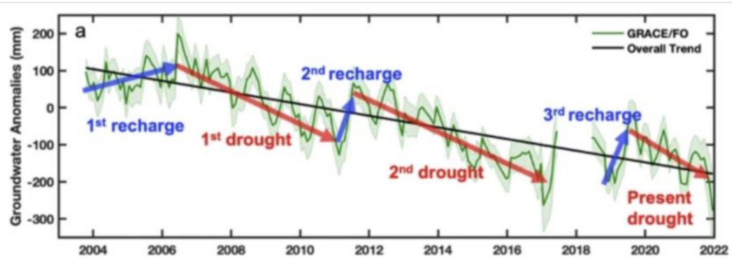


Figure 7: Groundwater pumping and recharging levels in CVA (USGS, 2023, Public Domain).

3.1.6 Manmade Water Systems

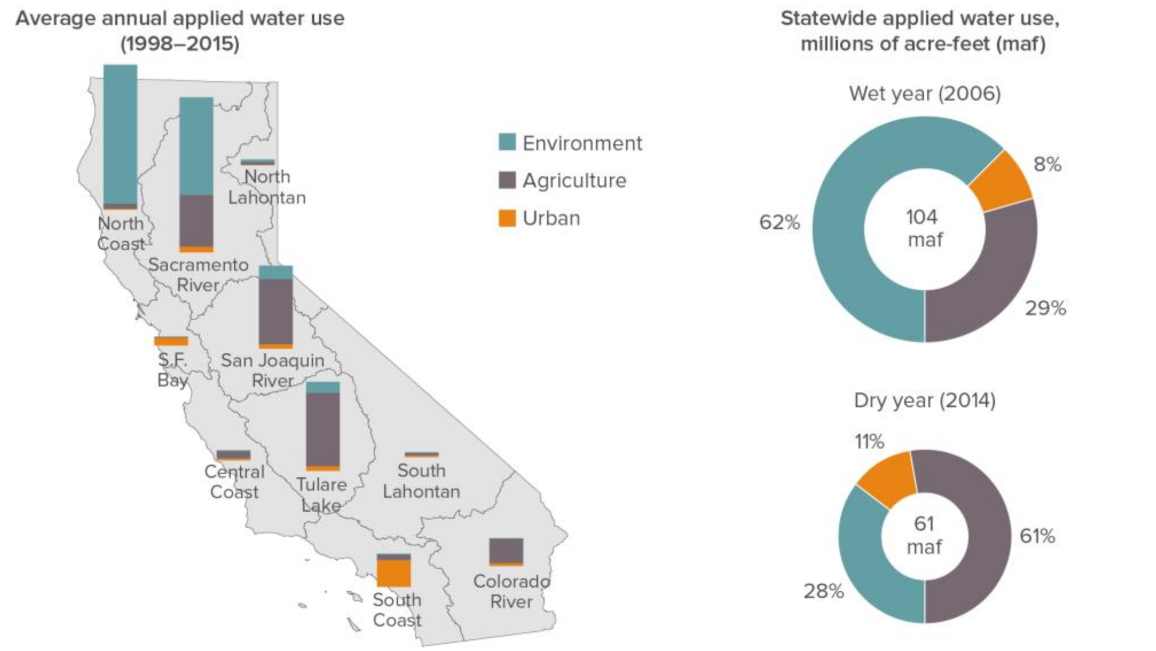
Because of the inconsistent rainfall by region, many areas of California have water imported to meet their needs. Much of the economy and culture in California are affected by the scarcity or abundance of water in an area. In recent years, 75% of the rain and snow falls into the watersheds north of Sacramento, but 80% of the water demand in California is in the southern two-thirds of the state (California Department of Water Resources, n.d.). California has several water projects to help supply water to arid regions. The federal government constructed the Central Valley Project in the 1930s to help the arid region's agricultural economy. This project transports 7.4 million acre-feet of water annually in the north from Lake Shasta to the San Joaquin Valley in the South for agricultural, urban, and wildlife use. The Colorado Aqueduct is another water system built in the 1930s to bring water into southern California. It is the region's primary water source for 19 million people for agricultural and municipal use. Today, the aqueduct can transport approximately 3,069 acre-feet of water daily (MWD, n.d.). In the 1960s and 1970s, the State Water Project was built to supply water to more than 27 million people and 750,000 acres of farmland. It is an extensive system of dams, reservoirs, power plants, and pumping stations that starts at the Oroville Reservoir on the Feather River. With complex water systems in place, in many instances transporting water hundreds of miles, California residents regularly pay the country's second-highest water bills. Water bills in CA, on average, are $77 a month, while the lowest water bills in the United States are around $20 per month. The median nationally is around $35 (Wisevoter, 2023).

3.2 Water Supply and Use in California

This section provides information on how and where water is used in California and how this use has changed from previous years. Various supply options used to support each sectors' demand are also discussed and historical data and trends are provided.

3.2.1 Water Use by Industry

Three major sectors encompass California water use. These are the Environmental, Agricultural, and Urban sectors and data collected includes fresh and saline groundwater and fresh and saline surface water (USGS, 2018). The distribution between the major sectors is 50% environment, 40% agriculture, and 10% urban, although it can vary year to year depending on the amount of rainfall that occurs within that calendar year. In years with drought issues, water-use in each year is affected by the implementation of conservation requirements. Use by sector in a dry and wet year and the annual applied water use by sector in different areas in California in 1998-2015 is shown in Figure 8 (CWC, 2019). In 2006, which was a wet year, the data provided shows that the environmental sector is the largest consumer at 62%, followed by the agricultural sector at 29%, then the urban sector at 8%. The total use in 2006 was 104-million acre-feet. However, in the dry year 2014, the agricultural sector consumed the most water at 61%, followed by the environmental sector at 28%, and the urban sector at 11%. The total use was 61-million acre-feet. According to the average annual applied water use portion of the figure, the North Coast and Sacramento River areas consumed the most water of the counties and had the Environmental sector as the largest consumer. The San Joaquin Valley, Colorado River, and Tulare Lake have the agricultural sector as their largest consumers. The South Coast and San Francisco Bay have the urban sector as their largest consumer. North Lahontan, South Lahontan, and Central Coast consume the least amount of water.



Source: Department of Water Resources, *California Water Plan Update 2018 (Public Review Draft)*.

Notes: The figure shows applied water use. The statewide average for 1998–2015 was 77.2 maf. Environment (38.3 maf average) includes water for "wild and scenic" rivers, required Delta outflow, instream flows, and managed wetlands. Urban (7.9 maf) includes residential, commercial, and industrial uses; and large landscapes. Agriculture (31 maf) includes water for crop production. Net water use—i.e., the volume consumed by people or plants, embodied in manufactured goods, evaporated, or discharged to saline waters—is lower. The figure excludes water used to actively recharge groundwater basins (3% for urban and 1% for agriculture on average), conveyance losses (3% for urban and 8% for agriculture), and water used for energy production (less than 2% of urban use).

Figure 8: Average annual applied water use in California by sector and location in California 1998-2015 (California Department of Public Resources, 2019, Public Domain).

3.2.1.1 Public Water Systems/Urban Use

A public water system is a publicly or privately owned system that provides water for human consumption through pipes or other constructed conveyances to at least 15 service connections or serves an average of at least 25 people for at least 60 days a year. California has 7,248 public water systems. These systems use groundwater, surface water, and purchased water. The water systems range from serving as few as 3 people to over 3 million people and contain 1 to 839 facilities. Of these systems, 2,842 (40%) are community water systems that serve the same population year round, 2,922 (40%) are transient non-community systems that serve in locations where populations do not stay for long periods of time (such as campgrounds and gas stations), and 1,484 (20%) are non-transient non-community systems, where at least 25 people return to for at least 6 months out of the year (such as schools or office buildings). The combination of water systems provides about 12,000 acre-feet of water per day (US EPA, 2015).

From 1990 to 2010, water use fell from 0.26 acre-feet per capita per year to 0.20 acre-feet per capita per day. This decreased use can be attributed to efforts such as the mandatory installation of water saving appliances and monetary incentives (CWC, 2019). Between 2006 and 2015, 63% of water used in the urban sector went towards residential use; state institutions (hospitals, prisons) and commercial businesses (hotels, offices) accounted for 23%; 5.2% went to manufacturing; 4.2% for groundwater replenishment, 3.3% for conveyance losses; and 1.7% for energy production. These data are shown in Figure 9 (Cooley, 2020).

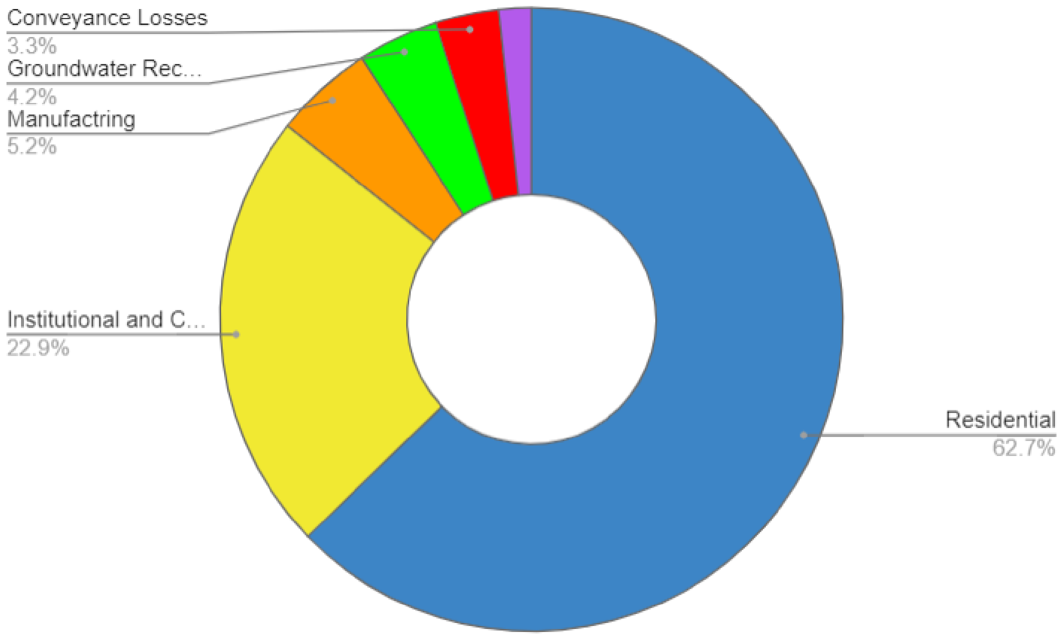


Figure 9: Urban sector use 2006-2015 by subsector adapted from Urban and Agricultural Water use in California, 1960-2015 (Cooley, 2020, Public Domain).

3.2.1.2 Agriculture

In California, the agricultural sector accounts for 40% of total water use, with over 9.6 million acres being irrigated using 34-million acre-feet of water (CWC, 2023). According to a fact sheet published by the California Water Commission, there has been a shift of focus to perennial fruit and tree nut crops, resulting in an increase in the acreage of irrigated crops used for these crops from 16% in 1980 to 33% in 2015 statewide. These crops are of higher monetary value at $2000/acre-foot versus field crops at $200-600/acre-foot and has therefore allowed an increase in the economic return on the water used, but also increased the water use due to their need to be watered regularly year to year (CWC, 2019). Tree nuts in particular require a significant amount of water to produce minimal yield, with almonds requiring 4.9-5.7 million acre-feet of water per year (C-WIN, 2022). The increase in frequent droughts poses a threat to the agricultural sector, which relies heavily on groundwater sources in times of drought, as under drought conditions other sectors shift to relying on groundwater to meet their need, causing an increase in the pump rate without a recharging source. As discussed in Section 3.1.5, there is a continuous downward trend in aquifer levels, which jeopardizes the sector's access to groundwater. These droughts also impact the revenue brought in by the sector, as it can affect both the production of livestock and the yield of crop farms. In 2012, drought resulted in a $14.5

billion loss, and in 2015, drought resulted in $1.84 billion in direct cost, the loss of 10,100 jobs, and a shortage in surface water of 8.7 million acre-feet (NOAA, n.d.).

3.2.1.3 Environmental

The environmental sector in California accounts for 50% of annual water consumption. In dry and critically dry periods, the amount of water used in the environmental sector is reduced and shifted to the agricultural and urban sectors, as shown in Figure 10. Environmental water use is broken down into 4 categories: “wild and scenic” rivers that are protected under federal and state laws, water bodies in wetlands on wildlife preserves, water for water quality maintenance, and water for maintaining natural habitats in streams (CWC, 2019). Of these categories, 63% of the water taken up by the sector falls under wild and scenic protected rivers, 4% for wetlands, 15% for water quality maintenance, and 18% for stream habitats (Mount et al., 2023). Environmental use in California varies by region, with the majority (approximately 50%) occurring in the North Coast Region. 36% of environmental use occurs in Sacramento Valley, 12% in San Joaquin Valley, and <2% across the rest of the state. The average distribution of environmental water by county from 1998-2018 in wet versus dry years is shown in Figure 10 (Mount et al., 2023). The figure shows that northern regions of California are mostly responsible for environmental water use. These regions are North Coast, Sacramento River, San Joaquin River, and Tulare Lake. The North Coast region is the largest consumer of these regions, as discussed above, with the majority being used in wild and scenic rivers. Due to their protection under federal and state regulations, these rivers are not connected to the state’s water system and thus discharge into the ocean (Nichols, 2015)

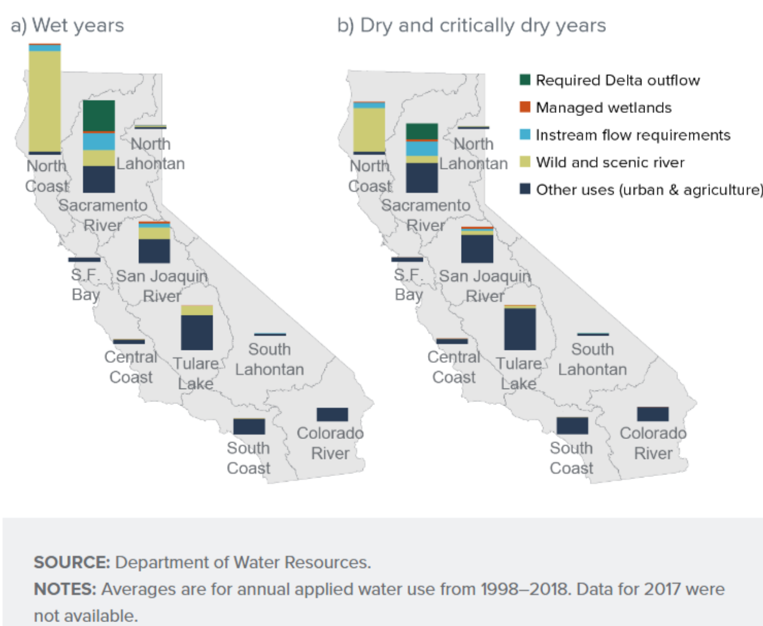


Figure 10: Average distribution of water used by the environmental sector from 1998-2018 (California Department of Water Resources, 2023, Public Domain).

3.2.2 Desalination

Desalination plants use reverse osmosis membranes to remove salt and impurities from seawater to create municipal water. This technology was first thought of as a potential solution during the drought that occurred from 1987-1992, resulting in the building of the West Coast's first seawater desalination plant in 1991. As of 2023, there were 12 coastal desalination plants with 6 more being planned (California Department of Water Resources, 2023). In the Western Hemisphere, the largest desalination plant is Poseidon Water's Claude Lewis Carlsbad Desalination Plant in Carlsbad, CA. This plant was constructed in 1995 and delivers water to residents and businesses in the San Diego County and produces 153.4 acre-feet of desalinated drinking water a day (Poseidon Water, n.d.). This plant provides around 10% of the regional water demand in San Diego (SDCWA, 2023).

Table 4: California desalination plants as of 2023 (Lobner, 2023)

Treatment Plant	**Location**	**Capacity (acre-feet/day)**
Diablo Canyon nuclear power plant (NPP) desalination plant	San Luis Obispo County	4.6
Cambria Community Services District desalination plant	San Luis Obispo County	0.72
Sand City Coastal desalination plant	Monterey County	0.822
WRD Robert W. Goldsworthy Desalter	Torrance	15.34
Southern California Edison (SCE) desalination plant	Catalina Island	2.46
Poseidon Resources Corp. Claude "Bud" Lewis desalination plant	Carlsbad	153.40
City of Santa Barbara's Charles E. Meyer desalination plant	Santa Barbara	20.53
Doheny Ocean Desalination Project	Orange County	46.03
California American Water (Cal-Am) desalination project	Marina Coast	14.73
DeepWater Desal project	Huntington Beach	27.47
The People's Moss Landing Desalination Project	Moss Landing	36.67
Armstrong Ranch brackish water desalination plant	Marina Coast	7.40

The California State Water Resources Control Board is trying to invest in desalination to diversify the local water supply. In 2023, they established a Water Desalination Grant Program to support the construction and design of desalination plants. The grant program has awarded three projects with $5 million each; these projects are in Mendocino, Fresno, and Los Angeles counties. The first project that received funding is the Water Replenishment District of Southern California Construction Project, located in Los Angeles, which plans to create a conveyance pipeline linking an existing well with the established Goldsworthy Desalter system while installing a self-cleaning strainer. The goal of this project is to reduce the need for water imports in the community and provide a local potable water supply. This plant would increase the desalination production by 1,120 acre-feet per year, which is enough water for about 2,200 households. The second project is the Wetlands Water District Design Pilot Project, in the county of Fresno. This project entails desalination of brackish groundwater sourced from an aquifer and will incorporate salt-tolerant plants to sustainably extract salts from the brine. The overarching goal of this procedure is to provide reliable, high-quality, and cost-effective water to the surrounding communities. The last project receiving funding is the City of Fort Bragg Design Pilot Project which plans to install a wave-powered seawater desalination buoy to provide its residents with carbon-free potable water (California Department of Water Resources, 2023). According to California's Water Supply strategy to adapt to a hotter and drier future, they plan to increase the production of desalination plants by 28,000 acre-feet per year by 2030 and 84,000 acre-feet per year by 2040.

3.2.3 Water Reuse

Water reuse has historically been supported in California due to a high demand and low supply of water though it has seen some challenges in terms of public opinion and cost. There is a higher motivation to recycle because it creates an additional water source when water is scarce (Olivieri, 2020). Recycling water provides an alternative to discharging wastewater into surface waters (Olivieri, 2020). "Most treated sewage — about [1200 acre-feet] a day in Los Angeles County alone — is released into rivers, streams and the deep ocean" instead of being recycled (Backer, 2023). The preconceptions of water reuse and associated costs are explored in Sections 3.4.3 and 3.5.3, respectively. There has been an increase in recycled wastewater production in California in 2023, which follows historical trends for this region.

Recycled water use in California has been an increasing trend over time, starting in the late 1800s. The California State Water Resource Control Board and the California Department of Water Resources conducted surveys that indicated a yearly recycled municipal wastewater increase from 175,000 acre-feet in 1970 to 669,000 acre-feet in 2009 (Newton, 2015) as shown in Table 5. In 2022, California Governor Gavin Newsom created the goal of a 9% increase in recycled water use by 2030 and more than doubling current use by 2040 (Becker, 2023).

Table 5: Recycled municipal wastewater trends adapted from data provided by The California State Water Resource Control Board and the California Department of Water Resources (California State Water Resources Control Board, n.d.)

Year	**Recycled Municipal Wastewater (acre-feet)**	**Regional notes (Central Valley, San Antana, Los Angeles, San Diego, San Francisco, Lahontan, Colorado River, and the North Coast Regions are shown)**
1970	175,000	Most from the Central Valley Region as with every year listed.
1977	184,000	Every region increased amount except the San Diego Region this year.
1987	267,000	Central Valley and Los Angeles regions increased greatly between 1977 and 1987.
2001	525,000	Every region had significant increases except the North Coast region between 1987 and 2001.
2009	669,000	The trend of recycled amounts of wastewater are all increasing between 2001 and 2009 but are decreasing in speed of increase.

Use of recycled water can be categorized by industry as shown for 2009 in Table 6. Agriculture uses the largest amount through irrigation by a vast amount, followed by groundwater recharge and saltwater intrusion barriers. Water usage has been increasing nearly every year for all uses. However, agricultural use and irrigation have increased the most. Relatively, geothermal energy production, saltwater intrusion barriers, and groundwater recharge have increased significantly compared to other uses too (Newton, 2015).

Table 6: Recycled municipal wastewater consumption by use in 2009, adapted from data provided by The California State Water Resource Control Board and the California Department of Water Resources (California State Water Resources Control Board, 2014).

Sector Use	**Recycled Municipal Wastewater Consumed (acre-feet)**
Irrigation	400,704
Commercial	6,382
Industrial	47,137
Geothermal Energy	14,939
Saltwater Intrusion Barrier	49,032
Groundwater Recharge	79,714
Recreational Impoundment	25,838
Natural System Restoration	29,622
Other	15,789
Total	**669,157**

3.3 Conservation Efforts

This section discusses policy and laws regarding water conservation in addition to active conservation methods in common sectors of water use. Conservation practices in the home, industry, and agriculture are all discussed.

3.3.1 Water Policy and Laws

There are varying restrictions in California depending on the amount of available water and severity of a drought, and if drought conditions are in effect. These restrictions are broken down into six stages of varying degrees of extremity. Stage one includes basic restrictions such as addition of shut-off valves on car wash hoses and prohibiting watering until 48 hours after measurable rainfall. Stage six, the most extreme stage, includes the imposition of a moratorium on new water service connections and the prohibiting of all irrigation. Stage six is designed to cut all water demands by 50% of normal use. Each stage compounds the restrictions of the previous stages with the addition of the new ones, and the financial penalties of violating these restrictions increases along with the stages. (California Water Service, n.d.).

Table 7: The 6 stages of drought restrictions and the penalties for violations from the California Water Service (California Water Service, n.d.)

Stage of Drought	**Rules Implemented During Stage**	**Repercussions of Violations**
1	- Implement policies to reduce water usage by 10% - Residential and business customers are subjected to water-use restrictions - Outdoor irrigation is subjected to limited times - Leak repairs must be done in a timely manner - Shut-off nozzles are required when washing cars - Outdoor watering is prohibited within 48 hours of rain	- Installation of water measuring devices - Fines up to $50 for subsequent violations - Possible installation of flow-restriction devices for egregious violators
2	- Implement policies to reduce water usage by 20% - Residential and business customers are subjected to water-use restrictions - Outdoor irrigation for residential and commercial customers is limited to 1-3 times per week depending on local ordinance - Use of non-recirculating systems in conveyor car washes and laundry systems are prohibited - The use of single pass cooling systems in new connections is prohibited	- Installation of water measuring devices - Fines up to $100 for subsequent violations - Possible installation of flow-restriction devices for egregious violators

Table 7 Continued: The 6 states of drought restrictions and the penalties for violations from the California Water Service (California Water Service, n.d.)

3	- Implement policies to reduce water use by 30% - Residential and business customers are subjected to water-use restrictions - Water use for construction and dust control is prohibited - Irrigation of ornamental turf on public street medians is prohibited - Filling ornamental lakes or ponds is prohibited	- Installation of water measuring devices - Fines up to $200 for subsequent violations - Possible installation of flow-restriction devices for egregious violators
4	- Implement policies to reduce water use by 40% - Residential and business customers are subjected to water-use restrictions - Vehicle washing is prohibited, except with recirculated water or low-volume systems - Use of water for recreational purposes, such as waterparks, is prohibited - Filling swimming pools is prohibited	- Installation of water measuring devices - Fines up to $400 for subsequent violations - Possible installation of flow-restriction devices for egregious violators
5	- Implement policies to reduce water use by 50% - Residential and business customers are subjected to water-use restrictions - Net zero demand increase is required on new water service connections - Single-pass cooling systems are prohibited - Swimming pool covers are required	- Installation of water measuring devices - Fines up to $800 for subsequent violations - Possible installation of flow-restriction devices for egregious violators
6	- Implement policies to reduce water use by more than 50% - Residential and business customers are subjected to water-use restrictions - All landscape irrigation is prohibited - New water service connections are prohibited	- Installation of water measuring devices - Fines up to $1,600 for subsequent violations - Possible installation of flow-restriction devices for egregious violators

The first of the major conservation laws in California was the Water Conservation Act of 2009, also known as Senate Bill X7-7. This law requires water suppliers to increase their use efficiency to decrease the amount of water used. For this bill, the DWR is responsible for 18 different actions/projects to make water use more efficient in urban, agricultural, and combined suppliers. Some of these actions consist of standardizing the water use reporting process, reviewing and proposing statewide goals, and reviewing funding criteria to reduce or stop providing funding to suppliers who are not compliant of the provisions stated in 10608.56, which requires a plan to be submitted on how they will achieve per capita reductions (California Department of Water Resources, n.d.). In 2015, the State Water Resources Board expanded the reach of these restrictions when the Governor signed Executive Order B-29-15 which set the goal to decrease water usage by 25% by replacing 50 million square feet of lawns with drought resistant landscaping, replacing appliances with more efficient models, and restricting water use for places such as golf courses and cemeteries (City of California, n.d.).

Recently California has experienced an uptick in drought conditions discussed in Section 3.1.3, resulting in a change in the way water use is regulated. In an effort to conserve the available water, lawmakers in California have initiated statewide emergency conservation regulations to combat the issues caused. The first round of regulations was put into place in January 2022 that prohibited any water use that was deemed wasteful. In May of that year, the emergency regulations were increased, preventing the use of potable water for unnecessary purposes, and required that urban water suppliers implement all demand-reduction actions under Level 2 of their Water Shortage Contingency Plans (WSCP) (State of California: California Drought Action 2022). The WSCP is in place as a series of response measures to mitigate future water supply shortages. This plan consists of 6 levels, with Level 1 taking action when there is a shortage up to 10% and Level 6 taking action when there is a shortage of 50% or more.

3.3.2 Industry Conservation

Industrial water is typically used for processes such as processing, washing, diluting, cooling, or transporting a product. While water usage may not be able to be decreased without finding new ways to complete these processes, there are other ways industry can reduce the amount of water they use. By 2017, the Commercial Water Conservation Ordinance required commercial buildings in California to repair any plumbing leaks and replace inefficient fixtures (Chapter 12A San Francisco Housing Ordinance, 2017). Since 2017, this ordinance has forced commercial property owners to make changes with hard deadlines and fines if ignored. In September of 2022, the California Natural Resources Agency released a memorandum addressing recommendations for the State Water Resources Control Board. These recommendations included a water classification system with 19 categories to help determine where water is used most in industries. There was also a recommendation to use best management practices, which can include water audits and water management plans to ensure efficiency standards are being met. Due to the variation in industry, they also suggested ensuring companies follow specific performance measures rather than forcing them to comply with certain values in the water audits. The goal was for this system to be in place by 2030. Beyond direct industrial practices, there was an emergency regulation, Bill 1572, put into place saying that decorative grass, that is not used for recreation, could not be watered due to its wasteful nature (Bill 1572, 2023). This permanent ban applies to grass patches in industrial areas, put in place for aesthetic purposes.

3.3.3 Home Conservation

Over the last 3 years, California has enforced restrictions during droughts targeting various aspects of at-home water usage. Vehicle washing without an automatic shutoff nozzle and washing hard surfaces such as driveways are prohibited. Other restrictions include filling decorative fountains, lakes, or ponds without a recirculation pump, along with a ban on street cleaning or construction site preparation. The regulations encourage warnings before imposing monetary penalties, but enforcement mechanisms treat violations as infractions, allowing the State Water Resources Control Board to impose fines of up to $500 per day (WCP, 2023). Residents are encouraged to report their neighbors or other residents for potential water use violations through a website titled SaveWater.CA.gov.

Technology plays an important role when it comes to water efficiency and decreasing the cost of water. High-efficiency toilets, faucets and showerhead aerators, high pressure (lower volume) spray washers and cleaning systems, spring loaded shutoff nozzles, and simply purchasing and using water-saving models of equipment when the previous version wears out could all greatly improve water efficiency (EPA, 2023). Pressure and volume are inversely proportional, meaning the higher the pressure coming out of nozzles, showerheads, and faucets the less volume will be used. Aerators mix air into the water, taking up volume that would otherwise be lost to water. All these devices can quickly be installed, and none of these options are particularly cost intensive.

Table 8: Common home technologies to reduce water consumption (Region H2O, 2023).

Technology	Description	Benefits
1. Faucet Aerators	Screws onto kitchen and bathroom faucets. Mixes air into the water stream, reducing water flow.	Up to 20% reduction in faucet water consumption.
2. Toilet Tank Fill Cycle Diverters (1 gallon = .00000307 acre-feet)	Efficient device for older toilets using 3.5 gallons per flush or more. Directs more water to the tank and less to the bowl during refill, saving about half a gallon per flush.	About 0.5 gallons per flush saved. 8,559 gallons a year saved per household.
3. High efficiency Shower Heads	Reduces water usage up to 50% compared to standard shower heads.	Up to 50% reduction in water use per shower.
4. Shut-off Hose Nozzle	Water-efficient nozzle stops water flow when the hose is not in use. Reduces water usage during gardening or car washing.	Water used only when needed.

3.3.4 Agriculture Conservation

The Water Conservation Act of 2009 mandated that agricultural water suppliers for over 25,000 irrigation acres must submit an agricultural water management plan to the Department of Water Resources. These plans must include updates on the implementation of efficient water management practices (Agricultural Water Use Efficiency, 2023). There are several technologies in the agricultural industry that can optimize water efficiency. Agriculture faces the problems of non-productive transpiration and water consumption by ineffective tillers. Non-productive transpiration includes plant and soil water evaporation, meaning some water is lost back into the air. Ineffective tillers will cause soil to hold onto water and nutrients without letting them be absorbed by the plant. There are many strategies to reduce this problem including precision irrigation, smart irrigation systems, and drought-resistant crops. Precision irrigation provides the exact amount of water to the crop, minimizing extraneous amounts from being evaporated. Some systems may drip water straight to the roots (called subsurface drip irrigation, or SDI) which has been seen to work very well in some studies but not in others if the system significantly affects the fertilizer, gas, or temperature within the soil (Liu, 2017). However, the effect of these systems on nitrogen in the fertilizers needs further research to be better understood (Gupta, 2023).

A database of information can be helpful for a smart irrigation system. Smart irrigation systems use data from a web of sources to spread information to farmers to improve the efficiency of crops. More specifically, data on climate, soil water quantity, vegetation cover, soil type and structure, and cropping techniques are available for farmers to access. This database could provide information to help determine the best solution to conserve water for each unique geographical location and crop selection (Casadei, 2021). Spreading this information and building a framework for decision-making for farmers will make it easier for the agricultural industry to use water more efficiently. Furthermore, the use of drought-resistant crops would conserve water as well. This is called Xeriscaping and allows the use of crops in environments that would naturally perish. The reuse of rainwater or wastewater is included in xeriscaping practices along with widely spread irrigation systems that purposefully encourage deeper rooting systems and drought resistance in plants (Azaiez, 2008). The choice of crops should be based on drought resistance but also the irrigation systems should be designed in a way that stresses the plants to be more drought resistant as well.

Table 9: Agriculture Water Saving Practices

Practice	Description
Drip irrigation	Delivers water and nutrients directly to the root zone of each plant in precise amounts. Achieves higher yields with less water, fertilizer, and energy. Reduces waste through targeted resource application.
Water Harvesting	Collects and stores runoff and stormwater for various purposes. Reduces runoff volume, prevents water quality degradation. Promotes water conservation and reduces reliance on freshwater sources.
Irrigation Scheduling	Uses schedules based on weather forecasts, soil moisture, and plant conditions. Prevents under-watering and over-watering of crops. Optimizes water use for optimal growth and avoids water waste.
Drought Resistant Crops	Cultivates crops adapted to the local climate, particularly drought-resistant varieties. Reduces the risk of crop failure during water scarcity. Optimizes water use and enhances economic stability.
Dry Farming	Relies on soil moisture from the previous rainy season instead of irrigation during dry periods. Emphasizes maximizing natural soil moisture content. Achieves sustainable crop production with minimal water use.
Compost and Mulch	Enhances soil health and fertility using compost and mulch. Compost enriches soil with organic matter and nutrients. Mulch conserves moisture, suppresses weeds, and moderates soil temperature.
Conservation Millage	Reduces soil disturbance, conserves water, and enhances soil health. Creates a protective layer on the soil surface to retain moisture. Prevents erosion and runoff.
Conservation Crops	Protects bare soil from erosion, water loss, and compaction. Competes with weeds for water and nutrients. Enhances soil fertility and water retention.
Organic Farming	Prioritizes natural methods to promote soil fertility and reduce reliance on synthetic chemicals. Crop rotation diversifies crops over time. Healthy soils retain water better.

3.4 Public Opinion

In the context of wastewater regulations, wastewater reuse, and drinking water regulations, public concern about environmental sustainability and the potential health hazards can impact the way these topics are handled within each state. This section analyses the public's opinion on the above topics and discusses the impact these opinions have on government policies.

3.4.1 Effect of Climate Change on Perceptions about the Water Crisis

A survey done in 2023 by a Senior Climate Scientist at the Union of Concerned Scientists (Fencl, 2023). This survey highlights the relationship between extreme weather events and concerns about water supply reliability. Data was gathered on the impacts of climate change on households and their attitudes toward local adaptation decisions, it included 704 Californian's responding to the survey. Of the respondents 85% of the 704 Californians reported having concerns for the future of the water supply. Over a third of the respondents reported experiencing at least one extreme weather event in the last 5 years that had effects on their water supplies. Drought being the most frequently cited extreme weather that affected respondents water supply 192 of the 704 that's 27% of the respondents reported. The survey gave different options of extreme weather impacts following droughts, wildfires were the next most common cause of water supply issues at 7.5%, then heat waves at 5.5%, other impacts at 2%, and last flooding at 0.8% (Dobbin, 2023). Different climate change events led to different effects on people's concern about the future water supply reliability. Respondents who experienced drought had a 167% increase in odds of being more concerned about droughts impacting the water supply (Fencl, 2023). Water supply impacts on households due to extreme weather was reportedly distributed evenly among Californian's regardless of their education, income level, and water provider. However, disparities emerged along gender lines founding that 37% of 394 women reported impacts to household supplies more often when compared to 27% of 296 men (Dobbin, 2023). Based on the survey, there were minimal differences in the concern across regions.

3.4.2 Marketing

In many instances, the opinion of the public is significantly influenced by how ideas are marketed. When the idea of water reuse started to become more seriously considered in California in the 1990s, the term "toilet-to-tap" was used in the LA Times in a story critiquing the idea of water reuse. It is unclear where the term originated exactly, but it is suspected to have come from Miller Brewing, a company concerned about the quality of the product they would be producing (Mackie, 2021). They later released an advertisement that stated the reasons that they were against the reuse project being widely discussed in the region. The claims provided include a lack of proof proving the safety of the drinking water and additional tests are needed (Mackie, 2021). Furthermore, they claim that the issues are nor really being addressed, claiming that artificial groundwater recharge wells are detrimental to the health of the wells and also the wastewater has an unknown amount of microorganisms and unidentified organic chemicals

(Mackie, 2021). These statements made in 1994 are misleading. The Miller brewing company uses a reverse osmosis technique to create ultrapure water to maintain consistency across its worldwide network. Furthermore, groundwater experts estimate that the water Miller used was only 2-3% reclaimed water which is negligible when considering the system used for treatment. As a direct result of Miller fighting the Los Angeles County Sanitation District, it was voted by government officials to shelve the water reuse project in favor of recharging the aquifer through natural rainwater and water imports (Mackie, 2021). Ripples of the phrase ‘toilet to tap’ continue for years, influencing officials like Los Angeles City Councilmember Joel Wachs who pushed back against the project and even used it as a call for secession of San Fernando Calley from the City of Los Angeles. In 2020, the company has made a statement saying they support communities that recycle water if the treatment process is sufficient. Miller Brewing encourages the change in phrasing away from ‘toilet to tap’ as they correctly feel there is a need for a title that provides more confidence to its consumers.

The WateReuse Foundation conducted a survey in the year 2009 in order to determine the psychology behind water reuse and reclamation (Haddad, 2009). They discovered that only 13% of Californians from these 5 locations were completely unwilling to drink recycled water. In the short term, information on certified safe recycled water has a positive impact on public opinions. In fact, once these respondents were asked to read a small paragraph about individual water molecules having been recycled through various life forms and environments over time. Beyond this, 30% of the surveyed were not interested in the technical aspect of water recycling but did care that they had a trustworthy source to confirm it was safe. 39% showed a willingness to drink recycled water if it had been in an aquifer for 10 years as opposed to 1 year. However, 14% still found 10 years less acceptable than 1 year.

With water becoming scarcer, people are becoming more open to the idea of water recycling. The Orange County Water District (OCWD) put a significant amount of work into changing the public opinion of water reuse. Public relations are one of the top priorities of the OCWD. They gained media attention by securing a world record for the most recycled water produced in 24 hours. The OCWD produced over 307 acre-feet of wastewater converted into potable water and pumped into the groundwater basin for that record in 2018 (Lund, 2019). Media coverage did not include phrases such as “toilet-to-tap” due to the negative connotation and even used the headline “Magic in a Bottle.” Positive public relations and marketing strategies make a significant difference in the public opinion surrounding water reuse (Lund, 2019).

3.4.3 Public Opinion on Recycled Drinking Water

Historically, researchers have been analyzing the willingness of people to drink treated wastewater. Based on global polls, the acceptance toward water reuse has been growing, however, public opinion shifts in the US. One poll conducted on Southeastern Americans surveyed 203 residents and found that only 8% were willing to drink treated ‘recycled water’ at all (Pathiranage, 2023). Other places, such as Europe, have higher acceptance rates, which shows the possibility of wastewater reuse occurring in all areas. The willingness to drink recycled water in European Union is 75%, 67%, and 73% of those surveyed in the Netherlands, Spain, and the United Kingdom, respectively (European Commission, 2022). California polls reflect that of the European's stance. A 2016 California study done by the company Xylem which conducted an online survey that randomly selected 3,000 California voters. The study showed that 87% of Californians were supportive of recycled water being an additional source of water. In total 90% of respondents believe that California needs to continue to invest in recycled water treatment plants for the future (Tobin, 2017). It's worth noting that the California survey was conducted during a prolonged period of drought across the state. 75% of Californians surveyed stated that they trusted the wastewater treatment process for personal use. There is a positive trend in Californians' relationship with recycled water. After being educated on the water treatment process, support for using recycled water for cooking, drinking and bathing notably increased from 2015 to 2017 (Xylem, 2017).

3.4.4 Public Opinion on Conservation

A poll conducted on San Diego residents was done to understand the community census surrounding water efficiency and conservation in San Diego. The poll collected data from a random sample of 889 adults residing in the San Diego County in July of 2022. Despite the shift from drought-free conditions in 2019 to severe drought in 2022, there was an increase from 3% to 7% of residents identifying water-related issues as the most important issue the county was facing. Over 90% of respondents prioritized other issues, such as affordable housing, homelessness, cost of living, public safety, etc. Even though water-related issues were not the most prominent responses in 2022, 81% of San Diego County residents are aware of the current drought situation in the state (Mora, 2022). Of the people surveyed, 88% believe they have a civic responsibility to the environment and community members to use water responsibly. When respondents were asked about their awareness of their water usage, a combined 81% of the respondents described themselves as either very attentive at 45% or somewhat attentive at 36% (Mora, 2022). The survey found that attentiveness to household water uses varied across age groups with older individuals aged 65 and older reporting that 93% were very or somewhat attentive to water usage compared to the 18 to 24 year olds reporting that 66% were very or somewhat attentive to water usage. The survey revealed that most respondents had implemented various water conservation actions in their households. The most common practice includes fixing inefficiencies associated with leaks and drips at 82%. The next most common practice at 81% was specifically only running the dishwasher or laundry when it was full. Next, reducing water usage during activities such as showering, dishwashing, and toothbrushing by turning off the water as soon as possible was done by 78% of respondents. Also, 64% said they reduced water usage during activities such as watering landscapes and plants by using the minimum amount possible or not watering at all (Mora, 2022).

3.5 Treatment Costs

This section provides a cost comparison for different water sources currently used in California. The unit used in this section is m^3, which is equivalent to 0.0008 acre-feet. Fresh water sources are typically the most economical sources of water, with groundwater being the least expensive. Figure 11 shows a comparison of the costs of alternative – and typically more expensive - water sources. According to this figure, seawater desalination is the most expensive, with the median cost falling between $2-3 per cubic meter of water. Small-scale brackish desalination, large-scale stormwater capture, non-potable reuse, and indirect potable reuse all have median values of $1-2/m^3. Large-scale brackish desalination and large-scale stormwater capture are shown to be the least expensive among the options shown, with median values less than $1/m^3. The costs of each source are discussed in more detail below.

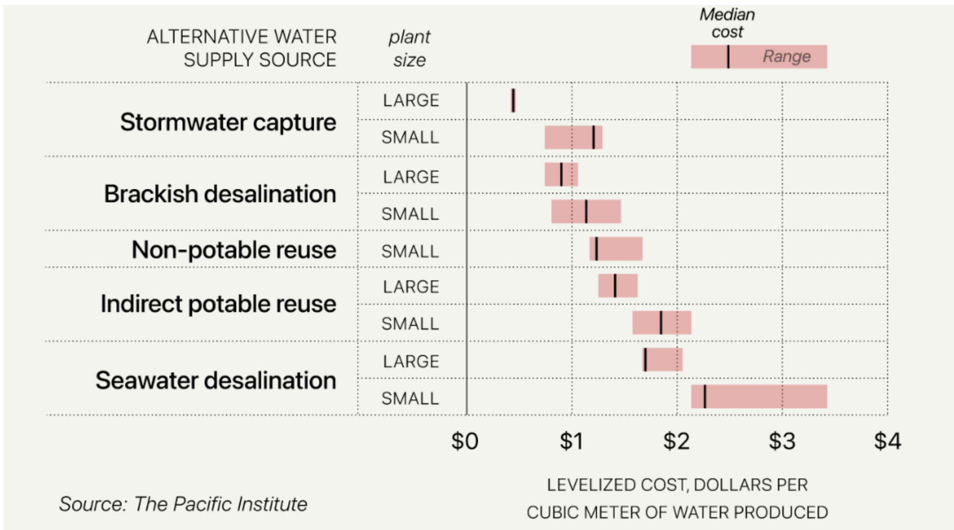


Figure 11: Range of costs and median costs associated with alternative water sources in $/m^3 (Standford University, 2023, Public Domain).

3.5.1 Freshwater Sources

While it is difficult to compare the costs of surface water and ground water in California (due to the large number of systems using multiple sources), it is well known that the costs associated with producing drinking water from fresh water sources are less than that of the alternatives. While groundwater may contain contaminants from seepage and soil percolation, in general most groundwater systems require no treatment or minimal treatment due to it being naturally filtered through subsurface material, resulting in a lower overall cost (O'Donnell, 2021). Surface waters are susceptible to more contamination from air pollutants and runoff. To ensure that this water meets water quality goals and regulations, it goes through extensive treatment to ensure the contaminants are removed. Surface water is thus considered more expensive than groundwater due to the costs associated with these treatments (O'Donnell, 2021).

3.5.2 Desalination

The cost of desalination, whether for brackish water or seawater, varies based on several factors. Cost increases with higher salinity of the water as it requires more treatment. Labor and land costs are present in all water treatment facilities, but energy and equipment for operation and maintenance may be high. The high energy costs arise from the reverse osmosis process. When saltwater and freshwater are separated by a barrier, with both ends open to the atmosphere, water will travel from the freshwater to the saltwater as water molecules would be in lower concentration (Greenlee, 2009). This process is called osmosis. Therefore, in reverse osmosis, a pump to push water under pressure through the barrier towards the freshwater side will have to work to the system proportional to the concentration of saltwater.

Brackish water desalination is more cost-effective due to lower salt and total dissolved solids levels. As seen in Table 10, smaller brackish water projects have a higher median cost compared to larger facilities. This is because as systems scale up, efficiency increases. Using the treated water in the drinking water distribution system adds a cost, described by the integration column. Integration is a higher cost for seawater desalination because brackish plants are located closer to the water distribution system. Overall, treating brackish water with a large plant is less expensive than treating seawater (Cooley, 2019). However, for geographical reasons, this option is not always possible.

Table 10: Cost of brackish water desalination facility, integration, and total cost of projects of small to large sizes (Cooley, 2019).

Type of Plant	**Size of Plant**	**Cost (per m^3)**	**Integration ($/$m^3$)**	**Total cost (per m^3)**
Brackish Water	Small project <20 million m^3	Low - $0.73 Median - $1.22 High - $1.40	$0.09	Low - $0.83 Median - $1.31 High - $1.49
	Large project >20 million m^3	Low - $0.68 Median - $0.82 High - $0.99	$0.09	Low - $0.77 Median - $0.91 High - $1.08
Seawater	Small project <20 million m^3	Low - $2.01 Median - $2.13 High - $3.31	$0.16	Low - $2.17 Median - $2.29 High - $3.47
	Large project >20 million m^3	Low - $1.53 Median - $1.57 High - $1.90	$0.16	Low - $1.69 Median – $1.72 High - $2.06

3.5.3 Wastewater Reuse

Implementing advanced technologies for wastewater treatment to reuse water mitigates the burden on conventional water sources. There are some costs associated with this process that make wastewater reuse less economically feasible. For non-potable reuse, less treatment is needed so the costs are lower as shown in Table 11. Expanding non-potable reuse may require the installation or extension of a separate water distribution system, which would result in an additional cost. Potable reuse needs to be treated well before distribution. As a result, an indirect potable reuse facility has greater costs. Larger plants have a decreased cost due to larger plants being more efficient with their energy consumption.

If treated water is going towards groundwater recharge, there is an additional cost to convey the water to the basin underground. Furthermore, there is an additional expense to extract the groundwater and treat it to drinking water standards for potable reuse. In such a case, the total cost for small potable reuse projects is relatively expensive. The issues with wastewater reuse systems stem from these costs compared to other options along with public opinion on the matter as discussed in Section 3.4.3.

Table 11: Cost of facility, distribution, and total cost of potable reuse projects of small to large sizes (Cooley, 2019).

Type of plant	**Size of Plant (values per year)**	**Cost (per m^3)**	**Distribution (per m^3)**	**Total cost (per m^3)**
Non–potable reuse facility	Small project <12 million m^3	Low - $0.44 Median - $0.48 High - $0.93	$0.77	Low - $1.21 Median - $1.25 High - $1.70
Indirect potable reuse facility	Small project <12 million m^3	Low - $1.21 Median - $1.50 High - $1.80	$0.37	Low – $1.59 Median - $1.88 High - $2.17
	Large Project >12 million m^3	Low - $0.91 Median - $1.06 High - $1.28	$0.37	Low - $1.28 Median - $1.43 High - $1.66

3.5.4 Imported Water

In 1930, the Colorado Aqueduct was built to transport water to Southern California from the Colorado River. The Metropolitan Water District (MWD) controls the distribution of the imported water and calculates water prices based on energy usage and statewide water availability. For example, the Santa Margarita Water District pays $0.927 per cubic meter of drinking water and the Orange County Water District pays $0.983 per cubic meter (Santa Margarita Water District, n.d.; Orange County Water District, n.d.). Imported water tends to be the most expensive portion of the water bills and these prices are increasing over time. Between 2022 and 2023, the Volumetric Full-Service Treated Rate for the Metropolitan Water District of Orange County increased by $0.053 per cubic meter (Santa Margarita Water District, n.d.). Certain parts of California adjust water rates for residents based on their efficiency due to the expense of importing water from these water districts. In the Irvine Ranch Water System, there are four different rates: low volume, base rate, inefficient, and wasteful. This is a tiered system that gets progressively more expensive due to the high cost of water imported from the MWD (BGWG, n.d.).

3.5.5 Stormwater Reuse

Stormwater may be reused for many applications such as potable use or groundwater recharge. However, stormwater tends to be highly contaminated if fallen on impermeable or semi-permeable surfaces like roads or buildings (Diringer, 2020). As a result, stormwater is more commonly used for non-potable uses. One study examined 50 stormwater capture projects in California to determine the value of such projects. They found that non-urban stormwater capture projects were more expensive than urban, but it is suggested that they are more similar than the data suggests due to a small sample size (Diringer, 2020). The cost of produced water greatly depends on the system's size as well as co-benefits given. Examples of co-benefits include conservation efforts like technology that prevents greenhouse gas emissions as well as energy usage. Urban and non-urban stormwater capture projects can be given co-benefits by the World Bank (The World Bank Group, n.d.). After these benefits are considered, net costs can decrease by as much as 85%, making it much more economically feasible (Diringer, 2020). Costs in Table 12 factor in estimated co-benefits.

Stormwater projects can be categorized as recharge, conveyance, or decentralized. Recharge projects replenish groundwater through soil infiltration. Conveyance projects transport water to lakes, rivers, or detention basins. Decentralized projects promote use of the water as close to where it falls as possible. There is also MAR, or Managed Aquifer Recharge. In Table 12, the cost of such projects and systems are presented. Treatment is another source of costs entirely. Because of the large amounts of contamination in the water, stormwater is more commonly used for non-potable reuse and indirect potable reuse. As shown in Table 12, it is less expensive to treat for non-potable reuse as less treatment is needed. MAR techniques are shown to be more expensive as the energy used to move water and recharge wells is costly. Especially when scaled in urban areas, stormwater capture can be a viable water supply resource in California to improve reliability.

Table 12: Cost of capture for urban, non-urban, large, and small stormwater capture and cost to use storm water for aquifer recharge, decentralized (which includes conveyance), and recharge.

Size/Type of Capture	Cost
Non-Urban Capture	$\$.957/m^3$
Urban Capture	$\$.430/m^3$
Large Capture >8 million m^3	$\$.478/m^3$
Small Capture <1.85 million m^3	$\$1.22/m^3$
Aquifer Recharge (MAR)	Low: $\$.332/m^3$ Median: $\$1.25/m^3$ High: $\$2.16/m^3$
Recharge Projects	$\$10.78/m^3$
Decentralized Projects	$\$.187/m^3$
Centralized Projects (Includes Conveyance)	$\$.619/m^3$

3.6 Design

The previous sections provided information on California's hydrography, water use, conservation, public opinions, and treatment costs. In this section, a water management plan was created for Coalinga, California, using the previously stated information. California has many cities with water shortages, but few cities struggle to the degree that Coalinga, California, does. A sustainable water plan would have the most significant feasible impact on this city.

Coalinga, California, is located within the San Joaquin River Valley of Fresno County. The population was 17,560 as of the 2021 census, representing 1.65% growth from 2020. The unit used in this section is m^3, which is equivalent to 0.0008 acre-feet. Historically, Coalinga has used 8.8 million m^3 per year of water, domestically and agriculturally, during its wettest years (CNBC, 2022). Coalinga was historically allocated 12 million m^3 of water annually by the Bureau of Reclamation (USBR, n.d.). However, as shown in Table 13 below, this amount has decreased far below their needs. During the drought in 2021, water price per unit volume increased by 2000%, straining an already struggling economy. In November of 2022, The Department of Water Resources (DWR) provided $1.2 million to the City of Coalinga for a winter emergency water transfer (CA Department of Water Resources, 2024). In 2022, Coalinga gained national attention because its allotted annual water supply of 2.5 million m^3 was expected to dissipate before December; this forced an emergency purchase of 740,000 m^3 to prevent total loss of water (DWR CA, 2022). These water volumes are summarized in Table 13.

Table 13: Allocated water imported by Coalinga in the years 2021 and 2022 including additional water imports and potable portion amounts (CNBC, 2022).

Historical Water Use	**Allocation Amount by CA Dept. Of Water Resources (For all uses)**	**Additional Imports by Coalinga**	**Potable Portion of Total**
2021 Allocation	8.8 million m^3	N/A	655,000 m^3
2022 Allocation	2.5 million m^3	740,000 m^3	655,000 m^3

The sustainability of buying water and the supply allocated to them by the California Department of Water Resources is uncertain. Therefore, a long-term water management plan for the city must consider alternative water sources and measures that can reduce overall water usage. Table 14 provides a summary of water management options, ranked based on cost, geographical applicability, infrastructure needs, and public acceptance. The overall feasibility was then determined. Each of the management options is discussed in the subsequent sections.

Table 14: Management options ranked on cost, geographical applicability, infrastructure needs, public acceptance, and overall feasibility.

Management Option	**Criteria**				
	Cost	Geographical Applicability	Infrastructure Needs	Public Acceptance	Overall Feasibility
Tiered Billing System	Feasible	Feasible	Feasible	Feasible	Yes
Wastewater Reuse	Neutral	Feasible	Infeasible	Neutral	Yes
Efficient Technology	Neutral	Feasible	Feasible	Feasible	Yes
Desalination	Neutral	Neutral	Infeasible	Feasible	No
Artificial Aquifer Recharge	Neutral	Infeasible	Neutral	Feasible	No
Stormwater/ Rainwater Harvesting and Reuse	Neutral	Neutral	Neutral	Feasible	Yes
School Conservation Education	Feasible	Feasible	Feasible	Feasible	Yes
Funding Applications	Feasible	Feasible	Feasible	Feasible	Yes

3.6.1 Tiered Billing System

Municipalities in many parts of California and the United States utilize a tiered system to determine water costs. This system encourages conservation by charging a premium for water used for non-essential purposes. In the tiered system, households using up their allotted water would have lower water rates than those who use more than the budgeted amount. This has been successful in many locations, including San Diego, Pasadena, and Los Angeles, California. In 1990, Los Angeles implemented a tiered rate system and was one of the first cities in the country to do so. In this system, the water supply and demand, operation and management costs, water purification, and other variable factors are used to calculate the water rates in each tier. This system decreased the average water demand from 180 gallons per capita per day (gcd) in the 1980s (equivalent to daily per capita use of about 0.7 m^3, 0.24 HCF, or 0.0005 acre-feet) to below 160 gcd (daily per capita use of about 0.6 m^3, 0.21 HCF, or 0.0004 acre-feet) in the 1990s. It was projected that the tiered system not only saved water but saved consumers $11 billion cumulatively in operation and management costs since the system was implemented (Chesnutt et al., 2019). This was calculated by estimating the short-term and long-term costs of water treatment and multiplying it by the water demand difference. If Coalinga utilized a tiered system, it would encourage water conservation and decrease water bill prices. Assuming a similar usage decrease as in Los Angeles, with a population of 17,560, water use could be reduced by approximately 351,200 gallons per day (daily reduction of 1330 m^3, 470 HCF, or 1.1 acre-feet). In a year, they would save 485,450 m^3 of water, more than half of the emergency water purchase. Even though the quantity of the emergency purchase would not be in their water supply, they would only need to purchase 35% of what they previously purchased, saving them money as well.

Coalinga currently has a volumetric flat rate system split into four categories: urban-residential, urban-commercial, rural, and California Department of Corrections facilities. Following a model like that in Los Angeles, the residential water rates would be split into four tiers. The first tier would be the rate for the lowest water usage, allowing for basic needs to be met. In Los Angeles, each customer is allocated 8 HCF (about 6,000 gallons, 22.7 m^3, or 0.006 acre-feet) monthly for tier one. For context, one unit of a multifamily residential home uses about 2-4 HCF per month on average (1496 – 2992 gallons, 5.65 - 11.32 m^3, or 0.004 - 0.009 acre-feet) (Goleta Water District, n.d.) The amount allotted to each customer in Coalinga would need to be determined based on the available water and the local/seasonal water conditions, including droughts. The second and third tiers are determined by the property's lot size, season, and weather patterns, as it mainly consists of outdoor use. The fourth tier is for customers who use water excessively, going beyond the allocated water in the first three tiers. In the 2015-2016 fiscal year, the tiered prices in Los Angeles were (per HCF) $4.45, $5.41, $6.31, and $7.91 for tiers 1-4, respectively. These prices would need to be evaluated for Coalinga before a tiered system can be considered.

3.6.2 Wastewater Reuse

Though wastewater has significant challenges for implementation, it is still a feasible option for Coalinga to supplement potable water supply. Though this could be a very expensive project, converting water that enters the wastewater treatment plant into potable water is achievable. Currently, the wastewater treatment plant in Coalinga uses mostly natural remediation to clean wastewater before it is reused for irrigation purposes (City of Coalinga, 2024). Coalinga potable water needs are typically between 2 and 12 million m^3 per year. The wastewater plant influent is approximately 3,500 m^3 per day, or 1,277,500 m^3 annually. Thus, reusing the local wastewater could provide 11% to 63% of the needs of the city. Currently, wastewater flows to the plant downgrade with only 4 pump stations involved in the transportation of wastewater to the facility (City of Coalinga, 2024). Influent water is run through screens and naturally treated in one of 5 treatment ponds. No chemicals are added at any point in this process. Therefore, the wastewater treatment plant would require additional treatment processes for the water to be used as potable water.

Wastewater treatment typically includes processes such as preliminary, primary, and secondary treatment; some treatment plants also include tertiary (advanced) treatment. This plant currently only has preliminary, primary, and secondary treatment. Investments in processes such as biological and chemical treatment, filtering, and disinfection would likely need to be made to clean the water up to regulatory standards according to the policies set in place by the State Water Resources Control Board (California Environmental Protection Agency). Then, the water would need to be pumped against the force of gravity to connect with the existing potable water distribution system in order to deliver the water to homes and businesses. These pumps would consume power and heighten costs. Furthermore, because Coalinga would utilize a system suitable for tens of thousands of persons, there would be an absence of savings from efficiencies associated with scaling up by comparison. In the same county, the city of Fresno (population 550,000) already treats wastewater to potable drinking standards (Benjamin, 2018). This required a $105 million loan from the state of California. A regionalized system such as the one in Fresno just over 100 miles away by road could decrease capital costs of treatment but would increase piping and pumping costs.

3.6.3 Efficient Technology

California has enacted bills forcing contractors and builders to install water-efficient systems. However, older houses do not have to abide by these regulations. Coalinga has 4,812 housing units, most of which were built decades before these regulations were created. This has made the residents responsible for improving the water efficiency of their homes at their own expense. There is potential for Coalinga to improve its water efficiency by households switching to efficient appliances and showerheads. A standard low flow toilet costs $200 and saves roughly 2 gallons per flush compared to the standard toilets of the mid-1980s. The switch to a low flow toilet saves roughly 5,475 gallons annually per household, amounting to over 26 million gallons (roughly 98,420 m^3, or 80 acre-feet) throughout Coalinga. Low flow showerheads save 1 gallon per minute, roughly 8 gallons per shower, 8,760 gallons per household annually, and 42 million gallons (approximately 158,987 m^3, or 130 acre-feet) across Coalinga. The investment of switching to low-flow toilets can save homeowners $140 on average in the US. During the 2022 drought in Coalinga, when water prices increased by 2000%, this would have saved homeowners $233 in December. This conservation initiative would have the most immediate impact financially on the people of Coalinga. In addition, this would lessen the amount of imported water that is needed. If residents of Coalinga had these low flow toilets and showerheads, a combined 257,407 m^3 would be saved, which is about 35% of what the city needed in additional imports in 2022. This was found from using the values in Table 13 and by using the cumulative values of saved water from low flow showerheads and toilets.

3.6.4 Desalination

Utilizing desalination in Coalinga as a water management solution has the potential to make a significant impact on the water availability issue. A desalination plant could offer Coalinga a reliable water supply and also an emergency water supply in the event of interruptions to imported water delivery caused by natural disasters. Coalinga currently does not have any desalination plant infrastructure, which would make the design and build of this project expensive. Coalinga is about 100 miles from the coast by traveling on developed roads. These existing roads provide accessible transport which would aid in the development of the infrastructure and piping needed to move salt water from the coast to the city of Coalinga.

Due to Coalinga's population as stated in Section 3.6, the city would need a system that could produce water for nearly 20,000 residents as well as industry and other demands. A desalination project would require an initial investment to build the piping needed to get seawater to flow to the treatment facility, the treatment facility, and then the piping needed to connect the treated water to a potable water distribution system. This initial cost would be expensive and would require a lot of time to be constructed. In California, the South Coast Water District is currently constructing the Doheny Ocean Desalination Project which received $140 million from the California Coastal Commission in October of 2022 (Dana Point Times, 2024). This project is located strategically 100 yards from existing potable water distribution lines to reduce construction costs and impacts. The capacity of this facility is up to 5 MGD and utilizes subsurface intake wells at Doheny State Beach, which employs environmentally friendly technology buried beneath the ocean floor to protect marine life. This project proposed discharging the brine, the byproduct of desalination, through an existing treated wastewater outfall pipe into the ocean at the San Juan outfall, this is considered the environmentally preferred discharge method (SCWS, 2024). A desalination project in Coalinga would likely not be feasible due to the costs.

3.6.5 Artificial Aquifer Recharge

Groundwater recharge through anthropological means is unfeasible due to groundwater contamination already present in the Coalinga area. The EPA declares sites as Superfund sites when they possess a risk to human health or the environment due to hazardous substances (EPA, 2024). Coalinga has an asbestos mine that covers 120-acres in an area 16 miles northwest of Coalinga. It consists of demolished buildings, waste piles, and open pit mines. The actions conducted in this area contaminated the air, soil, sediments, and surface water with asbestos. The site also contained nickel and chromium from buildings which can be toxic as well. To clean up the site, 20,000 cubic yards of soil were excavated and placed in an underground waste management unit. This was covered by an impermeable cap to prevent further spreading of contamination. Though cleaning has been finished since 1995 and the site is no longer a Superfund site, the EPA and California Department of Toxic Substances Control monitors the soil, groundwater, and air contaminant levels as of 2021 (EPA, 2024). Historically, the water quality in the aquifer present in Coalinga has been poor. This is due to the high sodium sulfate concentrations which render groundwater useful for irrigation practices only (Coalinga Asbestos Mine Review Report for EPA, 2021). As a result, there are no groundwater wells in Coalinga. Past contamination and present poor water quality render aquifer recharge unfeasible for potable use.

3.6.6 Rainwater Harvesting and Reuse (Non-Potable)

Stormwater capture and reuse is dependent on rainfall amounts and infrastructure availability. Coalinga consists of an arid landscape. The City of Coalinga receives an average of approximately 8.25 inches per year of rainfall according to U.S. Climate Data. Coalinga has a population of 17,560 and requires less than 12 million m^3 of water annually. Prices could be approximately $\$1.22/m^3$ compared to a larger city like Fresno where costs could be approximately $\$.478/m^3$. Also, the 2022 seasonal rainfall variability varied from 0.01 inches in July to 1.12 inches in January (Coalinga Urban Water Management Plan, 2022). As a result, maintenance and operation of the plant fluctuate throughout the year, adding an obstacle for Coalinga to build a combined stormwater capture, treatment, and conveyance system for distribution.

While it may not be viable to reuse stormwater city-wide, rainwater harvesting can be used for at home use. In this process, rainfall on buildings and other developed areas is captured and a rebate is given to residents or business owners. Rainwater harvesting offers numerous benefits by providing a usable water source with minimal cost and low maintenance requirements and is useful in communities that are in water-stressed areas. Rainwater harvesting has the flexibility to be retrofitted to existing structures or incorporated into new construction projects. Additionally, it reduces stormwater runoff which alleviates strain on sewer systems during heavy rainfall and prevents pollutants from entering the environment. Thus, harvesting systems can help mitigate flooding risks in homes and public spaces, which enhances public safety (WateReuse Association, 2024).

The rain harvesting rebates system for Coalinga could be similar to the system in San Diego, California. The San Diego system has set up incentives for rainwater harvesting with different types of projects that range from residential and commercial parcels that collect rain in rain barrel systems to large landscapes that need help from multiple agency programs. San Diego offers rebates to residents and business owners who adopt water-saving practices on their property. These rebates cover various developments such as rain-saving features for their yards, including garden design, dry creek, and drought-tolerant landscaping. Agricultural properties can benefit from free audits and irrigation system upgrades through the Agricultural Irrigation Efficiency Program. These rebates not only help save money and provide a water source but also enhance a property's value and protect the natural environment. In San Diego, the rebate for rerouting rainwater from a roof into a yard is up to \$200 per m^3 (\$0.75 per gallon) stored without exceeding \$2,100 on residential properties and \$6,000 on commercial properties. From the Rebates in San Diego, the average resident will get a rebate of \$385 for capturing approximately 1.95 m^3 (515 gallons) from their home (SD Department of Public Works, n.d.).

According to the U.S. Climate Data, San Diego gets on average 10.34 inches of annual precipitation compared to Coalinga with 8.25 inches. San Diego has a successful rainwater rebate program, showing it is feasible for Coalinga. According to the United States Census Bureau, the average roof size in the US is 1,700 square feet and Coalinga has 4,552 households. For every 1 inch of rainfall, a 1,000 square foot roof captures 2.37 m^3 (625 gallons) of water. Using the ratio between rain gallons captured and the square foot of roof, the estimated amount of residential rainwater capture can be found. This ratio (625 gallons/1000 ft^2) multiplied by an average roof area of 1,700 square feet, the average Coalinga annual rainfall of 8.75 inches, and all 4,552 homes in Coalinga result in the annual volume of water that could be captured in Coalinga at approximately 151,000 m^3 (40 million gallons) annually. This amount makes an impact as the amount of water imported by Coalinga in 2022 was 2.5 million m^3. This volume would be available for use on residential or commercial property, and diverted from storm drains every year (SD Public Utilities, n.d.). The implementation of rainwater harvesting, and reuse rebates system would offer Coalinga an opportunity to conserve water, reduce cost, and enhance sustainability for the benefit of both the consumer and the environment.

3.6.7 Water Conservation Education in Schools

Education on water conservation in elementary, middle, and high school could decrease water consumption. Through numerous organizations over 1,000 teachers have received training on water conservation practices. In California, educators have opportunities to enhance water conservation education within schools. The Education and the Environment Initiative (EEI) offers a K-12 curriculum, serving as a model for integrating environmental literacy into classroom instruction. The Project WET Foundation, a renowned non-profit organization, provides educators with resources, including curriculum materials, fostering a global perspective on water-related topics. The US Geological Survey (USGS) Water Science School provides a wealth of resources covering the water cycle, groundwater, and water quality, available in multiple languages. Allowing these organizations to train educators in Coalinga could further help decrease water usage.

3.6.8 Apply for Funding

Without the funds, it is challenging to properly manage resources using the best practices. According to a 2020 Water and Wastewater Financial Analysis of the city, Coalinga needs funding to ensure the safe and reliable operation of its water systems (Bergmann, 2020). While they could increase the water rate prices and use part of the incoming money towards fixing old infrastructure, that would put more financial stress on residents of the city. Applying for funding could give Coalinga the money to make some much-needed upgrades. The EPA has loans and grants Coalinga can apply for. With the Bipartisan Infrastructure Law of 2022, $50 billion was granted to the EPA to help improve water infrastructure around the country. With this money, the State of California can provide funding or loans to areas that need to upgrade their current water infrastructure (EPA, 2022). The Water Infrastructure Improvements for the Nation Act (WIIN Act) is a grant program committed to addressing, supporting, and improving drinking water infrastructure throughout the country (EPA, 2021). Through the WIIN Act, municipalities can apply for funding for several projects including those that enhance water use efficiency, design or construct desalination facilities, enhance a water supply through watershed management, and measure to increase the resilience of drinking water systems to natural hazards. To apply for these grants, Coalinga may need to increase staff in their local government. A 2023 survey sent to all local governments in California found that 53% of the respondents considered federal and state grants a top need, and 42% said they needed help finding and applying to available funds. Most of the respondents (66%) also said they had either none or less than one full time staff looking for and/or applying for funding (Perry et al, 2023).

3.6.9 Summary of Potable Water Management Plans for Coalinga

The management plan and recommendations for Coalinga, in summary, consists of the following:

- Create a Tiered Billing System – A tiered billing system is very feasible for the city of Coalinga. Using a model similar to Los Angeles, Coalinga can employ a four-tiered system. The first tier allots a certain amount of water calculated by considering the available water. The second and third tiers are determined by the available water, the season, and the drought conditions in the area. The fourth tier would be water use much higher than the previously allocated amount. The prices need to be calculated by the Coalinga Municipality and would vary.

- Efficient technology – By changing out old toilets and shower heads with new low flow technologies, Coalinga can save over 200 acre-feet a year.
- Indirect Stormwater Reuse – Rainwater harvesting through residential and business capture systems with rebates as incentives is recommended as it is low cost and has been efficient in similar cities.
- School Conservation Education – Education is a very inexpensive and effective way to decrease water consumption in residences and industry.
- Funding Applications – Funding is necessary for addressing the many problems Coalinga faces in water. Even though more staff may be needed, applying for funding is a very feasible option for finding solutions, and could make more options available to them.

Chapter 4: Conclusion

Water scarcity is a major issue in many parts of California including the city of Coalinga in Fresno County. The goal of this project was twofold: (1) to evaluate water use, water availability, conservation efforts, public perception of water strategies, and cost of water treatment in California, and (2) to design a water management plan and recommendations for the city of Coalinga which has faced significant water scarcity with limited applied strategies. The key findings are presented here.

- Water availability in California is geographically and temporally inconsistent over the course of a year. From 1901 to 2000, rainfall ranged from approximately 80.16 inches in the northernmost county to 3.38 inches in the southernmost county. In 2020, one country received 1.26 inches of rain and 3.0 inches in 2022. Further, droughts have diminished freshwater availability in California. A 20-year study of the 4,800 Californian wells found more than half are experiencing a downward trend in water volume.
- Wastewater reuse projects in California from 2015 to 2021 have increased from 881 million cubic meters to 903 million cubic meters. These plants are located in higher populated areas like Fresno which has 500,000 residents.
- Conservation efforts can include mandatory installation of water saving appliances, monetary incentives, legislation, fines, and public education. In industry, best management practices are put into law to encourage efficient performance. A tiered billing system adds zero costs to residents and has been proved to be successful in regions such as San Diego and decreased the average water demand from 0.20 acre-feet per capita per year in the 1980s to below 0.18 acre-feet per capita per year in the 1990s.
- Public opinion of water treatment technologies changes due to marketing or environmental disasters. Marketing from a private company called Miller successfully misinformed citizens about dangers of wastewater reuse in the 1990s. Additionally, out of 704 Californians, respondents on a survey who experienced drought had a 167% increase in odds of being more concerned about droughts impacting the water supply.
- Freshwater sources (ground and surface water) are the least expensive options. Alternative water sources such as importing, desalination, reuse, and stormwater capture are generally more costly, with the most expensive costing up to three times as much as freshwater sources.

Coalinga is a small city of 17,265 people as of 2021 and located in Fresno County. Coalinga was historically allocated 12 million m^3 of water annually by the California Bureau of Reclamation; however, this was reduced decreased to 2 million m^3 in 2021 following a drought. Coalinga does not receive much rain at 8.25 inches per year, and it varies a few inches between seasons. Coalinga does not have a suitable surface water source and does not use groundwater for potable use due to high sodium sulfate and asbestos concentrations. The recommendations for

Coalinga are to create a tiered water system to encourage conservation; provide incentives for installation of water saving technologies; educate consumers on water use; and explore funding options to supplement water sources.

4.1 Recommendations

The water management recommendations as summarized above for Coalinga are specific to that city. Options for other cities need to consider geographical, hydrological, and economic factors specific to a particular locale. Before a long-term management plan is initiated, the following actions are recommended:

- Funding for projects that promote sustainability and prevent environmental degradation should be found with consideration of climate change's impacts.
- The costs of a potential potable water source, including extraction, treatment, storage, and distribution should be further researched for all sources of water.
- Scale up studies should be conducted for wastewater reuse and desalination treatment plants. This may allow for regional solutions based on economies of scale.

Bibliography

American Land Title Association (1944, Revised 2001); *Land Title Institute: Water Rights and Related Issues.* https://www.alta.org/media/pdf/CH09.pdf (accessed 2023-11-06).

Azaiez, M.*; An Integrated DP-MIP Model for Optimal Crop Mix Selection With Deficit Irrigation. Asia-Pacific Journal of Operational Research [Online]* **2008**, 25 (5) 625-647 (accessed 2024-01-22).

Barton, Dana; *Coalinga Asbestos Mine Review Report 2021 (Fifth Five-Year Review Report) by the U.S. Army Corps of Engineers for U.S. Environmental Protection Agency.* https://semspub.epa.gov/work/09/100025371.pdf (accessed 2023-11-29).

Becker, R.; *Don't Call It "toilet to Tap" - California Plans to Turn Sewage into Drinking Water*. https://calmatters.org/environment/2023/08/california-toilet-to-tap-water/ (accessed 2023-11-17).

Benjamin, M.; *Fresno, Clovis Plan To Mix Recycled Sewer Water For Drinking*. KVPR Valley Public Radio. https://www.kvpr.org/government-politics/2018-07-17/fresno-clovis-plan-to-mix-recycled-sewer-water-for-drinking (accessed 2023-11-13).

BGWG; *Residential Water Rates. Irvine Ranch Water District.* https://www.irwd.com/services/residential-water-rates (accessed 2023-12-09).

Bloetscher, Frederick; Sham, Chi Jo, Danko, Josepj J. III; Ratick, Samuel; *Lessons Learned from Aquifer Storage and Recovery (ASR) Systems in the United States;* Journal of Water Resource and Protection, Vol.6 No.17, 2014 (accessed 2023-11-08).

Bradford, C.; *Catch Basins: What Are They and How Do They Work?* ABT Inc. https://abtdrains.com/catch-basin-what-are-they-and-how-do-they-work/ (accessed 2023-10-10).

Brigan, K.; *State of California*. **2022**. https://www.drought.gov/states/california (accessed 2024-02-25).

California Department of Water Resources; n.d. *SB-X7-7.* https://water.ca.gov/Programs/Water-Use-And-Efficiency/SB-X7-7 (accessed 2023-11-27).

California Land and Ranch; *Water Rights.* http://www.californialandandranch.com/Information/WaterRights (accessed 2023-11-27).

California State Water Resources Control Board; 2014. *The California Water Boards' Annual Performance Report - Fiscal Year 2013-14.*

https://www.waterboards.ca.gov/about_us/performance_report_1314/plan_assess/12515_ww_recycling.shtml (accessed 2023-11-03).

California State Water Resources Control Board; 2018. *Total Maximum Daily Load Program* https://www.waterboards.ca.gov/water_issues/programs/tmdl/background.html (accessed 2023-11-03).

California State Water Resources Control Board; *Water Conservation Portal - Emergency Conservation Regulation.* https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/regs/emergency_regulation.html (accessed 2023-11-12).

California Water Board; *Storm Water Program.* https://www.waterboards.ca.gov/water_issues/programs/stormwater/ (accessed 2023-11-03).

California Water Impact Network; July 2022. *California Almond Water Usage.* https://www.c-win.org/cwin-water-blog/2022/7/11/california-almond-water-usage (accessed 2023-11-03).

California Water Service; *In the News: Long-Term Water-Use Efficiency Standards*. https://www.calwater.com/in-the-news/2018-0611-long-term-water-use-efficiency-standards-bills/ (accessed 2023-11-11).

California Water Service; *Water-Use Restrictions.* https://drought.calwater.com/restrictions (accessed 2023-11-03).

California Water Watch; *Statewide Hydroclimate and Water Supply Conditions.* https://cww.water.ca.gov/regionscale (accessed 2024-02-16).

Casadei, Stefano; Peppoloni, Francesco; Ventura, Flaminia; Teodorescu, Razvan; *Application of Smart Irrigation Systems for Water Conservation in Italian Farms*. Environmental Science and Research International [Online] 2021, 28 (21) 26488-26499 (accessed 2023-10-10).

Chesnutt, T. W.; Pekelney, D.; Spacht, J. M.; *Water Conservation and Efficient Water Rates Produce Lower Water Bills in Los Angeles*. Journal AWWA **2019**, *111* (4), 24–30. https://doi.org/10.1002/awwa.1268. (accessed 2023-12-05).

City of California; n.d. *Mandatory Water Conservation Measures extended and increased effective immediately* https://www.californiacity-ca.gov/CC/index.php/mandatory-water-conservation (accessed 2024-01-17).

City of Coalinga; (2024). *Wastewater Treatment & Collections | Coalinga CA.* www.coalinga.com/225/Wastewater-Treatment-Collections. (accessed 2024-01-20).

City of Coalinga; *2022 Urban Water Management Plan* https://www.coalinga.com/DocumentCenter/View/1245/2020----Urban-Water-Management-Plan-UWMPPDF (accessed 2023-11-14).

Climate Check; *Top California Climate Change Risks: Drought, Fire, Heat*. https://climatecheck.com/california (accessed 2024-02-25).

Cooley, Heather; Phurisamban R; Gleick, Peter; *The Cost of Alternative Urban Water Supply and Efficiency Options in California*. Environ Res Commun. 2019; 1. https://doi.org/10.1088/2515-7620/ab22ca (accessed 2023-12-08).

Cooley, Heather; *Urban and Agricultural Water Use in California, 1960-2015*. Oakland, Calif.: Pacific Institute. (2020). https://pacinst.org/wp-content/uploads/2020/06/PI_Water_Use_Trends_June_2020.pdf (accessed 2024-01-24).

CWC; Agricultural Water Use Efficiency. 2023. CWC; *Water Use in California*. (May 2019). https://cwc.ca.gov/-/media/CWC-Website/Files/Documents/2019/06_June/June2019_Item_12_Attach_2_PPICFactSheets.pdf (accessed 2023-11-11).

CWC; *Agricultural Water Use Efficiency*. 2023. https://water.ca.gov/Programs/Water-Use-And-Efficiency/Agricultural-Water-Use-Efficiency#:~:text=California's%20agricultural%20success%20would%20not,with%201%20foot%20of%20water (accessed 2024-01-23).

Dana Point Times; *Coastal Commission Approves Permit for Doheny Desalination Plant.* https://www.picketfencemedia.com/coastal-commission-approves-permit-for-doheny-desalination-plant/article_a31fca51-8fee-5bcb-839e-3e6e3f096734.html#:~:text=South%20Coast%20Water%20District%20is,million%20project%20on%20Thursday%2C%20Oct. (accessed 2024-02-28).

Diringer, S.E.; Shimabuku, M; Cooley, Heather; (2020) *Economic evaluation of stormwater capture and its multiple benefits in California*. PLoS ONE 15(3): e0230549. https://doi.org/10.1371/journal.pone.0230549 (accessed 2023-12-09).

Dobbin, K. B.; Fencl, A. L.; Pierce, G.; Beresford, M.; Gonzalez, S.; Jepson, W.; *Understanding Perceived Climate Risks to Household Water Supply and Their Implications for Adaptation: Evidence from California - Climatic Change.* https://link.springer.com/article/10.1007/s10584-023-03517-0#citeas (accessed 2024-02-21).

EPA; *Basic Information About Water Reuse.* https://www.epa.gov/waterreuse/basic-information-about-water-reuse#:~:text=Examples%20of%20planned%20reuse%20include,supplies%2C%20and%20groundwater%20supply%20management. (accessed 2023-11-01).

EPA; *Coalinga Asbestos Mine Site Profile.* https://cumulis.epa.gov/supercpad/SiteProfiles/index.cfm?fuseaction=second.cleanup&id=0902075 (accessed 27-2-2024).

EPA; *Ideas for Industry*. https://www.epa.gov/sites/default/files/2017-03/documents/ws-ideas-for-industry.pdf (accessed 2023-11-11).

EPA; *NPDES Stormwater Program.* https://www.epa.gov/npdes/npdes-stormwater-program (accessed 2023-11-11).

EPA; *Urbanization - Wastewater Inputs.* https://www.epa.gov/caddis-vol2/urbanization-wastewater-inputs (accessed 2023-10-10).

European Commission; *Europeans say yes to drinking recycled. wastewater*. https://cordis.europa.eu/article/id/435516-europeans-say-yes-to-drinking-recycled-wastewater (accessed 2023-12-08).

Federal Energy Management Program; *Map for Reclaimed Water.* https://www.energy.gov/femp/reclaimed-wastewater-map (accessed 2023-11-01).

Fencl, A.; Scientist, W. S. S. C.; Director, K. M. A. C.; Mulvey, K.; Director, A. C.; Director, R. C. P.; Cleetus, R.; Director, P.; Scientist, L. D. M. L.; Merner, L. D.; Scientist, L.; *How Do Californians Perceive Climate Risks to Their Household Water Supplies?* Fencl Western States Senior Climate Scientist https://blog.ucsusa.org/amanda-fencl/how-do-californians-perceive-climate-risks-to-household-water-supply/ (accessed 2023-12-08).

Filali, H.; Barsan, N.; Souguir, D.; Nedeff, V.; Tomozei, C.; Hachicha, M.; *Greywater as an Alternative Solution for a Sustainable Management of Water Resources—A Review*. Sustainability 2022, 14 (2), 665. https://doi.org/10.3390/su14020665. (accessed 2023-11-11).

Flavelle, C.; Healy, J.; *Arizona Limits Construction Around Phoenix as Its Water Supply Dwindles*. The New York Times. June 1, 2023. https://www.nytimes.com/2023/06/01/climate/arizona-phoenix-permits-housing-water.html (accessed 2023-11-06).

Goleta Water District; *How Much Water Do I Use?* https://www.goletawater.com/how-much-water-do-i-use/ (accessed 2024-02-26).

Greenlee, Lauren F.; Lawler, Desmond F.; Freeman, Benny D.; *Reverse Osmosis Desalination: Water Sources, Technology, and Today's Challenges* 2009, 43 (9) https://doi.org/10.1016/j.watres.2009.03.010 (accessed 2023-11-14).

Gupta, Naveen; Singh, Yadvinder; S. Jat, Hanuman; K. Singh; *Love Precise Irrigation Water and Nitrogen Management Improve Water and Nitrogen Use Efficiencies Under Conservation*

Agriculture in the Maize-wheat Systems. Scientific Reports [Online] **2023**, 13 (1) (1) https://www.nature.com/articles/s41598-023-38953-6 (accessed 2023-12-08).

Haddad, B.; *The Psychology of Water Reclamation and Reuse: Survey Findings and Research Road Map.* 2009. (accessed 2024-01-19).

Hoover, F.-A.; Hopton, M. E.; *Developing a Framework for Stormwater Management: Leveraging Ancillary Benefits from Urban Greenspace*. Urban Ecosyst 2019, 22 (6), 1139–1148. https://doi.org/10.1007/s11252-019-00890-6 (accessed 2024-02-26).

James, I.; *Thousands of California wells are at risk of drying up despite landmark water law*. Los Angeles Times. https://phys.org/news/2023-09-thousands-california-wells-drying-landmark.html (accessed 2024-02-25).

LADWP; *Water Rate Changes Now in Effect*. https://www.ladwpnews.com/ladwp-water-rate-changes-now-in-effect/ (accessed 2024-01-19).

Liu, Junguo; Yang, Hong; Gosling, N. Simon; et. al; *Water Scarcity Assessments in the Past, Present, and Future. Earth's Future [Online]* **2017**, 5 (6), 545-559 (accessed 2024-11-19).

Lobner, P.; *Status of Desalination Plants in California.* https://lynceans.org/tag/water-replenishment-district/ (accessed 2023-11-27).

Lund, Jay R.; Improving Public Perception of Water Reuse. https://californiawaterblog.com/2019/01/20/improving-public-perception-of-water-reuse/ (accessed 2024-02-26).

Mackie, A.; *California Water History: The Origin of 'Toilet-to-Tap.'* California Water Environment Association. https://www.cwea.org/news/whats-the-origin-of-toilet-to-tap/ (accessed 2023-11-19).

Mora, A.; *New Public Opinion Poll Shows Most County Residents Are Saving Water*. San Diego County Water Authority. https://www.sdcwa.org/new-public-opinion-poll-shows-most-county-residents-are-saving-water/ (accessed 2023-12-06).

MWD*; Securing Our Imported Supplies*. https://www.mwdh2o.com/securing-our-imported-supplies/ (accessed 2023-11-06).

NCEI; County Mapping - Climate at a Glance. https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/county/mapping/4/pcp/202002/12/value (accessed 2023-11-06).

Newton, D.; *Results, challenges, and future approaches to California's municipal water.* (2015, January 1).

https://www.waterboards.ca.gov/water_issues/programs/grants_loans/water_recycling/docs/article.pdf (accessed 2023-12-09).

O'Donnell, D.; *Groundwater vs. Surface Water – What's the Difference?,* Sensorex, 2021, https://sensorex.com/groundwater-vs-surface-water/ (accessed 2023-11-08).

Olivieri, Adam W.; Pecson, Brian; Crook, James; Hultquist; Robert; *Chapter Two - California water reuse—Past, present and future perspectives.* Advancements in Chemical Pollution, Environmental Management and Protection **2020,** 5, 65-111 (accessed 2023-12-02).

Orange County Water District; *How water works in OC.* https://www.ocwd.com/learning-center/how-water-works-in-oc/ (accessed 2023-12-09).

Parker, E. A.; Grant, S. B.; Sahin, A.; Vrugt, J. A.; Brand, M. W.; *Can Smart Stormwater*

Pathiranage, W. B.; Bray, L.; Jones, K.; Redwine, N.; Saralvarez, J.; D'Alessio, M.; *Perception and Acceptance towards Water Reuse in the Southeast United States: A Public Survey.* Science of The Total Environment **2024**, *908*, 168224. https://doi.org/10.1016/j.scitotenv.2023.168224 (accessed 2023-12-06).

Porath, M.; Slembrouck, P. V.; McGhee, G. *Understanding California's Groundwater | Water in the West*. https://waterinthewest.stanford.edu/groundwater/ (accessed 2023-12-08).

Poseidon Water; *Carlsbad Desal Plant*. https://www.poseidonwater.com/carlsbad-desal-plant.html (accessed 2023-11-06).

Public Policy Institute of California; *Floods in California*. https://www.ppic.org/publication/floods-in-california/ (accessed 2024-02-25).

Sacramento Valley Subregion; *Sacramento River Watershed Program*. https://sacriver.org/explore-watersheds/sacramento-valley-subregion/ (accessed 2024-02-21).

San Francisco Public Utility Commission; *Commercial Water Conservation*. https://sfpuc.org/construction-contracts/design-guidelines-standards/commercial-water-conservation (accessed 2023-11-11).

Santa Margarita Water District; *Civic Engage*. https://www.smwd.com/Faq.aspx?QID=96 (accessed 2023-12-09).

SCWS; *Doheny Ocean Desalination Project.* https://www.scwd.org/about/district_projects/doheny_ocean_desalination_project/index.php (accessed 2024-02-28).

SD Department of Public Works; *County of San Diego Waterscape Rebate Program.* https://www.sandiegocounty.gov/content/sdc/dpw/watersheds/RebatesIncentives/RainSaving.html (accessed 2024-02-28).

SD Public Utilities; *Rainwater Harvesting Rebate Program.* https://www.sandiego.gov/sites/default/files/new_gutter_rebate_guidlines_2.pdf (accessed 2024-02-28).

SDCWA Report to Congress on Impacts and Control of Combined Sewer Overflows and Sanitary Sewer Overflows; *Seawater Desalination*. https://www.sdcwa.org/your-water/local-water-supplies/seawater-desalination/ (accessed 2023-11-06).

Smith, L.; *Exploring California's Watershed Areas - IX Power Clean Water*. https://ixwater.com/exploring-californias-watershed-areas (accessed 2024-02-19).

Society, R.; *Is the Climate Warming?* https://royalsociety.org/topics-policy/projects/climate-change-evidence-causes/question-1/#:~:text=Yes.,%2D1970s%20%5BFigure%201a%5D. (accessed 2024-01-24).

Stanford University; *In times of scarcity, California's best new source of water? Reuse*. February 8, 2023. https://andthewest.stanford.edu/2023/in-times-of-scarcity-californias-best-new-source-of-water-reuse/ (accessed 2023-11-15).

State of California: *California Drought Action* 2022. *Statewide emergency water conservation regulations.* https://drought.ca.gov/state-drought-response/statewide-emergency-water-conservation-regulations/ (accessed 2023-11-15).

State of California; *Agricultural Water Use Efficiency.* https://water.ca.gov/Programs/Water-Use-And-Efficiency/Agricultural-Water-Use-Efficiency (accessed 2023-11-12).

State of California; *California Invests in Desalination Projects and Research to Help Diversify Local Water Supplies for Communities.* https://water.ca.gov/News/News-Releases/2023/April-23/California-Invests-in-Water-Supply-and-Research-to-Diversify-Local-Water-Supply (accessed 2023-11-06).

State of California; *California's Water Supply Strategy.* 2023. https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Water-Resilience/CA_Water_Supply_Strategy_Progress_Report_2023.pdf (accessed 2023-11-06).

State of California; *Flood*. https://water.ca.gov/Water-Basics/Flood (accessed 2024-02-25).

State of California*; Governor Newsom Issues Executive Order to Use Floodwater to Recharge and Store Groundwater*. https://www.gov.ca.gov/2023/03/10/governor-newsom-issues-executive-order-to-use-floodwater-to-recharge-and-store-groundwater/ (accessed 2023-11-17).

State of California; *The California Water System*. https://water.ca.gov/Water-Basics/The-California-Water-System (accessed 2024-01-25).

State Water Resources Control Board; *Investigation on the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse – Report to the Legislature.* https://www.waterboards.ca.gov/waterrights/ (accessed 2024-01-14).

Systems Outsmart the Weather? Stormwater Capture with Real-Time Control in SouthernCalifornia. ACS EST Water **2022**, *2* (1), https://doi.org/10.1021/acsestwater.1c00173 (accessed 2023-11-09).

Tibbetts, J; *Combined Sewer Systems: Down, Dirty, and Out of Date. Environ Health Perspec*t. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1257666/ (accessed 2023-12-01).

Tidwell, Vincent; *Mapping Water Availability, Cost and Projected Consumptive Use in the Eastern United States with Comparisons to the West*. **2018**, *13* (1), 014023–014023. https://doi.org/10.1088/1748-9326/aa9907 (accessed 2024-02-25).

Tobin, M; *Recycled Water Public Opinion Polling.* https://waterpolls.org/recycled-water-public-opinion/ (accessed 2023-12-06).

U.S. Census Bureau; *Coalinga City California.* https://www.census.gov/quickfacts/fact/table/coalingacitycalifornia/PST045223 (accessed 2024-2-15).

U.S. Climate Data; *Weather Averages Coalinga, California.* https://www.usclimatedata.com/climate/coalinga/california/united-states/usca0235 (accessed 2024-02-28).

US EPA; *2022 Bipartisan Infrastructure Law Clean Water and Drinking Water State Revolving Funds (SRFs)*. https://www.epa.gov/infrastructure/2022-bipartisan-infrastructure-law-clean-water-and-drinking-water-state-revolving (accessed 2024-02-27).

US EPA; *Aquifer Recharge and Aquifer Storage and Recovery*. https://www.epa.gov/uic/aquifer-recharge-and-aquifer-storage-and-recovery (accessed 2023-10-10).

US EPA; *Information about Public Water Systems*. https://www.epa.gov/dwreginfo/information-about-public-water-systems (accessed 2023-11-11).

US EPA; *San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan).* https://www.epa.gov/sites/default/files/2014-12/documents/ca2-sanfrancisco-basin.pdf (accessed 2024-01-14).

US EPA; *The Water Infrastructure Improvements for the Nation Act (WIIN Act) Grant Programs*. https://www.epa.gov/dwcapacity/water-infrastructure-improvements-nation-act-wiin-act-grant-programs (accessed 2024-02-27).

US EPA; *Water Systems.* https://sdwis.epa.gov/ords/sfdw_pub/r/sfdw/sdwis_fed_reports_public/103 (accessed 2023-11-11).

US EPA; *What causes a sinkhole?* https://www.dep.pa.gov:443/Citizens/My-Water/Sinkholes/Pages/What-causes-a-sinkhole.aspx (accessed 2023-10-10).

USGS; (2018, June 19), *California Water Use.* https://www.usgs.gov/centers/california-water-science-center/science/california-water-use#overview (accessed 2023-12-11).

USGS; *Domestic Water Resources.* https://www.usgs.gov/mission-areas/water-resources/science/domestic-water-use?qt-science_center_objects=0#qt-science_center_objects (accessed 2021-10-01).

USGS; *Industrial Water Use.* https://www.usgs.gov/mission-areas/water-resources/science/industrial-water-use?qt-science_center_objects=0#qt-science_center_objects (accessed 2021-10-01).

USGS; *Irrigation Water Use.* https://www.usgs.gov/mission-areas/water-resources/science/irrigation-water-use?qt-science_center_objects=0#qt-science_center_objects (accessed 2021-10-01).

USGS; *Public Supply Water Use.* https://www.usgs.gov/mission-areas/water-resources/science/public-supply-water-use?qt-science_center_objects=0#qt-science_center_objects (accessed 2021-10-01).

USGS; *Sinkholes.* https://www.usgs.gov/special-topics/water-science-school/science/sinkholes#overview (accessed 2023-10-10).

USGS; *Thermoelectric Power.* https://www.usgs.gov/mission-areas/water-resources/science/thermoelectric-power-water-use?qt-science_center_objects=0#qt-science_center_objects (accessed 2021-10-01).

USGS; *Trends in Water Use in the United States, 1950 to 2015*. https://www.usgs.gov/special-topics/water-science-school/science/trends-water-use-united-states-1950-2015 (accessed 2023-11-01).

Warddrip, L; Perreira, G; Kihara, A; Maguire, S; *Storm Water Management in California.* https://risksafety.humboldt.edu/sites/default/files/risksafety/stormwater_factsheet%20%281%29.pdf (accessed 2023-11-03).

Water Education Foundation; *California Water 101*. https://www.watereducation.org/photo-gallery/california-water-101 (accessed 2023-11-06).

Water Education Foundation; *Layperson's Guide to Water Rights Law*: *Water Rights in California*. https://www.watereducation.org/aquapedia/water-rights-california (accessed 2023-12-10).

Water Education Foundation; *Riparian Rights*. https://www.watereducation.org/aquapedia/riparian-rights (accessed 2023-12-10).

Water Education Foundation; *State Water Project*. https://www.watereducation.org/aquapedia/state-water-project (accessed 2024-01-25).

Watereuse Association; *Stormwater Reuse*. https://watereuse.org/educate/types-of-reuse/stormwater-reuse/ (accessed 2024-02-28).

Watereuse Association; *WateReuse Association Congratulates Orange County on Completing the World's Largest Water Recycling Facility*. https://watereuse.org/orange-county-completes-largest-water-recycling-facility/ (accessed 2023-10-10).

Watereuse; *Transforming Water, Sustaining Our Future*. https://watereuse.org/ (accessed 2023-11-27).

Wisevoter; *Water Prices by State 2023*. https://wisevoter.com/state-rankings/water-prices-by-state/ (accessed 2023-11-06).

World Bank Group; *What you need to know about climate Co-Benefits*. (2021, September 16) https://www.worldbank.org/en/news/feature/2021/03/10/what-you-need-to-know-about-climate-co-benefits (accessed 2024-01-15).

Zhang, Heng; *A Review of the Manages Aquifer Recharge: Historical Development, Current Situation and Perspectives, Physics and Chemistry of the Earth, Parts A/B/C*. (October 2020). https://www.sciencedirect.com/science/article/pii/S1474706519300269 (accessed 2024-01-15).