Will the West Have Water?

A Multidimensional Framework for Collaborative and Integrated Water Management

By

Judith Abigail Garman

University of Colorado Boulder

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Thesis committee

Nancy Billica, Department of Political Science, Thesis Advisor
Kyungsun Lee, Department of Environmental Studies, Honors Council representative
David Ciplet, Department of Environmental Studies, Outside Reader

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Abstract

The question of water availability in the American West, and specifically Southern California, is becoming increasingly important as the population continues to grow while water is being used unsustainably. Moreover, the hydraulic impacts from climate change will only put further pressure on this complex system of water users and needs. Therefore, this thesis seeks to answer the question of what kind of considerations go into decision making around water management, and how can those considerations be used in a framework that facilitates collaborative and integrated resource management? It was revealed through a cross-comparative analysis of options, coupled with interviews with stakeholders in Ventura County, that there are a multitude of complex considerations that should be included into water management decisions. Yet, historically these considerations have not been fully investigated and incorporated into decision making, leading to the water crisis the West faces today. Ultimately, the evaluative framework weighing all the different options based on a set of relative criteria highlighted the impact and importance of including those considerations into the analysis of solutions. Moreover, the case study stakeholder analysis revealed further complexities that should be considered in relation to different individuals' priorities, needs, and values. These considerations should be built into decision making through engaging and collaborating with the stakeholders throughout the planning process to overcome the tensions that persist. To do this, stakeholder collaborations should use the evaluative framework created in this thesis to rank their preferences across the set of criteria and options. This thesis concludes that ultimately there is no one size fits all approach, and in order to achieve sustainable and equitable water use in the American West we must integrate our considerations of planning across resources, between users, and in relation to future changes.

Introduction

As climate change continues to transform our environment, and as humans continue to extract its resources, the issue of water use and accessibility will present itself as a major challenge that society must overcome in the next decade. If there is any hope in sustaining large populations in the American West, this issue must be addressed and corrected to support the people who call this region home. With large aquifers and reservoirs quickly depleting due to drought and overuse, it is paramount that this challenge is solved immediately. Even though California has experienced a very wet year this year, we cannot expect the rain to come just in time every time, and even when rain comes it is still not enough.

While there may be many different approaches to solving the water crisis, there must be an understanding of the three main problems that arise from this issue that must be addressed: supply, demand, and distribution. Currently, water demands are near exceeding supply as water is being inefficiently used and as groundwater is being overdrafted. Moreover, the water supply is dwindling due to this overuse, coupled with decades long drought conditions leaving lake beds dry and rivers depleted. Furthermore, these two dimensions exacerbate water scarcity challenges for disadvantaged communities in accessing a fair distribution of freshwater resources. While weighing all of these challenges when trying to create solutions can be daunting, this paper aims to break solutions down to understand the impacts and trade-offs between different options.

First, there are areas in which water is being unsustainably used, where actions must be targeted toward conservation and using this supply more efficiently. We must start with this side of the equation so that there is a more sustainable framework in place for water usage in the future. Most laws and practices relating to water usage are outdated and need to be restructured to fit our present conditions and future predictions.

Yet, even with more sustainable practices it will still be difficult to serve the needs of the population in the future without increasing the water supply. Therefore, this project will explore the feasibility of innovative water supply projects, such as solar desalination or recycling water, in comparison with traditional water supply projects. By examining the costs, logistics, trade-offs, and impacts from these projects it can allow decision makers and the private sector to understand the prospect of implementing these projects.

The final consideration that must be addressed is that of equity. With millions of Americans currently lacking access to reliable clean water, this plan must include a safeguard for these populations to ensure they have adequate fresh water. Water access is closely tied with race and wealth, especially affecting Native American communities. Moreover, expanding access to reliable clean water is closely tied with community development because of its impact on long term health and quality of life (Roller, 2019). Therefore, these communities must be placed at the forefront of decisions relating to water use and accessibility. Due to this important dimension of the problem, all of the aforementioned solutions will be weighted based on their equitable impacts.

Finally, there must be a discussion around the political feasibility of these ideas by examining legislation proposed by policy makers, views of relevant stakeholders, and understanding the various bureaucratic or political roadblocks. By interviewing these stakeholders, this analysis can provide an in depth look into the tensions around these options and how these changes would positively or negatively impact them. Furthermore, it is crucial that the realities of our political system are understood within this framework in order to minimize the challenges for implementation.

This study will first conduct a literature review focused on the historical background of these problems, where we are today, and future predictions. In addition, it will compare the impacts from new policies or deployment of new projects to address water concerns across a set of relevant evaluative criteria. Moreover, this study will make use of interviews with real stakeholders in the relevant fields of water management, engineering experts, farmers, and community representatives. This will allow more in-depth insight and evaluation into how feasible different options for addressing water concerns are, and the potential impacts they might have. In addition, this analysis of stakeholder views will help identify gaps in knowledge or trade-offs in the concerns of different stakeholders. As the goal of this study is to identify solutions that provide the greatest benefits to the population, the views and concerns of all stakeholders must be considered in this analysis.

The guiding research question behind this study is; what kind of considerations go into decision making around water management, and how can those considerations be used in a framework that facilitates collaborative and integrated resource management? The goal of this thesis project is to create a working framework for how we can sustainably and equitably meet the needs of Southern California's water demands now and in the future. This project is aimed at creating an evaluative framework that decision makers can use to understand the pros and cons of different approaches to solving the water crisis across a variety of factors. Without a comprehensive plan for how we will address these challenges that takes into account the multidimensional nature of the problem, it will be impossible to meet the demands of a growing population in the American west. Therefore, this analysis is crucial for answering the ever-pressing question: Will the West have water?

Background

History of Water in the West:

Before assigning blame or creating solutions to the problem, we must first look at the history of the region to understand why the American West is facing this water crisis in the first place. First and foremost, water rights look very different in the western half of the U.S. due to the history of this region. As settlers moved west, claiming territories for their own, this also came with the water attached to that land. This process of prior appropriation was based on a practice of “first in time, first in right”, creating a scheme of senior and junior water users (Lustgarten, 2015). This system of upstream and downstream users, where in most cases those who have senior rights or are upstream users have priority for using and diverting water. Moreover, these water rights came with “use it or lose it” laws to protect against hoarding water. However, today this law translates into farmers and ranches using more water than they really need because if they do not use their full allotment they could lose it (Lustgarten, 2015). This process not only applied to the settlers of this region, but also to the newly formed states themselves.

The primary watershed in the American West is the Colorado River, serving millions of people in 7 states and Mexico. This waterway was appropriated to the basin states through the 1922 Colorado Compact, which promised upper basin states (Colorado, Utah, Wyoming, and New Mexico) 7.5 million acre-feet per year, and 8.5 million acre-feet to lower basin states (Ariziona, California, and Nevada) (USBR, 1922). While this water is a vital resource for the people who call this region home, the river has been slowly drying up due to the past century of overuse and drought. However, this problem can partly be traced back to the conception of the Colorado Compact in 1922, when an abnormally wet year threw off water allocations. The original allocation estimated 18 million acre-feet of water per year, dividing 15 million acre-feet between the 7 basin states, yet the following decades would reveal that sometimes only as little as 12 million acre-feet would flow through the basin (Lustgarten, 2015). The faulty estimation is further exacerbated by the fact that many tribal nations were left out of the original compact, or lacked resources to receive their full allotment (Sanchez, et.al., 2020). While thankfully many tribes are adjudicating their rights or building out infrastructure to access water for their communities, this puts further pressure on the water demand of the river (Roller, et. al, 2019).

Population Growth in California:

Now, turning to the state with the largest water use and population in the nation, California. The state alone accounts for 9% of the total water withdrawals in the US, primarily being used for irrigation (USGS, 2018). The necessity to store and move water was realized early in California's statehood with the formation of reclamation districts and infrastructure projects. As California's population boomed throughout the 20th century, bigger projects were required to move water hundreds of miles to the population centers that needed it. Aquifers were built, lakes were drained, and rivers were dammed, all to support the rapid population growth and subsequent economic growth in the Californian oasis (C-WIN, 2017) .

The two primary water conveyance systems in California are the California State Water Project (SWP) and the Federal Central Valley Project, primarily moving water from north to south. The SWP, "is one of the world's largest water, power, and conveyance systems supplying water to more than 27 million people and 750,000 acres of farmland."(Water.ca.gov). However, these projects were approved by the legislature in 1959, meaning they have junior water rights to senior users in the Northern California watershed. This has ultimately led to the State Water

Project failing to meet the water demands of Southern California without the ability to divert their full allotment. This misallocation of water came to a head following a severe drought in 1994, where SWP contractors met in secret to discuss water issues. The tension was brought on in part by farmers and agricultural contractors losing out on their share of water during the drought, as water was prioritized for municipal use. In addition, water managers needed to address issues around the endangered species ranking of the Delta Smelt as ‘threatened’. The outcome of this meeting was the Monterey Amendment, which eliminated the urban preference, creating more tension by appeasing agricultural users yet potentially hurting urban communities. However, issues over misallocation and drought have only continued to worsen over the past few decades. Today, there is only around 29 million acre-feet of available water in the Delta, yet 153.7 million acre-feet of water rights entitlements for that water (C-WIN, 2017).

The history of water in the West is clearly a convoluted system of various users, relying on a gross overallocation of water, living in an already dry, arid climate. On top of this, the tensions between different water users, such as agricultural vs municipal and water managers vs environmental groups, only add more dimensions to the problem. While the West, and particularly Southern California, is already experiencing a serious water crisis, the next 100 years of climate change impacts will only exacerbate this fragile system.

Climate Change’s Future Impact on Water:

Globally, climate change is expected to make wet seasons wetter and dry seasons drier, while also increasing the seasonal variability, impacting the frequency and severity of precipitation (IPCC, 2021). This is due to the increased radiative forcing caused by increasing greenhouse gasses in the atmosphere. This radiative forcing often translates into higher temperatures, causing more evaporation, increasing the H_2O in the atmosphere, thus causing more precipitation (IPCC, 2021). Moreover, changing atmospheric circulation patterns are impacting the regional and seasonal distribution of precipitation around the globe.

While some regions are experiencing increased average precipitation, other regions such as the Western US are experiencing increased drying. Already dry regions such as the Western US are not likely to see a major change in their precipitation due to the fact that they already experience low-precipitation and an uneven distribution (Konapala et.al., 2020). This is expected to worsen as evaporation and evapotranspiration increase, subsequently drying up surface water and soil moisture (IPCC, 2021). Although precipitation patterns are more varied across different regions, average yearly evaporation is expected to increase everywhere, impacting the global spatio-temporal distribution of water (Konapala et.al., 2020).

Moreover, due to the fact that Southern California relies heavily on snowmelt from the Sierras for water during the spring and summer, climatic impacts on alpine regions must be understood to make future predictions for water use. It is very likely that mountain glaciers will decline in all regions, and thus the average snow water equivalent (SWE) from snowmelt will decrease as well due to less snow cover overtime. However, in the shorter term there is a risk for increased flooding in these regions due to warmer temperatures increasing snowmelt earlier in the year (IPCC, 2021). It is expected that in California's central valley, the seasonal peak flow will occur in January or February as opposed to when peak streamflow occurred in May 40 years ago (Liu, et.a., 2021). It is expected that snowpack in the southern Sierras is estimated to decrease by 70% by the end of this century. This is not only due to the increased radiative forcing interplaying with the hydrological cycle outlined above, but also due to albedo feedback loops absorbing sunlight as opposed to reflecting it, further increasing temperatures (Liu, et.a., 2021). This earlier snowmelt, coupled with hotter, dryer summers leads us to major questions for summer water availability in the future.

Current Situation in California:

Faced with the reality of the future water availability in California, and the greater American West, California and other basin states are reevaluating their water use allocations for the Colorado river. However, this process is proving to be a lengthy adjudication battle between users, with California fighting to maintain the largest share (Flavelle, 2023). Outside of that, California is taking steps to “make conservation a way of life” by implementing water use efficiency standards, encouraging new water supply projects, and requiring overdrafted groundwater basins to develop sustainability plans (CA Water Dept, 2022). The California department of water resources reports that the total volume of water used by all users in California ranges from 60 to 90 million acre-feet per year. Using climate change predictions they estimate a potential loss of 10%, equivalent to 6 million acre-feet lost from the water supply (CA Water Dept, 2022). In order to offset this loss, the state is implementing a water supply strategy that uses a broad portfolio of options with four main goals. These include: maintaining and diversifying water supplies, protecting and enhancing natural ecosystems, building connections for physical infrastructure and data management, and being prepared for changing climatic conditions (CA Water Dept, 2022).

Starting on the supply side, recycled water currently supplies 9% of the state’s water, with a current output of 728,000 acre-feet per year, with projects underway to supply an additional 124,000 acre-feet (CA Water Dept, 2022). However, this is still far from their goal of sourcing 1.8 million acre-feet of water from recycling in 2040, which would require an investment of $27 billion to carry out. Next, seawater and brackish desalination is the other major source of supply increases. Currently, there are 14 seawater desalination plants that supply 89,000 acre-feet per year, in addition to 23 brackish groundwater desalination plants that supply 139,627 acre-feet of water per year. Although these projects come with additional environmental regulations and high costs, the Department of Water Resources is working to facilitate research and development for new innovative technologies, proposing that, "As California becomes hotter and drier, we must become more resourceful with the strategic opportunity that 840 miles of ocean coastline offer to build water resilience."(CA Water Dept, 2022).

In order to reduce the demand for water, California is working toward achieving the new efficiency standards adopted by the legislature in 2018. It is predicted that these new standards could save 450,000 acre-feet of water per year by 2030, enough to support 1.35 million homes (CA Water Dept, 2022). These efficiency improvements would allow for long term progress so that water demand does not continue rapidly increasing in relation to population growth. A major component of this strategy is incentives to convert outdoor landscaping to be more drought resistant and require less water. They estimate that removing 500 million square feet (equivalent to 18 square miles) of grass would save 66,000 acre-feet of water per year (CA Water Dept, 2022). In addition, the State Water Board is working to create efficiency conservation reduction targets for each retail water supplier based on their unique supply and demand conditions.

Moreover, the state is also working in accordance with agricultural users to adopt more drought resilient practices and implement the Sustainable Groundwater Management Act (SGMA). It is estimated that the eight million acres of irrigated farmland in California will likely decrease by 500,000 to one million acres in the coming decades in order to achieve a sustainable level of groundwater use. These efficiency improvements include changing crop patterns, fallowing fields, continuing existing conservation practices, and supporting flexible land use changes (CA Water Dept, 2022).

In addition to improving the supply and demand of water, the state is working to expand storage capacity to improve water capture during wet seasons. Although recognizing that expanding storage alone does not bring more water, it does allow them to take advantage of water resources when it does come and recharge groundwater basins for dry seasons. The state has appropriated $350 million for groundwater recharge projects that have the potential to store an additional 2.2 million acre-feet of water during a wet year, with an average annual storage of around 500,000 acre-feet (CA Water Dept, 2022). The California State Department of Water Resources will provide assistance to local agencies to carry out these projects.

The final major step of California's water supply strategy is to improve the management of water systems. First and foremost, the plan includes an improvement of future predictions using climate change data (CA Water Dept, 2022). This section is specifically targeted toward updating snowmelt forecasting models for the Sierras, which as previously mentioned in the climate change section, the Sierras will likely experience less snowfall on average in the coming decades. As the Sierras contribute to around a third of the water supply in California, long term forecasts need to be incorporated into planning considerations. Next, the department of water resources is working to update aging infrastructure to be more resilient, efficient, and well connected. This would allow for better transport of water and coordination between conveyance systems, as well as protecting the system from failures during natural disasters (CA Water Dept, 2022)

The last piece of the puzzle is to modernize the water rights administration to reflect the conditions of modern day water challenges. In order to meet these challenges, the State Water

Board is working to improve accurate data and increase their ability to control water diversions during droughts (CA Water Dept, 2022). First, they are investing 30 million dollars into improving the state's water rights data management system to keep better track of water right allocations. Moreover, they are working to adopt new regulations that would allow them to control water allocations even in years when there is not a declared drought emergency situation so that ongoing efficiency improvements can be made.

All of this comes with the recognition of water affordability in lower income households and communities. Clearly large investments are required to implement these major projects over the next few decades, on top of rate increases from retail water providers due to increased conservation, putting the question of water affordability at the forefront of equity considerations. The state is working to identify programs for funding or abatements for low income communities to aid in this transition (CA Water Dept, 2022).

Although this issue is a statewide and regional issue, every community has its own unique conditions that must be understood in order to create solutions that satisfy that specific community's needs. While the State Water Board has created an overall water supply strategy plan, it relies on the implementation of solutions at the local level. A deeper understanding of all of the community level dynamics between relevant stakeholders, and the challenges they face, is vital for interpreting how California's water management goals will be realized. Therefore, this thesis will use Ventura County as a specific community level case study for water management in Southern California.

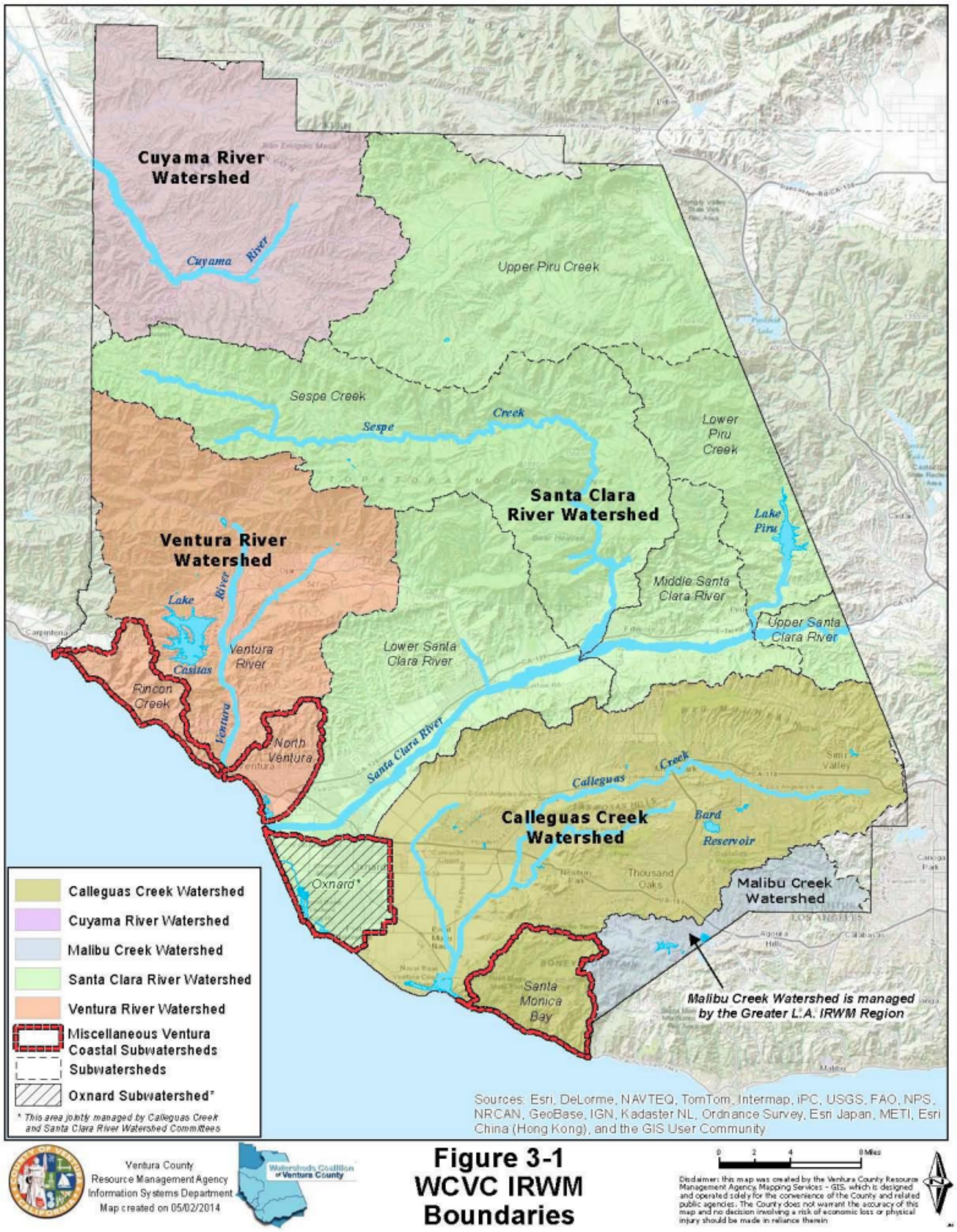
The Case of Ventura County:

Ventura County is home to over 800,000 people, located northwest of Los Angeles County and southeast of Santa Barbara County. The region is made up of 42 miles of coastline, over 500,000 acres of national forest land, 4 main urban population centers, 259,000 acres of agricultural land, and a Naval base (Watershed Coalition, 2019). The wide variety of land use and various different stakeholders involved, coupled with the geographic location of the county makes it a perfect case study for water resource management policy options in Southern California.

Ventura County gets its water from surface watersheds, local groundwater basins, as well as access to imported state water and recycled wastewater facilities. The three main watersheds in Ventura include Calleguas Creek, Ventura River, and the Santa Clara River. Spanning Los Angeles and Ventura County, the Santa Clara River is one of the last natural rivers in Southern California (Watershed Coalition, 2019). Although the vast majority of the county's water is sourced from groundwater, 63.2%, they also receive 25% from imported water delivered through the SWP, as well as 8.2% from surface water and 3.5% from recycled water. Agricultural users utilize the largest share of groundwater while municipal and industrial users primarily receive imported water. Similar to most groundwater basins in the state, pumping is currently exceeding a sustainable yield and needs to be corrected in accordance with the Sustainable Groundwater Management Act (Watershed Coalition, 2019).

Given the unique conditions of the county in relation to climate change, three major issues arise as being the highest priority. First, due to the importance of agriculture in the county, the impacts from rising temperatures and water shortages in addition to the need for sustainable groundwater extraction, requires the necessity to prepare for the impact on the industry. Next, there is a consideration for the impact of sea level rise on coastal communities and saltwater intrusion into coastal groundwater basins. Finally, there is an acknowledgement to the impact of decreased surface stream flows on fish and wildlife ecosystems (Watershed Coalition, 2019). Taken altogether with the goals and objectives outlined by the State of California in their Water Supply Strategy, Ventura County has some major challenges that must be addressed and overcome.

Figure 1: Map of Ventura County Watershed Regions



“2019 Integrated Regional Water Management Plan, Section 3.0 - Region Description” *Watersheds Coalition of Ventura County.* https://watershedscoalition.org/2019-irwm-plans/.

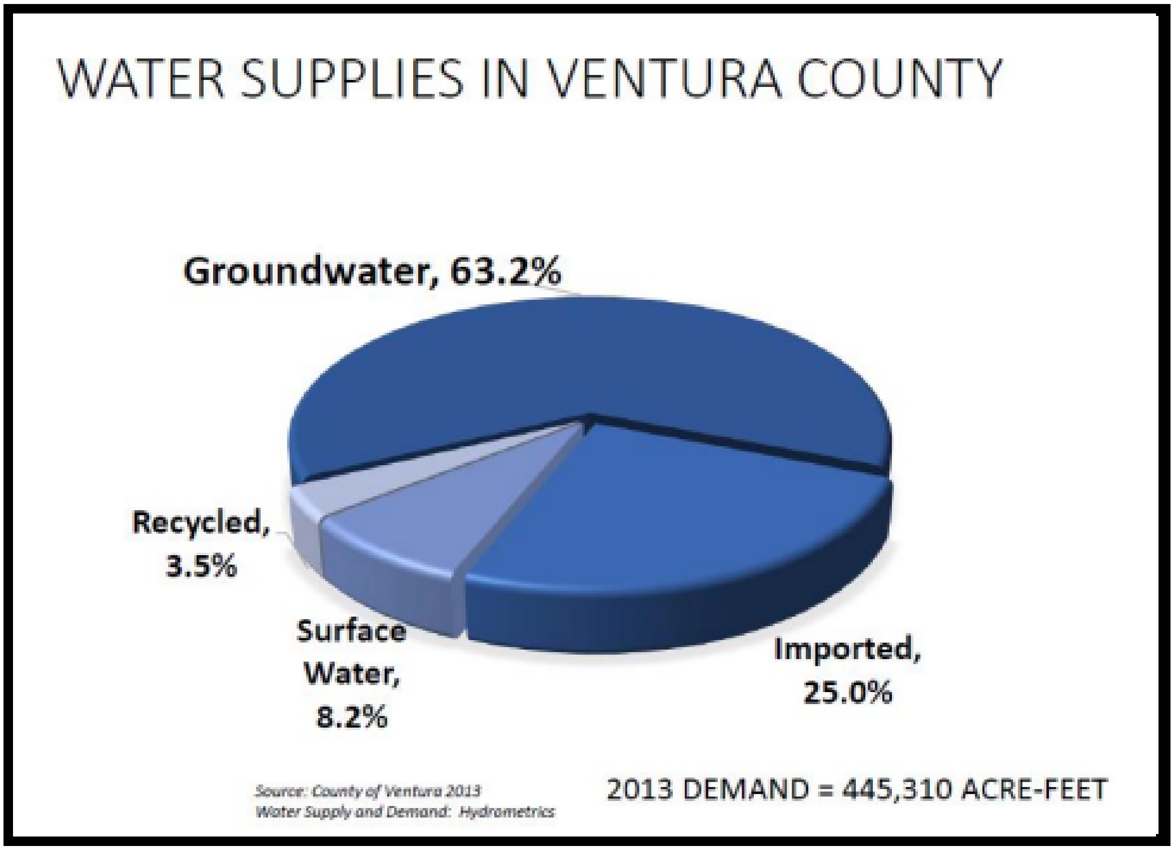
Map of surface waterways and watersheds in Ventura County to show what kind of water resources are available to them.

Figure 2: Map of Land Use Types in Ventura County

“2019 Integrated Regional Water Management Plan, Section 3.0 - Region Description” *Watersheds Coalition of Ventura County.* https://watershedscoalition.org/2019-irwm-plans/.

Map breaking down all the different land use types in Ventura county to show the spread and geographic location of stakeholders involved.

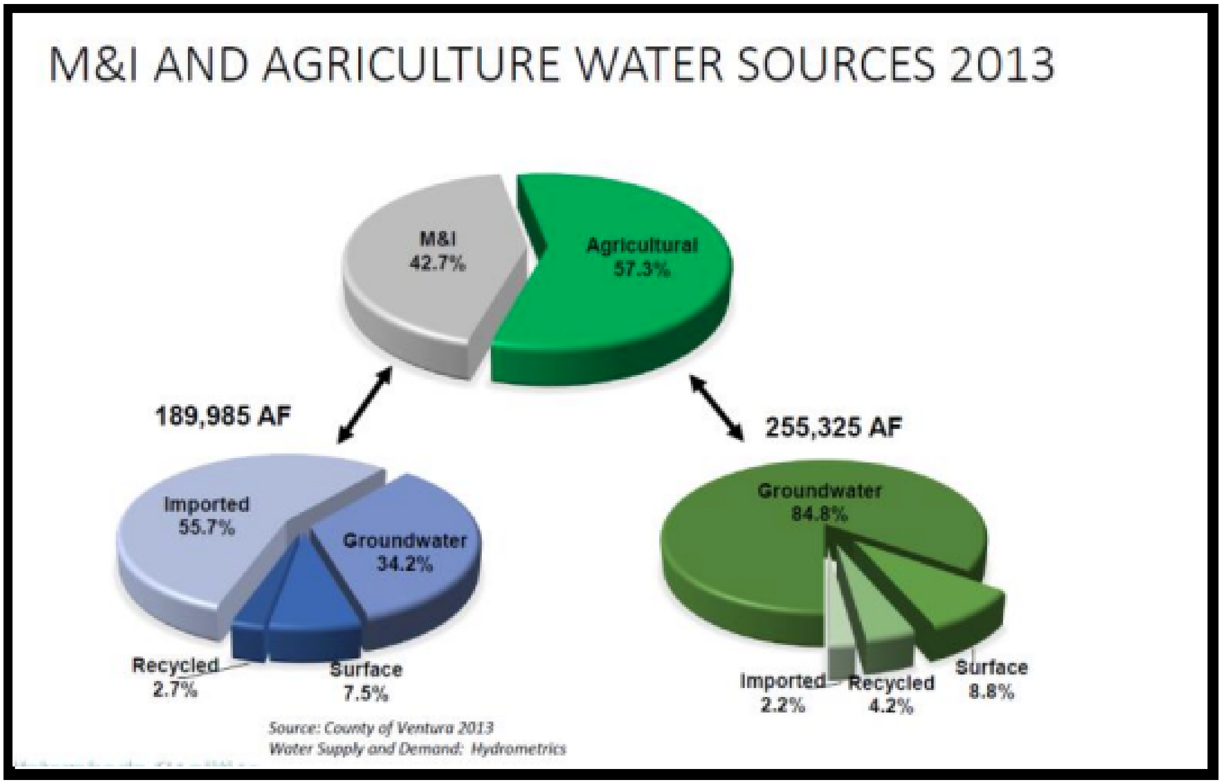
Figure 3: Share of Water Supplies in Ventura County by Source



"2019 Integrated Regional Water Management Plan, Section 3.0 - Region Description" *Watersheds Coalition of Ventura County.* https://watershedscoalition.org/2019-irwm-plans/.

Pie chart displaying where Ventura County primarily sources their water from as a percentage of the total water use.

Figure 4: Share of Water Use Between Agriculture and Municipal & Industrial by Source



“2019 Integrated Regional Water Management Plan, Section 3.0 - Region Description” *Watersheds Coalition of Ventura County.* https://watershedscoalition.org/2019-irwm-plans/.

Further breaking down figure 3 to show how much water is used in agriculture vs municipal and industrial, as well as where the different users source their water from.

Methods

This thesis used a mixed method approach, utilizing information found from the literature review for analysis of available options, coupled with semi-structured interviews with real stakeholders. These two sources of information are then used to develop the comparative framework to evaluate different options using a multi-attribute utility theory (MAUT) approach to compare across a set of criteria. This approach allowed for a high-level analysis of the problem at hand and the various options being considered, then used information acquired through interviews to apply the situation to a specific case study. Taken together, the mixed-method approach provided a more in depth perspective and analysis of all the complexities and tensions involved in solving the water crisis than can be achieved using the evaluative framework alone.

The literature review conducted for this thesis focused on understanding the interplay between the climate and population in the west over the past 150 years. Beginning with this broad historical overview of the region allowed for better interpretation of why they are experiencing the water challenges they are today. In addition, this section provides justification for intervention by outlining the current crisis Southern California faces today. Literature for this section was found using University of Colorado's library database, as well as peer-reviewed literature found through Google scholar and reliable news sources. This thesis utilized an evaluation of available solutions, starting with their respective definitions and justification.

Outline of Options and Criteria:

The list of solutions was compiled based on the literature review of case studies from Ventura County, the Southern California region, and other arid regions around the world. Using the knowledge gained from proposed and existing plans, best practices, and public opinion, the following list of options was produced. The available options respond to both the supply and demand challenges, for both agricultural and municipal water users, breaking down each category of solutions. While some options such as re-evaluating water rights was mentioned in the literature, it is not being evaluated here due to the high difficulty of implementation. Thus, this process yielded the following options:

- Ways to Decrease Demand
  - Agriculture Techniques
    - Irrigation
    - Drought Resistant crops
    - Fallow fields
    - Field Management
  - Municipal Solutions
    - zero-scaping
    - Efficient appliances
    - Household greywater reuse
    - Rainwater harvesting
- Ways to Increase Supply
  - Water Transfers
  - Capture and Storage
  - Recycled Water
  - Desalination

Once the best available options are identified, an evaluative framework must be determined based on the most important criteria needed for educated decision making. This list of criteria was compiled both from the literature review and from the views of relevant stakeholders, elaborated further below. This review established the following list of criteria:

- Cost-Effectiveness
- Efficacy
- Feasibility
- Equity/Fairness
- Environmental Impact

First and foremost, the cost-effectiveness or a cost-benefit analysis is a core element of any policy decision, as many projects require high investments that often require securing federal or state funding to implement. Next, efficacy refers to the actual impact on the water supply through conservation from demand management or through supply increases. Following this, another major consideration is that of feasibility, which broadly includes both political and technical feasibility. This is, of course, a primary factor for decision makers to know how realistic a plan is before committing funding toward implementation. These options must also consider how equitable their impacts are on certain communities so that further inequities do not persist when pushing forward with new plans. Finally, it is important to also evaluate the potential negative environmental impacts or co-benefits that these options may cause.

After the options and criteria are established, this thesis applied these approaches to a real scenario using Ventura County as a case study. Due to the fact that California's water resilience goals require implementation on the regional and community level, it is important to interpret what that actually looks like in reality. Therefore, a major component of this thesis is focused on a stakeholder analysis using information from interviews with different relevant stakeholders to understand the unique conditions and challenges in Ventura County.

Semi-Structured Interviews:

The investigator conducted interviews with state water managers, farmers, community organizations, and water providers from Ventura County. Participants were identified through an internet search of relevant agencies and organizations, as well as recommendations from existing interviewees. Interviews were conducted on Zoom or over the phone and lasted around an hour. Given consent of the interviewee, interviews are recorded to allow for analysis following the interviews. This study interviewed 6 people to present varied viewpoints.

Questions:

Questions were presented to interviewees prior to the meeting to ensure transparency and consent. There was a set of general questions for all participants, as well as a set of specific questions for each of the groups (state water managers, farmers, community members, water providers). These questions were aimed at understanding not only their specific knowledge and experience in their field, but also their personal anecdotes and opinions, in order to gather an understanding of the discourse around these issues and solutions. These questions are necessary for understanding the issue on a deeper level than what could be found by a literature review, by gaining first-hand knowledge from the experiences of stakeholders. A full list of questions can be found in the appendix.

Analysis:

The investigator will use the information gathered from interviews to create the evaluative framework to answer the research question of the kind of considerations that go into water management, and to understand how different groups view solutions to the water crisis. It was expected that different stakeholders view solutions differently based on their personal interests, goals, and experiences. These differing views are compared using the evaluative framework so that decision makers have an easier way of weighing the tradeoffs between options.

Cross-Comparison Framework Scoring:

This thesis used a cross-comparison framework to evaluate the various solutions and their tradeoffs. The available options form the vertical axis of the matrix, and the criteria form the horizontal axis. Some criteria, such as feasibility, are displayed qualitatively while others, such as efficacy, are displayed quantitatively. Information for this evaluation, especially regarding the qualitative elements, was gathered from interviews with stakeholders.

Although many of these criteria deal with qualitative elements, this thesis seeks to standardize these estimates based on their relative impacts. As decision makers often focus primarily on hard data and numbers, it is important to actually include these qualitative evaluations into the decision making framework to ensure they are getting a general understanding of the whole picture.

In order to standardize the qualitative and quantitative criteria results to easily cross-compare between options, this thesis used a multi-criteria decision analysis that utilizes the multi-attribute utility theory (MAUT) (Linkov, et.a., 2006). This process uses a numerical scale (0.1-1.0) to quantify the relative value attributed to the option. These scores were first identified at the individual level, then aggregated across the rows of the matrix. This process resulted in the following evaluative framework that can be used to compare options based on a range of criteria that inherently incorporates the views of relevant stakeholders into decision making.

The cost is evaluated based on the relative estimates found through the literature review and interview findings on a scale from low to high, translating into MAUT scores from low to high quantitatively. Next, efficacy is evaluated based on how much water is being saved or added as opposed to doing nothing, where a higher amount of water being gained translates into a higher score. Following this, the category of equity is evaluated based on the added costs applied to individuals or the percent of disadvantaged populations impacted, coupled with the potential for assistance and incorporation in decision making. In this case, an option that puts a fair amount of additional cost onto a low-income population without safeguards for assistance to offset costs or impacts would have a low quantitative score. Next, environmental impact is quantified based on a scale from negative impacts to positive impacts, from low to high respectively. Finally, feasibility evaluations are calculated based on both the interplay between the prior criteria as well as how common the option is already being used in practice. In this case, an option with very high feasibility would be something that is already being done often in practice, has a high cost/benefit ratio, and a low impact on disadvantaged populations. Using the process presented by Linkov's multi-attribute utility theory, and the justification for scoring outlined above, the criteria scale for score conversions can be found in figure 5 below.

Figure 5: Criteria Scale MAUT Score Conversions

Initial Cost	Cost MAUT score	Efficacy	Efficacy MAUT score	Equity	Equity MAUT score	Feasibility	Feasibility MAUT Score	Impact on Environment	Enviro MAUT score
$1 Billion -$500 million	0.1	Very Low efficiency or AF increase	0.1	Creates multiple negative externalities w/o comp.	0.1	Very low: not widely adopted and active opposition	0.1	Creates multiple severe negative impacts	0.1
$500-$250 Million	0.2	Low efficiency or AF increase	0.2	Creates severe negative externality w/o comp.	0.2	Low: not widely adopted and not favorable	0.2	Creates multiple negative impacts	0.2
$250-$10 Million	0.3	Low-medium efficiency or AF increase	0.3	Creates multiple negative externalities w/comp.	0.3	Low-medium: not widely adopted or not favorable	0.3	Creates a severe negative impact	0.3
$10-$1 million	0.4	Medium-low efficiency or AF increase	0.4	Creates negative externality w/comp.	0.4	medium-Low: adopted but not favorable	0.4	Creates a negative impact	0.4
$1million-$500,000	0.5	Medium efficiency or AF increase	0.5	No positive or negative externalities	0.5	Medium: adopted but not widely	0.5	Creates no positive or negative impacts	0.5
$500,000-$100,00	0.6	Medium-high efficiency or AF increase	0.6	Creates positive externality	0.6	Medium-high: adopted	0.6	Offsets a negative impact	0.6
$100,000-$10,00	0.7	High-medium efficiency or AF increase	0.7	Creates multiple positive externalities	0.7	High-medium: widely adopted	0.7	Creates a positive impact	0.7
$10,000-$5,000	0.8	High efficiency or AF increase	0.8	Provides inclusion in decision making	0.8	High: adopted and favorable	0.8	Creates a significant positive impact	0.8
$5,000-$1,000	0.9	Very high efficiency or AF increase	0.9	Incorporates collaboration in decision making	0.9	Very high: widely adopted and favorable	0.9	Creates multiple positive impacts	0.9
$1,000-$100	1.0	Extremely high efficiency or AF increase	1.0	Incorporates collaboration and multiple positive externalities	1.0	Extremely high: Adopted everywhere and favorable	1.0	Creates multiple significant positive impacts	1.0

Numerical standardization for the range of potential qualitative and quantitative criteria's impacts in which higher scores denote a positive or more favorable outcome.

Figure 5.1: Municipal Cost Scale Score Conversions

Cost for Municipal investments	Cost MAUT score
$15,000- $10,000	0.1
$10.000-$5,000	0.2
$5,000-$2,500	0.3
$2,500-$1,000	0.4
$1,000-$750	0.5
$750-$500	0.6
$500-$250	0.7
$250-$100	0.8
$100-$50	0.9
Less than $50	1.0

Numerical standardization for municipal costs due to the fact that municipal investments are on a much smaller scale than agricultural or supply investments. This separate scale allows for a better breakdown of the impact of costs on individuals.

Results

Decreasing Demand In Agriculture:

Working off best practices and ideas put forward by the State of California and other arid regions around the world, the following options are evaluated below. As agriculture is by far the largest user of water overall in California, the vast majority of the state's water resources are used to irrigate thousands of acres of cropland that fuel a multi-billion dollar industry. Moreover, three-quarters of all irrigated agriculture in the US is concentrated in the west, consuming 74 million acre-feet a year (Schaible & Aillery, 2012). Thus, we must find ways to reduce demand in agriculture so that water can be used as efficiently as possible while still maintaining the livelihoods of farmers. The four main practices that will be examined in this section are more efficient irrigation, drought resilient crops, fallowing, and field management.

As for irrigation, this entails updating equipment to drip irrigation as opposed to flood irrigation, in addition to using sensors to allow for flexible irrigation times. It has been found that drip irrigation is 95% efficient on average as compared to traditional flood irrigation applications that are only 50% efficient, showing a 45% efficiency increase (water footprint calculator, 2022). On top of that, drip irrigation is 20% more efficient than even sprinkler irrigation systems, which are only 75% efficient (Schwab, 2015). It has also been found that sprinkler/drip irrigation systems use only about 1.38 acre-feet of water per acre of crop land while traditional gravity systems use 2.37 acre-feet per acre (Schaible & Aillery, 2012). However, the investments required to improve irrigation equipment are mostly borne by farmers, with less than 10% reporting receiving assistance from public programs (Schaible & Aillery, 2012). Although drip irrigation systems have a slightly higher initial cost than sprinkler systems, $1,707 and $1,540 respectively, the total average annual cost is much lower for drip irrigation only costing $445 compared to $1,371 for conventional (Schwab, 2015).

Moreover, a study done in Northern China evaluated the impact from more efficient irrigation practices and found that a 29% reduction in irrigation would stop groundwater depletion and a 10% reduction in pumping would create net gains allowing for groundwater restoration (Hao,et.al, 2015). Furthermore, watering the soil with less water can also reduce agricultural run-off into waterways, providing environmental co-benefits for the quality of surface water.

Next, switching to drought resistant crops can save water by requiring less irrigation to survive, relying more on rainfed irrigation. However, this is a contentious option given the fact that many farmers have farmed the same crops for generations, or chose to farm certain crops based on their economic value. Yet, the same study in China found that the market value of low-water crops such as cereals was actually higher than the conventional crops of rice and wheat in the region, providing justification for switching cropping patterns (Hao, et.a., 2015). On top of this, there is a growing movement of using genetically modified drought tolerant varieties of the crops that farmers are already growing. Currently around 22% of US farms use drought tolerant corn crops, with as much as 42% in states like Nebraska (McFadden, 2019). There is a great deal of variation in prices, yet they note that there is about a $10 increase for a bag of Drought Tolerant (DT) seeds which is about enough to plant two acres of corn (McFadden, 2019). Moreover, even without changing the crops they grow, farmers growing alfalfa in Colorado have found that watering their crops with less water overtime has actually strengthened their root systems making them more drought tolerant. In addition, the less saturated soil decreases the risk of diseases and pests, decreasing the need for pesticides, providing further environmental co-benefits (Lustgarten, 2015). Furthermore, indigenous knowledge about the kind of plants native to the climate of the area could also be incorporated into changes in cropping patterns.

Finally, fallowing fields or crop idling can be done in times of severe drought when acres of cropland are not planted in order to conserve water, allowing the water to be transferred or conserved. In the Imperial Irrigation District, located inland in Southern California, over a 15 year period 300,000 acres of farmland were fallowed, correlating with 1.8 million acre-feet of water saved, at a cost of $161 million in payments to farmers to offset the cost of not cultivating their land (Naishadham, 2023). However, this option is not favorable to farmers long-term, who still have to pay the rent on the land they are not cultivating, losing money on the beneficial use of that land. In addition, fallowing fields in arid regions potentially degrades the soil into dust and causes dust storms that can harm residents of the area. On top of this, it also hurts the farm workers who may lose their jobs because less maintenance and harvesting needs to be done (Naishadham, 2023). Despite this, it is still acknowledged by farmers that some amount of fallowing is required to meet conservation goals.

Moreover, if farmers also take steps to conserve soil moisture through the use of mulch or cover crops and using no tillage practices, it reduces soil erosion and degradation. It has been found that for every 1% increase in organic matter in the soil helps store up to 25,000 gallons of water per acre (Bryant, 2015). Proper field management should also include smart metering to measure soil moisture to improve irrigation times. Improving the soil's ability to absorb water, coupled with the application of less water in turn decreases erosion and runoff into waterways, providing further environmental co-benefits.

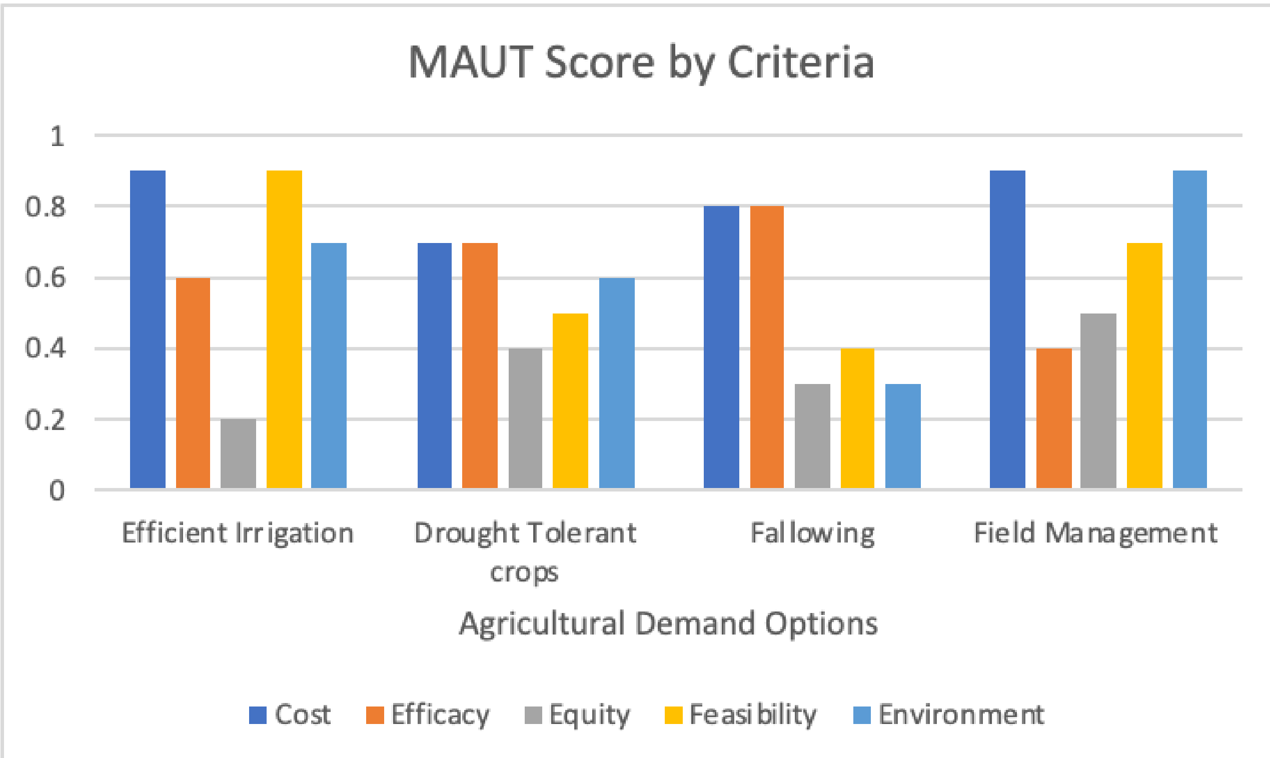
Figure 6: Agricultural Demand Options and Criteria MAUT Score Comparison Matrix

	Cost	Efficacy	Equity	Feasibility	Environment	Aggregated score
Efficient Irrigation	0.9	0.6	0.2	0.9	0.7	3.3
Drought Tolerant crops	0.7	0.7	0.4	0.5	0.6	2.9
Fallowing	0.8	0.8	0.3	0.4	0.3	2.6
Field Management	0.9	0.4	0.5	0.7	0.9	3.4

Figure 6 shows the comparative matrix between relevant agricultural demand options and list of evaluative criteria, in which numerical scores were derived from the associated values from figure 5.

After completing the comparative matrix found in figure 6, the individual numerical evaluative criteria scores for each option were extracted from the table and displayed on figure 6.1. This graph allows for easier cross comparisons between options by clearly visualizing certain factors that perform better than others for each option. For example, while all of the options are generally cost effective, drought tolerant crops and fallowing perform the worst in this category due to the fact that they are not economically favorable to farmers who could lose money. Moreover, while field management does not have a large impact on the water supply, they outperform other options for environmental impact due to the positive co-benefits it provides. Finally, although efficient irrigation was ranked the lowest for equity due to the fact that the costs are borne by individuals without much assistance, the still relatively low cost coupled with the fact that it is already being fairly widely used denotes a very high feasibility score.

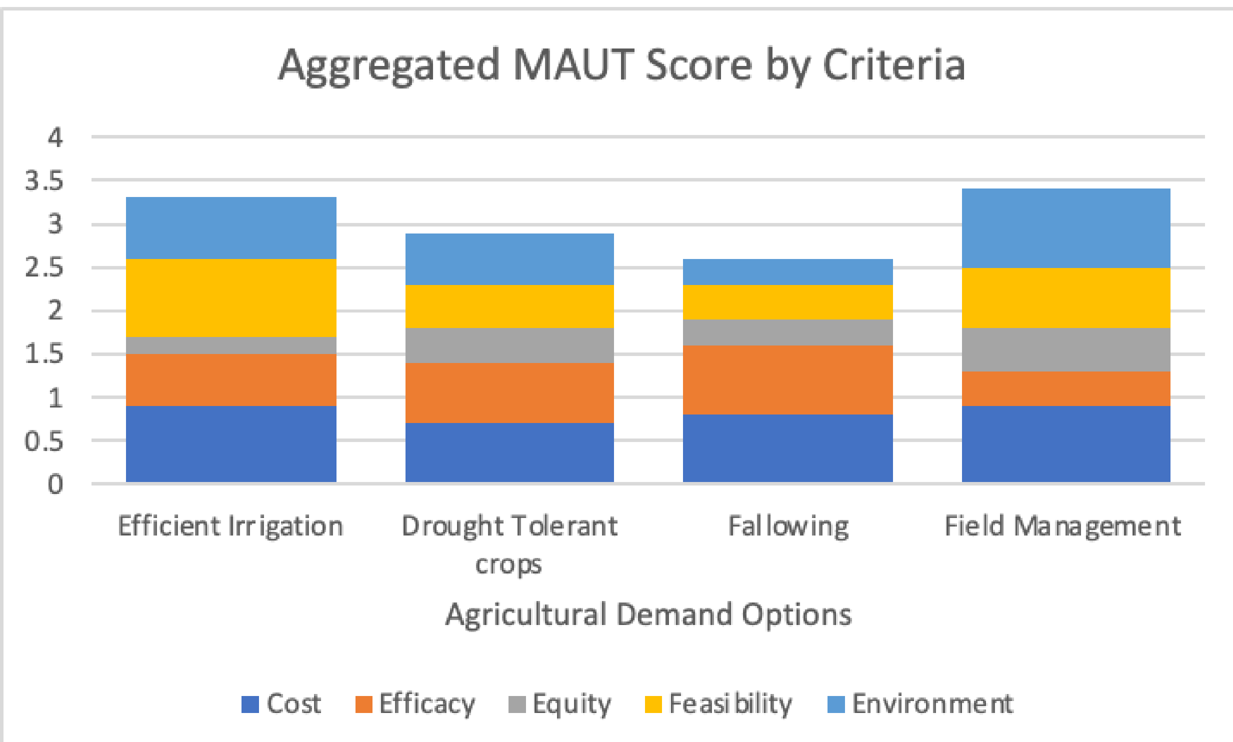
Figure 6.1: Agricultural Demand Options MAUT Score by Criteria



Results from figure 6 displayed in graphical form to visualize relative numerical scoring across the evaluative criteria for each option.

Following the graphical representation of individual impacts associated with each option in figure 6.1, the list of criteria was aggregated together in figure 6.2 to provide a whole picture view of each option. What is interesting is that although field management has the least impact on the water supply it has the most favorable overall impact when looking at all of the criteria together. However, efficient irrigation would still be regarded as a very favorable option due to its water supply benefits and high feasibility. Moreover, although fallowing has the greatest water supply benefits, it is regarded as the least favorable on this list due to its potential negative impacts.

Figure 6.2: Agricultural Demand Options Aggregated MAUT Score by Criteria



Aggregated results from figure 6 displayed in graphical form to display overall impact across the evaluation criteria for each option.

Decreasing Demand In Municipalities:

The other major piece of demand reduction is on the municipal side of water use. Although municipal and industrial water use are a smaller percentage of users, there are still many ways that water could be used more efficiently that could have a large impact on the water supply. On top of that, when restrictions are made they impact everyone, therefore it is important to learn how to live with less. It is estimated that the average American uses 82 gallons of water per day and spends over $1,000 a year on water costs (EPA, 2022). The four main approaches studied here include zero-scaping, efficient appliances, household greywater reuse, and rainwater harvesting.

First, switching to landscaping that requires less water during times of drought reduces or eliminates the need for outside irrigation. This does not mean everyone needs to have fake grass and concrete yards, but that landscaping should be native to the climatic conditions of the area. Outdoor water use accounts for over 30% of total household consumption, and up to 60% in dry regions such as Southern California (EPA, 2022). It has been reported that zero-scaping can reduce household water use by 50-75%, saving 120 gallons of water a day (Scavetta, 2020). The State of California is investing $1 billion into a landscape conversion program that seeks to remove 500 million square feet of turf, correlating with saving 66,000 acre-feet per year at a cost of $2 per square foot (CA Water Dept. 2022). Using the estimation that the average yard size in California is around 5,575 sq ft, this translates to a cost of about $11,150 per yard (Home advisor, 2018). Moreover, they should also be designed in a way that allows for absorption of storm water for groundwater recharge and flood reduction. This means using groundcover such as mulch to help increase water retention in the soil instead of hard cover like stone and rocks. The reduced irrigation coupled with better water infiltration will also reduce runoff into streets into waterways, reducing water contamination along the way. Moreover, if native plants are used in landscaping as opposed to a traditional grass lawn, it can help with local biodiversity and attract more pollinators (EPA, 2022).

Next, water efficient appliances could have a large compounding effect on water consumption. In addition to the fact that policies focused on incentivizing water saving appliances (WSAs) are more politically and socially feasible than forced water restrictions. A study in the UK evaluated the relative impacts from dual-flush toilets, low-flow taps, efficient bathtubs, shower restrictors, and efficient washing machines and dishwashers (Sadr, et.al., 2021). They found that dual-flush toilets had the largest impact on water use, consuming only 0.95 gallons per flush as opposed to standard toilets which consume 2.5 gallons to up to 7 gallons. Moreover, another study found that water efficient toilets can reduce water use by 20-60%, correlating with 13,000 gallons saved per year (Feng, 2020). These savings translate into $130 a year in water cost savings (EPA, 2022). A typical dual-flush toilet costs $150-$300 plus the potential cost of installation, making this a very cost effective option.

Furthermore, low-flow taps greatly reduce flow rates by up to 70%, leading to household water savings of about 5.2 m^3/year (Sadr, et.al., 2021). This conservation can save $250 in water and electricity costs over time (EPA, 2022). The cost for these upgrades can range from $70-$300 and save around $20 per year, ultimately saving around 700 gallons of water annually (EPA, 2022). Next, although low-flow showerheads have a more marginal impact on water efficiency savings, only moving from 1.1 gallon/min to .79 gallon/min, it can still save around 12.5 m^3/per household per year (Sadr, et.al., 2021). This is equal to about 3,000 gallons per year, or roughly the amount of water used to wash 88 loads of laundry, and save $70 in water and electricity costs (EPA, 2022). These water saving appliances are also very cost effective, only costing around $20 on the low end (EPA, 2022). Next, water efficient washing machines that only consume around 11 gallons per load as compared to the standard 15 gallons, can save 3.7% of total household water use (Sadr, et.al., 2021). For the purposes of this estimation, assuming the average person does three loads of laundry per week, this translates into a water saving of around 624 gallons per year. Finally, it has been found that even without investing in a new dishwasher, by being more efficient about when to run a load can save about 320 gallons of water per year (EPA, 2022).

Next, household greywater reuse through dual plumbing systems that store greywater can be reused for landscape irrigation or household appliances. The same UK study mentioned above compared water savings between efficient appliances and standard practices, but also added the consideration of greywater reuse into their evaluations. As greywater can make up as much as 70% of household wastewater, this represents a great potential for water savings through reuse. They found that the application of greywater for non-potable uses can correlate with 20-25% of household water consumption with a 2.5 gallon tank, and up to 31% for a 13 gallon tank (Sadr, et.al., 2021). Non-potable uses refers to water we do not drink, for example outdoor irrigation or flushing toilets. While cost depends on whether these systems are installed in new developments or retrofitted into existing homes, the purchase price ranges from $750-$2,500 (GWIG.org).

In addition to greywater reuse, stormwater capture or rainwater harvesting can also help offset household water use while also providing flood control benefits. Although some rainwater harvesting systems can be very intricate and expensive, implementing rain harvesting to help collect and store rainwater can be beneficial to underserved communities. A study in Mexico City found that installing 105,000 rainwater capture systems in disadvantaged communities translated into increasing water availability for 415,000 people (Fecht, 2021).

All of this also comes with the consideration of communicating with communities about their water use and why these improvements are necessary. Although water efficient appliances can have a large impact on water use alone, coupling these increases with an understanding of overall conservation can reduce the risk of rebounds. As is often the case when efficiencies are made, people believe that it is okay to continue using the same amount or even more, canceling out the improvements made by more efficient technologies. Therefore, attention must be paid to public education and outreach efforts so that communities understand their impact and can access assistance to acquire these technologies. Moreover, this also applies to efforts to increase greywater reuse to overcome biases people may have and increase the widespread adoption of this approach (Sadr, et.al., 2021).

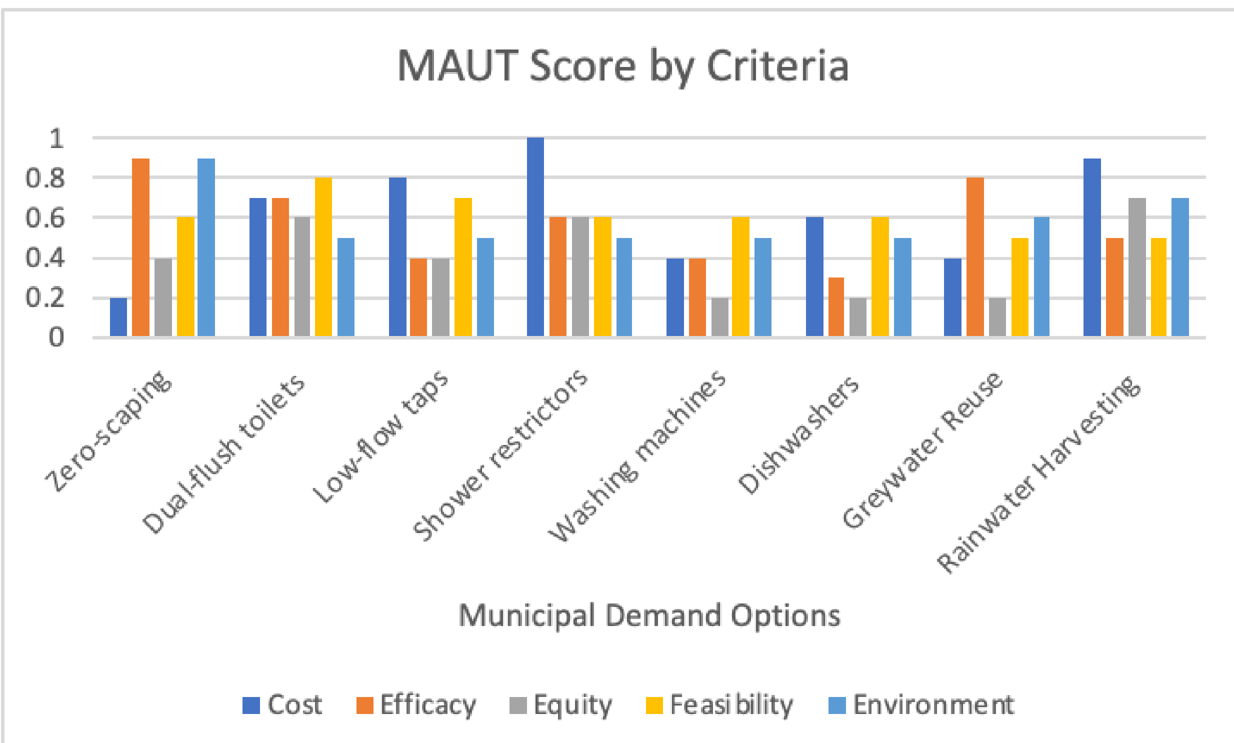
Figure 7: Municipal Demand Options and Criteria MAUT Score Comparison Matrix

	Cost	Efficacy	Equity	Feasibility	Environment	Aggregated score
zero-scaping	0.2	0.9	0.4	0.6	0.9	3
Dual-flush toilets	0.7	0.7	0.6	0.8	0.5	3.3
Low-flow taps	0.8	0.4	0.4	0.7	0.5	2.8
Shower restrictors	1.0	0.6	0.6	0.6	0.5	3.3
Washing machines	0.4	0.4	0.2	0.6	0.5	2.1
Dishwashers	0.6	0.3	0.2	0.6	0.5	2.2
Greywater Reuse	0.4	0.8	0.2	0.5	0.6	2.5
Rainwater Harvesting	0.9	0.5	0.7	0.5	0.7	3.3

Comparison matrix between relevant municipal demand options and list of evaluative criteria, in which numerical scores were derived from the associated values from figure 5 and figure 5.1.

Figure 7.1 displays the information extracted from figure 7 in graphical form to visualize the relative differences between the individual evaluative criteria across the different options. What first stands out on this graph is that low-flow taps, shower restrictors, and rainwater harvesting could all be considered favorable options due to their relatively low cost. Furthermore, zero-scaping and greywater reuse provide by far the greatest overall benefits on the water supply due to their existing large share of municipal water use and water waste. Finally, dual-flush toilets stand out as being the most feasible option due to their already widespread favorability and adoption.

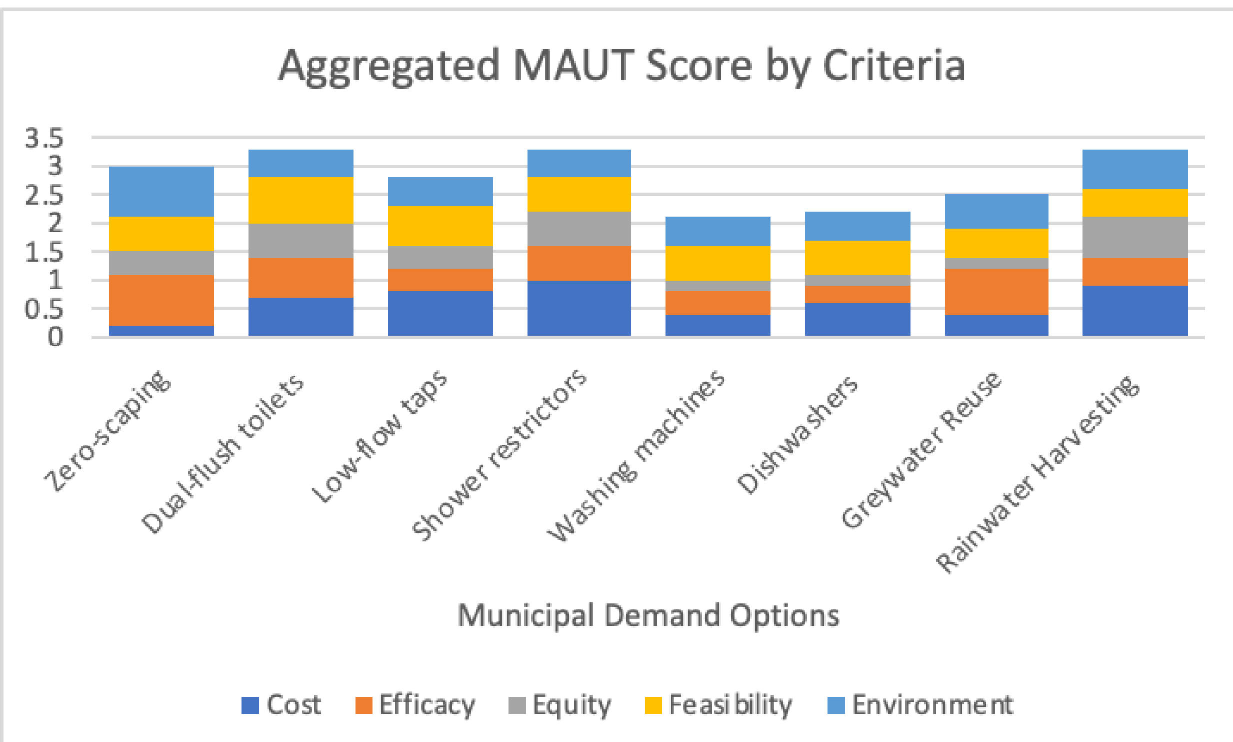
Figure 7.1: Municipal Demand Options MAUT Score by Criteria



Results from figure 7 displayed in graphical form to visualize relative numerical scoring across the evaluative criteria for each option.

Figure 7.2 aggregates the overall impact from all of the evaluative criteria across the different options for decreasing municipal demand. Taken altogether, zero-scaping, dual-flush toilets, shower restrictors, and rainwater harvesting stand out as the best overall options. Although zero-scaping has the highest cost, the associated water supply and environmental benefits coupled with a fairly high feasibility make it a generally favorable option across the set of criteria. Moreover, although shower restrictors and rainwater harvesting have slightly less of an impact on the water supply than dual-flush toilets, the relatively low cost of installation makes them equally favorable options overall.

Figure 7.2: Municipal Demand Options Aggregated MAUT Score by Criteria



Aggregated results from figure 7 displayed in graphical form to display overall impact across the evaluation criteria for each option.

Increasing supply:

The primary options for increasing the water supply being studied in this thesis include water transfers, expanding capture and storage, recycling water, and desalination. These options are also consistent with the approaches being considered by the State of California for their water supply efficiency plans.

First, although water transfers do not do anything to increase the overall water supply, they can help regional water management and resilience by increasing connections between different water sources and watersheds. This approach can be achieved simply by building diversions to divert water within a watershed or by building pipelines between watersheds. By using conjunctive management, water can more easily be delivered to the places that need it most on a short-term basis. This approach also helps water managers gain an understanding of the water supply for the entire region through integrating water resources (CA Water Dept, 2022).

Next, similar to water transfers, while expanding the capture and storage of water alone does not increase the water supply, it does help tremendously in wet years to capture stormwater for groundwater recharge and flood protection. This approach can be done by expanding reservoirs, protecting natural ecosystems and flood plains, or integrating water holding areas into urban development. The State of California is investing $340 million into expanding storage through 340 projects and anticipates that it will capture an average of 500,000 acre-feet/year (CA Water Dept, 2022). However, this option also comes with the consideration for fish populations in the waterways that need to reach the ocean, limiting the amount of water that can be stored upstream.

Following these approaches, there are also opportunities to expand the supply of water through recycling existing water resources. Recycled water is wastewater from municipal, commercial, and industrial users that is treated and returned to beneficial use. Despite unfavorable public opinion around the use of recycled water, communication and education has helped communities feel more comfortable. Moreover, while some recycled water can be delivered directly to the users, it can often be used for irrigation or returned to waterways to help wetland ecosystems and groundwater recharge through indirect potable reuse. In San Diego, a $2.85 billion dollar recycling plant will be designed to supply over 83 million gallons of water per day, equivalent to 255 acre-feet/day, and respond to a third of their water demand needs (Williams, 2018). However, this is an abnormally large project, where the recycling facility in Oxnard only costed $250 million and supplies the region with 7,000 acre-feet per year (United Water, 2021).

The final consideration for increasing the water supply is desalination. This section covers traditional ocean desalination, brackish groundwater desalination, and also considers solar/ renewable powered desalination. Some cities in Southern California have already built desalination plants, such as Santa Barbara and San Diego, yet there still remains a large opportunity to expand this resource. However, the primary concern with desalination is the high costs, high energy use translating into more GHG emissions, potential intake of marine life, environmental impacts from brine discharge, and long lead times for implementing projects and building infrastructure (Williams, 2018). The desalination plant in Carlsbad was built for $1 billion dollars and takes in 100 million gallons of ocean water to produce 50 million gallons of freshwater per day. This plant provides about 10% of the water needed to serve the 3.1 million people in the region, yet it costs twice as much as other sources of water at around $2,685 per acre foot (Robbins, 2019). Moreover, although a lot of energy is also required to transport water throughout the SWP, traditional desalination is the most energy intensive option on this list. While it does create a whole new source of water, this is notwithstanding the fact that the increased GHG emissions created from the process translates into further radiative forcing on the hydraulic cycle, further worsening our water woes (Williams, 2018).

While brackish groundwater desalination is more energy efficient due to the fact that there is a lower salt content that needs to be removed, these projects still have similar limitations. Therefore, this thesis also proposes the idea of implementing solar powered desalination plants for new constructions instead of traditional desalination. In 2013, a solar powered multi-effect distillation (MED) desalination plant was built in the Central Valley of California to help supply water for agriculture in the region. This pilot project revealed that this system used only one-fifth of the energy used by the traditional desalination plants in San Diego, which translates into a 50-60% decrease in production costs (Gorjian et.al., 2022). Furthermore, this project plans to scale up their production capacity to produce 1,981,290 million gallons of water per day. While solar-powered desalination plants provide benefits for long-term cost and energy savings, these projects also come with high upfront costs for acquiring the technology itself, which in turn hurts the feasibility of implementation. Similar to traditional desalination, these costs would also most likely be passed onto consumers of the water, making this option less equitable for low-income communities.

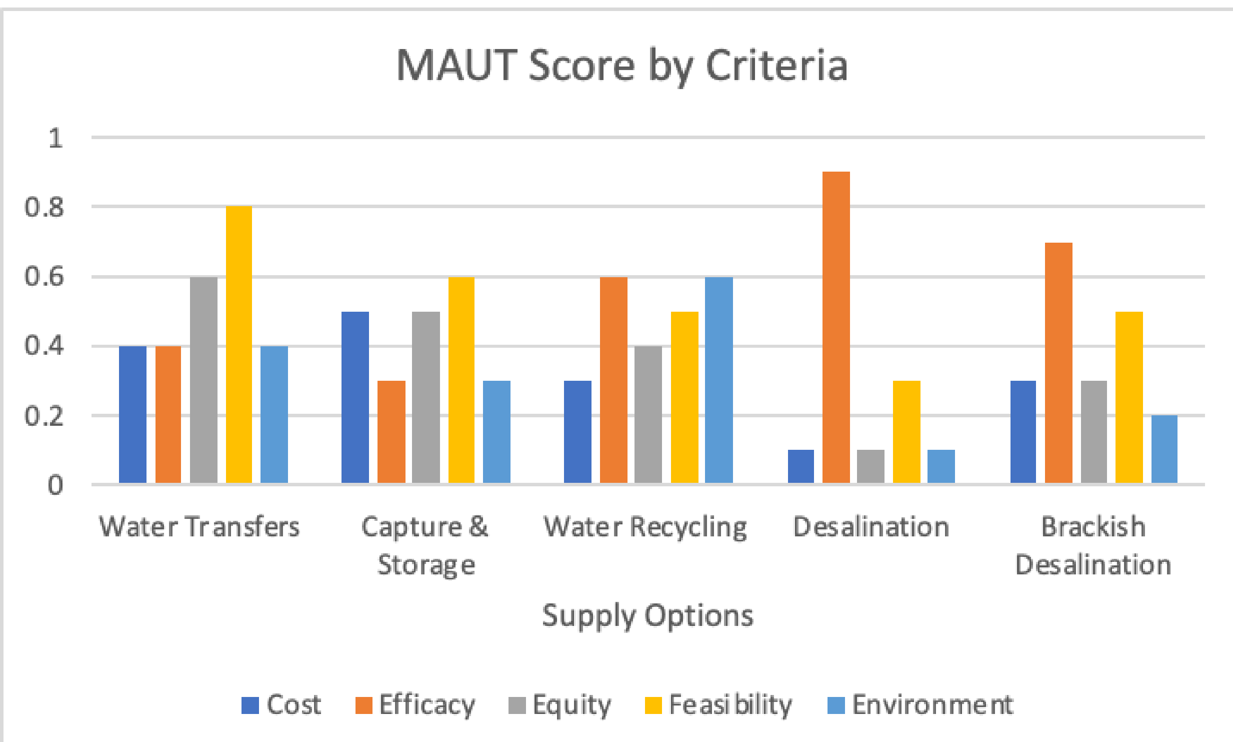
Figure 8: Supply Options and Criteria MAUT Score Comparison Matrix

	Cost	Efficacy	Equity	Feasibility	Environment	Aggregated score
Water Transfers	0.4	0.4	0.6	0.8	0.4	2.6
Capture & Storage	0.5	0.3	0.5	0.6	0.3	2.2
Water Recycling	0.3	0.6	0.4	0.5	0.6	2.4
Desalination	0.1	0.9	0.1	0.3	0.1	1.5
Brackish Desalination	0.3	0.7	0.3	0.5	0.2	2

Comparison matrix between relevant options to increase supply and list of evaluative criteria, in which numerical scores were derived from the associated values from figure 5.

Figure 8.1 displays the individual outcomes from each evaluative criteria across the set of supply options. What first stands out is the massive impact that desalination has on the water supply, yet has a very low favorability in all other regards. Next, water transfers stand out as being the most favorable in terms of feasibility due to the fact that this is already the option most commonly used in practice with the use of aqueducts and pipelines to move and divert water. Finally, water recycling displays the most favorable impact on the environment due to its ability to help recharge groundwater through insertion of recycled water into groundwater basins.

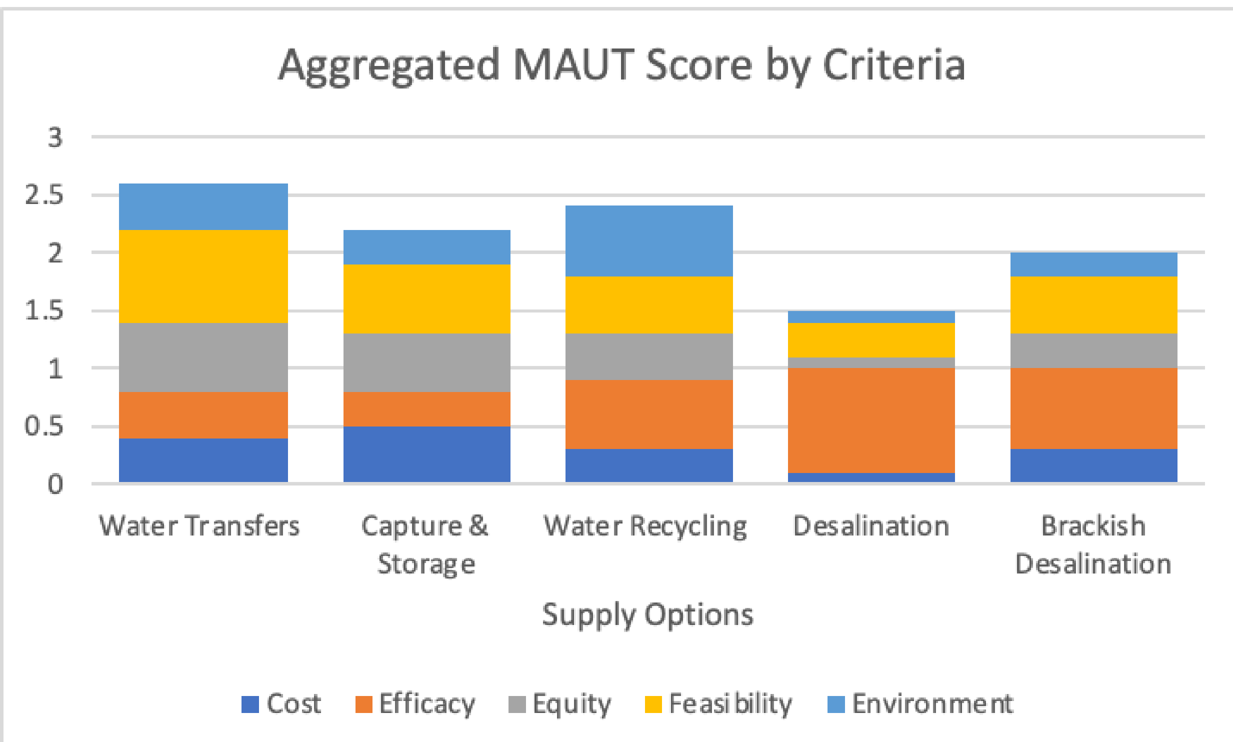
Figure 8.1: Supply Options MAUT Score by Criteria



Results from figure 8 displayed in graphical form to visualize relative numerical scoring across the evaluative criteria for each option.

When aggregating all of the evaluative criteria together in Figure 8.2, water transfers and water recycling stand out as the best overall options. However, while water recycling provides far better water supply benefits, it has a much lower feasibility score due to the fact that it is not as widely adopted and comes with a high cost. Moreover, while desalination and brackish desalination provide the greatest water supply benefits, they are ranked the lowest overall due to their high cost and potential negative environmental and inequitable impacts.

Figure 8.2: Supply Options Aggregated MAUT Score by Criteria



Aggregated results from figure 8 displayed in graphical form to display overall impact across the evaluation criteria for each option.

Interview Findings

Returning to the main overarching question of this thesis of understanding the kind of considerations that go into decision making around water use, these findings are applied to a case study through interviews with regional stakeholders to grasp how these initiatives are considered and implemented. This thesis conducted interviews with 6 different people connected to water use in Ventura County. This included a farmer; United Water, a wholesale water provider; Casitas Water, a retail water provider; Ventura Regional Watershed Coalition; Tree People, a community organization; and the California Department of Water Resources. These interviews helped to shed light on the tensions around these issues between the various stakeholders and the general things that different stakeholders are concerned about in relation to water issues. Interview questions are attached in the appendix of this thesis.

Farmers:

The first interviewee was Emily T. Ayala from Ojai Pixie growers, a region located in the mountains upstream of downtown Ventura. Overall, they tend to get along with sharing water for municipal and environmental uses, however as the population has grown this argument has intensified. The main takeaway from this interview was that many farmers in this region have tension with the downstream municipal users because they feel as though water is only flowing to those who can afford it, who generally are the big developers in the city. Often when agricultural land is being sold it gets replaced with ranchettes for the wealthy. She feels as though decision makers overlook the fact that we cannot keep growing forever and that locally grown food is essential. She compared this to the dichotomy between ecology vs economics, wherein the carrying capacity of our resources ultimately inhibit endless growth. She went on to say, “we have a finite amount of water, why don’t we just work with that instead of against it.”

Moreover, some specifics gained from this interview was that they have already been working hard to use their water efficiently since the 1980s, following a major drought in that time period. Although they reported that they did not really receive assistance from the county to make these improvements, she acknowledged the importance of the investments anyway. On top of this, she mentioned how laborious the irrigation process actually is, requiring them to check every sprinkler valve for leaks to ensure they do not waste water. In addition, Ms. Ayala reported that they have already had to take 15 acres of land out of production to conserve water use, going from 77 acres to 62 acres in production. Although this has caused them to lose money on the land they are not cultivating, she acknowledged that it is better to focus more intensively on a few crops than try to spread a scarce amount of water across all of their crops.

Furthermore, she mentioned that some farmers have a problem with the Sustainable Groundwater Management Act (SGMA) because it adds an extra cost of $85 per acre-foot to help fund monitoring and research activities. However, Emily stated that she supported it despite the extra cost because it allows them to have a better idea of the overall water supply. The final additional source of contention is with water providers raising the price of water when reductions are made, ultimately frustrating many farmers.

Moreover, although Ojai Pixies, a kind of tangerine, are native to the local climate, it was mentioned that other farmers are not favorable to the idea of switching their crops to more drought tolerant plants if they know they can make more money off the crops they are already producing. She also mentioned that farmers in Ojai are somewhat stuck in the kind of crops they can grow due to the weather and soil in the region.

It can be extrapolated that farmers, in general, are most concerned about water availability, the cost of water, and protecting their ability to farm the crops they have built their livelihoods off of. The main tensions they share are between urban water users on the issue of water for population growth vs food production, with state and regional water managers on the issue of added costs on water use, and with environmental groups on the ability to store water upstream. However, there were also some areas of convergence, specifically around wildfire risks. Ms. Ayala mentioned that, "we need to keep our farmland for fire protection benefits because in the Thomas fire large areas were protected by agricultural land." Moreover, she serves as a board member at groundwater management agencies and keeps in close touch with water providers due to the fact that they rely on each other for the mutual benefits they can provide.

Water providers:

This thesis conducted interviews with two water providers in Ventura County; Dan Detmer from United Water, and Kelly Dyer from Casitas Water. The main takeaway from both of these interviews is that efficient water use is diversified, this means balanced demand between different users and balanced sources of supply. On top of this, they mentioned that acquiring funding and continued conservation during wet years are two of the biggest obstacles they face. Overall, Ms. Dyer asserted that because every community is unique, "Every project has its challenges and there is no silver bullet..we can't take a one size fits all approach."

The primary demand reduction projects they are focusing on include turf replacement programs, efficient toilets, and greywater reuse. Although a lot of great improvements have been made, there is still a lot of low hanging fruit. The general sentiment is that ornamental turf without beneficial uses needs to be removed. Many regional wholesale water suppliers are funding turf replacement programs by giving $10/sqf. However, Kelly noted that while they used to offer a turf rebate, there is not as much turf in their area anymore because their market is becoming oversaturated. She referred to this situation as water hardening, when at a certain point everyone has already taken a lot of the measures needed to conserve. Furthermore, some water districts are requiring all new developments to have a greywater system for household greywater reuse. Even though it is very expensive to retrofit, requiring it for new developments makes it more doable. Furthermore, Mr. Detmer mentioned that although rainwater harvesting helps with reducing outdoor irrigation and runoff, it is not necessarily cheap or easy.

When looking at agricultural vs municipal demand, while in general water demand in Ventura has a fairly even distribution between the two, Mr. Detmer noted that it is hard to predict what the future demand will be. Although some new developments are taking over agricultural land, creating a net water gain, this also hurts the farmers and reignites their tensions with urban users. In addition, similar to what was mentioned by Ms. Ayala, efficient irrigation seems to be the most favorable option for decreasing water demand in agriculture, due to the fact that switching to drought tolerant plants is not a popular idea with farmers. As Dan put it, “There is the practice of efficiency but then there's a choice of what to grow and that is much more difficult to regulate.” As Lynn Rodriquez from the Watershed Coalition mentioned, it is much more difficult to tackle agricultural demand due to the tremendous amount of agriculture in the county and the sheer amount of water it requires. Furthermore, as SGMA is requiring all groundwater basins to be brought into balance, and as 67% of water use in agriculture is from groundwater, this raises questions for future water availability. This draws back to Lynn’s point that everyone needs to be doing their part, not just urban, yet at the same time is feeding people wasting water? On this point Dan noted that, “you can’t kill the community to save the water basin.”

The water providers also shared their views on the supply projects they are focusing on. A lot of their plans are looking into creating better regional interconnections between watersheds, like the Santa Barbara intertie pipeline, in order to create a more resilient and reliable way of delivering water to their customers. On top of this, they also work heavily with their natural environment by creating spreading grounds where water can be captured along the watershed to help recharge groundwater basins.

Furthermore, Mr. Detmer from United Water is working on a new effort to build a brackish groundwater desalination plant in conjunction with the Point Hueneme Naval Base. The issue here is that groundwater pumping near the coast has caused the water level to lower to the point where there is a great amount of salt water intrusion into the groundwater supplies. On top of this, while many areas in California have injection barriers to keep saltwater out, this would not work for them in Ventura. Therefore, they are pursuing a project to build an extraction barrier to create an artificial low point that lets seawater in. Although this project is in the very early stages of development, he expects the first phase of assessments to be done by 2025 with a budget of around $2 million. However, as with any large infrastructure project, the final phase of implementation will not be done until at least 2035 with a budget of around $200 million. According to United Water’s reports, the facility is projected to supply between 3,500 to 14,000 acre-feet of water per year (United Water, 2021). Although innovative new solutions for water supply projects are really expensive and long range, Dan noted that, “It is going to be expensive but we have a 2 billion dollar agricultural economy so if we need to spend 250 million to help with supplying water, it will be worth it.”

Moreover, to overcome potential environmental impacts from brine discharges, they are looking into connecting this with recycled water discharge to dilute the salinity of the brine discharge before returning to the ocean or waterway. Furthermore, although brackish desalination requires less energy input than traditional reverse osmosis desalination from seawater, it is still a very energy intensive process. However, when asked about the likelihood of implementing solar power to offset the energy usage, Dan replied that it was actually something they looked into, yet the local power company did not allow it because they did not have enough grid space in the area. However, water transfers alone require a lot of energy, as Dan noted that 3-4% of energy use in California is just to move water, therefore this serves as a baseline for energy demands.

Moreover, a point of contention they face is with environmental groups limiting the amount of water that water managers can capture and store due to the necessity to protect endangered fish species in the waterways. Dan noted that, “As much as we have good early water rights, the environmental issues with endangered steelhead has really pinched our ability to store and divert water.” Ms. Dyer mentioned that this has actually caused an unintended consequence in the past, where the water designated for fish flows created a warm water habitat for predators to feed on the species they were trying to protect, highlighting the need for thorough environmental assessments.

Furthermore, the next tension they face is focused on the cost of water. This was something that frustrated both farmers and community members, where they are required to conserve a certain amount of water, yet this ultimately translates into a price increase by that same amount. While this only applies to retail water providers like Casitas, the reality is that there is not much they can do about price increases due to the fact that they still have to pay for their operational costs, which account for 80% of their costs, when they are selling less water. On top of this, Dan noted that a lot of incentive is just in pricing. Although it can be discouraging for ratepayers, water providers need to communicate with them to justify why. Moreover, Kelly mentioned that they try to offset costs with penalties to avoid increasing water prices and communicate with the community.

On top of this, Ms. Dyer mentioned that communicating with the community in general is the biggest thing that often gets overlooked in decision making. She noted that it is necessary to bring them along from the beginning so that they are aware of the issue and when you are ready to start a project they aren't surprised. Therefore, these water providers work hard to hold board meetings and send newspaper updates to the community so that the users understand what is going on and have an opportunity to raise awareness to issues they are facing.

The main obstacle they face in carrying out these projects and achieving efficiency increases is maintaining support for conservation efforts during wet years. As Ms. Dyer stated, "A drought will come along and everyone will get behind solving the problem and then we get a good rainy year and everything gets put on the shelf." Instead, we must keep that momentum going and recognize that another drought will come and take advantage of that time to continue planning. On top of this, funding and regulatory approvals can further exacerbate the issue for delaying projects. As Ms. Rodriguez mentioned on this point, "We've made a lot of progress but humans are humans, and it is hard to make sacrifices in the short term to reach those long term goals."

Overall, it can be deduced from these interviews with water providers that their main objectives are to provide enough water to their users, maintain profit to cover costs, and to make restrictions when necessary to balance the water demands and the water supply. One of the main tensions they face are with communities and farmers over the cost of water. The other tension is with political roadblocks, such as environmental regulations with respect to riparian habitats, access to funding for new projects, and with year-to-year state water allocations and regulations. However, a prominent area of convergence is ensuring that they are communicating with their users to maintain their support and understanding. Furthermore, in the case of the brackish desalination facility, the Navy is a major partner in the project due to the fact that they need a reliable source of water.

Community Organizations:

This thesis conducted interviews with one representative from a community activism group in the LA area, Peter Massey from Tree People; in addition to a member of a regional coalition group, Lynn Rodriguez from the Watersheds Coalition of Ventura County. The main takeaway from these interviews is that decision makers do not look at the big picture for long term planning and impacts on communities. As Peter proposed, they need to stop thinking in silos and instead look at multi-benefit projects. Moreover, equitable outcomes require integrated, and iterative collaboration between stakeholders. This requires community outreach and education, including community members in decision making, treating them like the experts they are on their own community's needs, and actually following up with commitments made to communities to facilitate trust.

Peter highlighted from their needs assessments that communities are most concerned about the quality of tap water, quality of surface water, the cost of water, and water availability for fire protection. First on the quality of water, there is a lot of distrust in underserved communities, even if unwarranted, due to historical and current environmental justice issues. Moreover on the cost of water, it is difficult to balance the cost of water with the impact on communities debate due to the fact that water is already too cheap compared to its availability and importance, yet low-income communities already have difficulty paying a high cost for water. This point ties back to a sentiment Peter asserted, that people are so disconnected from their water today and they do not really think about where it comes from and the importance of it. While Native American communities have a deep spiritual connection to water, most people nowadays are just used to turning on a tap and water is there. Therefore, they are focusing a lot on community outreach and education to help build an understanding and appreciation for this critical resource. This was similar to what was noted by Kelly Dyer from Casitas water on helping inform and educate community members to understand the price of their water. Mr. Massey noted that, “As people get more sensitive to the threat of drought and lack of water supply, it can open the door on what we can do to further engage communities.”

Furthermore, on this point, Lynn agreed that as droughts get worse we are getting more creative, yet it also relies on all the moving parts coming together and human behavior that we have to work around. As she stated, “All of these things require everyone to do what they need to do and there needs to be some kind of master plan for all of the pieces, we don't necessarily need a water master, just a more robust regional planning effort where all of those parts are connected.” A key piece of this is collaboration across all the different facets so that things do not fall apart, where everyone is invited to the table to develop a long term plan that brings together all of this complexity. However, water agencies often have the most power in these discussions, and as crises get more severe tensions start to rise on who deserves to get more water. Therefore, we need to mitigate these crises before they happen by continuously facilitating collaboration and compromise.

On top of this, we should treat community members as important as the other experts in the room and actually pay them for their time, as volunteering is difficult for low-income people who cannot afford to take off work. As Mr. Massey said it best, “We need to flip the model from community *enragement,* to *engagement”*, in other words, asking the community what they want versus just asking for support after a project is already planned and underway. Indeed, he has found that when stakeholders form these kinds of reciprocal relationships, it actually helps streamline planning and approval processes for funding for new projects. While in the past the different stakeholders fought over how to spread money for infrastructure projects and it ultimately fell through, by using a consensus driven approach they were able to streamline the process and save hundreds of thousands of dollars.

Moreover, Mr. Massey mentioned a promising new avenue of stakeholder involvement by building bridges between community organizations, non-profits, engineering firms, and water agencies to create a pipeline of information sharing and collaboration. This pipeline also applies to people, where community leaders can move up through the chain of command to infiltrate decision making agencies with new ideas. In fact, Kelly Dyer from Casitas water herself used to work in integrated resource planning with stakeholders, in which she helped different stakeholders come together to collaborate on their ideas to find common ground. She helped form a stakeholder committee where representatives of the community could participate in planning and weigh their prioritization of ideas and objectives. Ms. Dyer mentioned in a powerful statement that, “Some of your biggest adversaries became advocates because they were a part of it.” Ultimately, although it can be difficult to bring people together, it can really be worth it in the long run.

However, taking this collaborative approach does not necessarily mean that decision makers will always follow through, but the relationships facilitated through this process are still valuable for future collaboration. Moreover, as Lynn asserted, “An equitable outcome isn’t necessarily board meetings full of people, but having the community at least know that their city or municipality knows what their needs are.” Water utilities need to continue making information available for people and actually put their priorities into decision making. There seems to be a general sentiment that integrated planning with people that incorporates long term planning is something that has been missed in water management for a long time, as it is easier to just focus on things right in front of you. Yet, as Ms. Rodriguez stated, by using a collaborative and integrated approach, “It brings people together who only previously saw each other in court.”

Overall, it can be concluded from these interviews that community members and groups are most concerned about water quality, the cost of water, and inclusion in decision making. Their main tensions are with water providers on the cost of water and water reliability, and with decision makers on inclusion in long-term planning and multi-benefit projects. However, an important finding brought up by Ms. Rodriguez is that the concern for fire risk and climate change are growing areas of common ground between different stakeholders, primarily between farmers and cities, as was also mentioned by Emily from Oaji pixies. Moreover, on this point she mentioned that people in the community appreciate the environmental benefits, fire protection, and local food that having protected open space and agriculture provides.

State Level Water Managers:

The final interview conducted for this thesis was with Dave Todd, an expert from the California Department of Water Resources. This interview helped to shed light on how these issues are being addressed at the top level, as the water crisis is a statewide issue. The main takeaway from this interview was that one of the biggest obstacles to overcome is the behavior shift in the population to actually care about conservation. On top of that, he mentioned that people often overlook the impact of surface evaporation when thinking about projects like recreational lakes and ponds. Overall, efficient water use requires us to become aware of how we are using water now and then looking at what the options and alternatives are to how we are using it.

His main focus was on urban water use efficiency, so he often brought up the importance of efficient water saving appliances like dual-flush toilets, as well as the turf replacement program. As was mentioned by the other water managers, these seem to be promising areas where significant gains can be made if implemented everywhere for a relatively low cost. Dave mentioned that Millions of toilets in the state do not meet the current standards and that having a high efficiency toilet replacement program would have the most impact in the shortest amount of time. However, for turf rebate programs it is much more expensive and takes time, as Mr. Todd mentioned that, at the current replacement rate it will take decades to convert a billion square feet (14,000 irrigatable square miles) of residential turf. Moreover, he asserted that we need to stop having the idea of the 'California oasis' because not everything can be green all the time, and instead we need to work with the mediterranean climate of the region.

Moreover, an interesting finding was that at the state level they are a lot more receptive to environmental concerns such as protecting waterways for fish habitats. While the regional water managers were less concerned on this subject and found it to be more of a nuisance to carrying out their operations, it appears that the state level water managers were more concerned about the environmental regulations that guide their operations. Mr. Todd stated that endangered species like the delta smelt are actually important species being at the base of the food chain that many other animals depend on. However, this is also not to say that regional water managers do not care about the environment, but more so highlights that these environmental concerns are not uniform in importance everywhere.

Furthermore, the other major point was around California's major plan of 'making conservation a way of life'. Mr. Todd mentioned that, "All of us have a role to play in our personal lives and we need to share that with our friends and family." They are trying to pursue awareness efforts to help Californians understand their water and forming green teams at schools that find ways to save water. As climate change continues we are only going to keep seeing extremes between flood and drought, and people must understand this and incorporate it into their daily lives. On this point Mr. Todd asserted, "What it comes down to is the inertia of tradition of how we've always done things and we need to understand that things are changing, but people don't change and adapt that quickly." Overcoming this requires working with people who are open to new ways of thinking and sharing new ideas.

Although this interview was with only one member who was primarily focused on water use efficiency, it can be deduced that some of the main concerns for state water managers is managing water allocations and restrictions across the state, providing funding and incentives for new initiatives, and coordinating across regional, state, and federal agencies. This last point ties into their points of convergence with the other stakeholders, in which they work together collaboratively with regional water managers and environmental groups.

Figure 9: Stakeholder Tensions Map

Figure 9 displays the stakeholders various points of tension between each other highlighted in red.

After extrapolating each stakeholders' main priorities, it became abundantly apparent that there were many points of tension between their divergent and competing interests and needs. Starting with the cost of water, it was mentioned by both the community and the farmers that the cost of water can be an issue for them. This was particularly an issue when they are being asked to make restrictions, yet the water providers need to still cover their operational costs, causing the price of water to go up and making the users feel as though they are being punished for doing the right thing.

Moving on to the tension between water for urban growth versus food production, it was mentioned by the farmer that they feel as though water is only flowing to those who can afford it, mostly being the big developers in the city. Ms. Ayala asserted that locally grown food is essential and needs to be protected, and that replacing agricultural land with urban growth will worsen their resilience to wildfires. Yet, at the same time, it was mentioned that when agricultural land is replaced with urban growth it causes a net gain of water.

The next major point of tension was with environmental regulations limiting the amount of water that farmers and water providers can capture and store. While on one hand environmental groups and regulations call for the protection of waterways for fish flows, particularly for endangered or threatened species, the water providers noted that it can really pinch their operations. Although still acknowledging the importance of these regulations, the farmers and water providers noted that more thorough assessments should be made so that they are able to capture and store water when the fish are not swimming through the waterways.

The final point of contention was between community groups and decision makers, asserting that, in general, decision makers overlook long term planning and multi-benefit projects. As was noted, it is much easier to focus on what is right in front of you and pursue projects that satisfy immediate goals. However, by doing this decision makers ultimately can leave certain considerations and groups behind.

Figure 10: Stakeholder Convergence Map

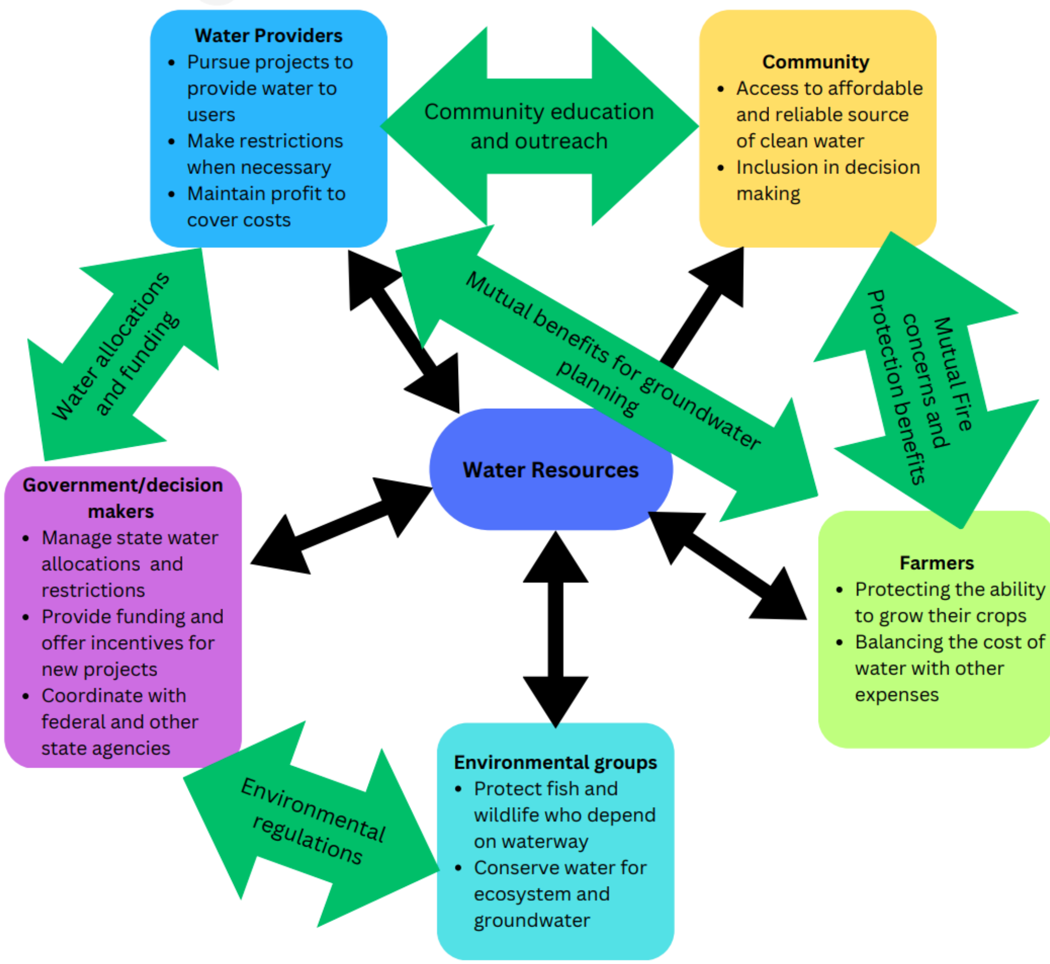


Figure 10 displays the stakeholders points of convergence highlighted in green.

Although the interviews brought to light many points of tension between the stakeholders, at the same time it also highlighted points of convergence between their interests. Going back to the tension around the cost of water in communities, the water providers acknowledged that this was a tricky situation, but they try to first compensate price increases with penalties to avoid raising rates. On top of that they work hard to communicate with the community on the importance of their water and why their rates may be increasing so that they understand they are not being punished for doing the right thing. Moreover, on the point of tension between farmers and water providers, the farmer I spoke to noted that she sat on groundwater management boards and has the water providers on speed dial due to the mutual benefits they can provide each other. She also personally supported groundwater regulations and the additional fees because of the importance of understanding the state of their water resources for the future.

Furthermore, on the note of water for urban growth vs agriculture, it was mentioned by multiple stakeholders that farmland actually acts as an important buffer between wildfires and urban areas. They noted that when the Thomas fire swept through the county a few years ago, large areas were protected due to the irrigated agricultural land surrounding it. It was also noted that the community members appreciate the local food and open space that having agriculture in their community provides.

Next, although regional water managers found regulations mandating fish flows were more of a nuisance to their operations, state level water managers were actually more receptive to these environmental concerns. They asserted that protecting endangered species like the delta smelt was important because they are a cornerstone species in the food chain that many other species rely on. Therefore, their extinction would cause cascading effects for the rest of the ecosystem and their habitats need to be protected.

Finally, the last point of convergence is between state and regional water managers. Although it was noted that sometimes acquiring funding can delay projects, when they keep better relationships with each other it can streamline the process. Moreover, plans and policies mandated at the state level are more often than not implemented on the regional level, meaning that they must work together to carry out these goals.

Figure 11: Stakeholder Analysis Map

Figure 11 visualizes interview findings in a concept map that displays the relative stakeholders and their relationship to water resources, their points of tension in red, and their points of convergence in green.

Taken altogether, figure 11 displays the overall findings for each stakeholder's main priorities, their points of tension with one another, and their areas of convergence. While still acknowledging these are generalizations and not everyone is going to think exactly the same, this kind of stakeholder mapping can provide a clearer picture of the complexities within this debate. It is apparent that everyone has their own unique perspective, interests, and needs which fuel their respective tensions and convergence with other stakeholders. These deeper level viewpoints and values must be understood in the context of decision making to understand where one another is coming from and work through the tensions that hold us back from progress.

Ultimately, many of these stakeholders found great successes when pathways and processes for engagement were incorporated into decision making. Starting with reaching out to the community to learn what their needs are, to bringing people together to rank their interests and preferred solutions to find common ground. This pipeline for stakeholder engagement and collaboration has subsequently led to a streamlined process for getting approval and funding for new projects, saving everyone time and money. Therefore, instead of viewing stakeholder involvement as an added complex cumbersome process, it can actually be a win-win solution for everyone involved.

Discussion

The literature review conducted for this thesis found a severe gap between the region's projected growth versus the state's plans to reduce water consumption and uphold the Sustainable Groundwater Management Act, all while trying to support a multi-billion dollar agricultural industry and a population of over 30 million people. All of this also comes with the consideration of projected future changes in water availability year-to-year due to the influence of climate change on the hydrology of the environment. We are at a turning point in which drastic changes must be implemented in order to achieve sustainable water use, in which the State of California has outlined a broad plan for how they will achieve this shift. However, this also comes with the acknowledgment that these changes must be implemented on a regional level, where every community faces different challenges and opportunities. Therefore, this thesis applies an analysis of the various available options to a specific case study of Ventura County to understand the reality of how these decisions would be made and the kind of considerations that go into implementation.

Starting with a discussion of the comparative analysis of different options across a set of criteria, the main takeaway is that although different options perform better for certain factors, when taken altogether all of the options are relatively equally comparable. This highlights the fact that decision makers need to look at all of these related factors together instead of thinking in silos. A striking example of this would be in the case of desalination, where if a decision maker was looking at the impact on the water supply alone, they would forgo considering all of the other potential negative impacts that it brings. Therefore, when looking at all of the options' aggregated MAUT scores it turns out that water transfers and water recycling present the best solutions across the criteria. Similarly, when looking at agricultural demand options, while field management has the least impact on the water supply, it is the best option across all of the criteria categories because it is relatively inexpensive and provides co-benefits.

Next, when comparing the interview findings with the matrix analysis, many of the findings were consistent across the two. Starting with agriculture, many farmers already use efficient irrigation and field management techniques, consistent with the findings from the analysis. Moreover, while drought tolerant crops would provide many benefits, they are not favorable with farmers who want to grow the crops they have built their livelihoods on, are able to farm, or know they can make money from. Finally, although fallowing has great water supply benefits, it is not favorable to farmers who lose money on the land they are not cultivating.

Moving on to the municipal side of demand, the findings are also fairly comparable across the analysis and interviews. As zero-scaping, or turf replacement, and efficient appliances were championed by water managers as being the best options to pursue. This is consistent with the findings from the matrix analysis that displayed dual-flush toilets, shower restrictors, and zero-scaping as the best options across the board. Furthermore, although rainwater harvesting appears to be favorable on paper, in reality it is not as cheap and easy for the everyday person. Insead, implementing greywater reuse in new developments would be a more favorable option.

For supply the findings are also relatively comparable, as all of these are options that water managers are already considering. Water transfers seem to present the best options across the criteria, which is consistent with the fact that this is already being done most of the time when diverting and moving water around the state. Moreover, the comparison between traditional desalination and brackish groundwater desalination is important for this discussion considering that Ventura is working on a brackish desalination facility, choosing the more favorable option.

Finally, the main overall take away from the interviews is that all of this, for whatever projects and initiatives we pursue, relies on human behavior. It relies on behavioral shifts on the individual level for people to care about their water and care about conserving it, even in wet years. Furthermore, it relies on behavioral shifts on the macro-level for people to learn how to work together on these issues instead of seeing each other as adversaries fighting over resources. Instead, by shifting their behaviors toward collaboration, it subsequently mitigates escalation of tensions during severe water shortages. By pursuing this collaborative model, over time all the different stakeholders connected to this issue begin to realize the mutual benefits and areas of convergence they share. By allowing everyone a seat at the table, and allowing everyone to come together and share ideas and break down their priorities and preferences, it will ultimately make us better adapted to the impacts of climate change.

Implications:

Overall, what is clear is that there is no one perfect solution that rises above the rest. At the end of the day, it will require an all of the above approach. An all of the above approach does not necessarily mean we have to do everything, but rather pursue a mixed portfolio of different options wherein everyone is doing their part. As water is connected to everything and the cornerstone of all life, this entails a whole system approach that recognizes the complexities and interconnectedness of water resources. This means we will need to integrate planning between users, across water resources, and in relations to future environmental changes.

An all of the above approach means that all of the different stakeholders need to do their part, meaning not only do they need to individually care about conservation, but also collectively trust that everyone else is also doing their part as well. This trust requires iterated cooperation and communication between the stakeholders so that everyone can come together to find compromise and common ground. Therefore we must pursue the model championed by many of the interviewees as best practices for integrated water management through stakeholder engagement. Wherein the community is actively involved in decision making, or are at least educated and informed on what is happening in their communities and can take steps to get involved.

Decision making should not just look at single benefit projects without input from stakeholders, but instead should be a collaborative process that weighs options across impacts and between stakeholders. Water is inherently a complex issue with a web of users who all have an impact on water and a dependence on it. Therefore, understanding this interplay and incorporating it into decision making is crucial for sustainable and equitable water management.

Limitations:

First, due to the fact that much of the information used to complete the criteria analysis was found throughout the internet from different sources some of the information was not perfectly comparable. I primarily had this issue when trying to compare what percent of efficiency increase is equal to a certain amount of acre-feet or gallon increase in the water supply. Moreover, there is some amount of inherent bias in the way I chose to rank and score the qualitative elements of the analysis, due to the fact that this is a little bit more of a discretionary ranking. Particularly relating to the equity evaluations, this scoring framework used a mix of procedural and structural justice, however a more thorough evaluation would require breaking all of these elements down separately. Finally, I wish that I was able to interview more stakeholders as part of this analysis, particularly someone from an environmental group. Unfortunately with time constraints due to the lengthy approval process, I did not have time to gather more information from a broad set of stakeholders.

Areas for Further Research:

An interesting area for further research would be to compare stakeholders in different regions, as this stakeholder group was only focused on a particular county. This kind of analysis could highlight differences in the way different communities think about these issues, and could highlight similarities and differences in their points of tension and convergence across different communities.

Moreover, another area for further research could be to look at the impact from collaborative decision making to see how much of a difference it makes overtime. As this was something mentioned in the interviews, that working collaboratively and forming relationships ultimately helped streamline the approval process for funding and implementing new projects. Yet, at the same time it was also mentioned that decision makers did not always follow what the stakeholders agreed on if they already had a plan in place. Therefore, it could also be interesting to see how often the stakeholders got what they wanted when they took part in the collaborative decision making process and if that had any impact on their willingness to continue participating.

Conclusion

Ever since land was claimed in the west, so was the water, and has been treated as a commodity that can be bought, sold, fought over, diverted, and depleted. Harnessing this resource has allowed us to grow major urban centers home to millions of people, as well as a multi-billion dollar agricultural industry to feed this growing population and support the state's economy. However, the past century of drought and overuse has led to serious questions about water scarcity with many of the major reservoirs and groundwater basins drying up. Although California has experienced a very wet season this year, we cannot hope for the rain to come 'just in time' everytime. Therefore, we must also keep momentum up even in wet years to take advantage of what we have when we have it.

Furthermore, the impact of climate change will continue to put added pressure on the future of water availability, with rising temperatures, increased variability in precipitation, and related impacts on snowpack and snowmelt. These predictions must also be built into every part of decision making, by considering not only the impact that climate change will have on water, but also the impact that certain solutions will have on climate change.

While this thesis's main focus is the water crisis in Southern California, this model for multi-benefit analysis and stakeholder engagement can, and should, be applied to all areas of decision making around environmental issues. As climate change and environmental issues are inherently extremely complex problems with a multitude of interconnected factors and stakeholders, we must acknowledge and incorporate this reality into decision making. Moreover, the necessity for this kind of framework for decision making was something echoed by many of the stakeholders interviewed in this thesis; calling for the incorporation of long term planning, multi-benefit projects, the acknowledgement of related impacts, and greater stakeholder involvement. Ultimately, the evaluative framework created in this thesis should be used in stakeholder collaborations to allow everyone to rank their preferences between all of the different criteria and options.

Returning once again to the overarching research question behind this thesis, there are clearly a lot of considerations that go into decision making around water management, as water is interconnected with every part of our society and environment. Yet, these complexities have not historically been incorporated into decision making around water management, ultimately leading to the current situation we are in today. Instead, we should be looking for multi-benefit projects by comparing the relative impacts between different solutions by using an approach similar to the evaluative framework outlined in this study. On top of this, decision making needs to incorporate the viewpoints of people who care about, and depend on, this vital resource through facilitating collaboration and communication. As pursuing a sustainable and equitable outcome for water use ultimately rests on achieving a behavioral shift in the population, this foundation of trust and cooperation must be laid down in order to create collaborative and integrated resource management.

As with many aspects of climate change, instead of thinking about this issue in silos we need to fundamentally change our way of thinking to respect the fact that water is fluid and transient, and is the cornerstone for all life. Water is something that everyone has an impact on and is also something we all rely on for survival. Therefore, it should not be treated as an ‘us vs them’ issue, but rather all of us together. This is how the west will have water for generations to come.

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Appendix

Interview Questions:

General Set of Questions for all Stakeholders:

1. What are the overarching water issues you are concerned with?
2. What do you see as the greatest obstacle for solving the water crisis?
3. What is your preferred strategy and why? Most feasible?
4. What is the greatest challenge you've faced working with these issues and what was the outcome?
5. What are some unintended consequences you have found or would expect to find working with these options?
6. What is the most important thing decision makers overlook?

Community Organization Specific Questions:

1. How do you engage the community in grassroots campaigns or activism efforts?
2. To what extent are you included in stakeholder discussions and decision making?
3. What does an equitable outcome look like? How do we achieve it?
4. What is the most important thing you have learned working with communities?
5. How do you bring together the stakeholders and what are those discussions like?
6. How do you deal with stakeholders who are more vocal/powerful in collaborative discussions?
7. What are some areas of common ground that haven't been realized yet?

Water Provider Specific Questions:

1. How do you balance the needs of the community vs farmers?
2. How much impact would you expect x option to have on the water supply?
3. What are the tradeoffs between building pipelines for water transfers vs building recycling or desalination facilities?
4. What does efficient water use look like?
5. How do you navigate tensions over the cost of water?
6. How do you assist in water efficiency improvements for your users? How common is it?
7. Do you prioritize who gets water in times of shortage and restrictions?
8. What penalties do you have for those who waste water?

Farmer Specific Questions:

1. How has the drought impacted your operations?
2. Have you ever had to limit your production or give up water in response to restrictions?
3. Are there ways you are trying to conserve/ use water more efficiently?
4. Where do you get your water from?
5. Are there ways you can capture/store water locally?
6. What kind of assistance do you get from the state/county to make improvements?

California State Water Department Specific Questions:

1. How do you maintain support for conservation in wet years?
2. How do you balance the needs of all the different users?
3. What are some potential options that haven’t been fully implemented yet?

4. What does efficient water use look like to you?
5. What do you do to assist communities and how common is it in practice?
6. How do you manage water sources between the State Water Project, groundwater, and the Colorado River?
7. How are you preparing for long term water availability challenges?
8. Do you involve stakeholders in decision making?