System Dynamics Modeling to Characterize Water Sustainability in the Oxnard Basin, California

by

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ABSTRACT

The State of California is experiencing exceptional drought conditions that are threatening the availability of water resources for potable and non-potable applications. Water infrastructure development, water governance, and management of water resources is multidimensional and is impacted by complex natural and human changes. A system dynamics model was developed and used to simulate historical conditions and potential future conditions for the Oxnard Basin, a critically over drafted groundwater basin in Southern California. The model was calibrated to historical data from 1985 to 2015 and then used to project future conditions. A sensitivity analysis was conducted to evaluate the variability of the model and its sensitivity to model parameters such as population growth and irrigation demand. The calibrated model was used to simulate future projected climate scenarios and to evaluate the impact of potential future infrastructure projects on the basin. The findings from the study illustrate the complex nature of the system while identifying the impact of three major infrastructure projects on the basin's future water sustainability. The model results indicated that population growth, groundwater pumping regulation, coastal flux, and extended drought periods are threats to water security in the basin. Infrastructure implementation, particularly the use of recycled water provides an opportunity to improve water security in the basin.

These results illustrate the importance of integrated decision-making, the challenges in planning for uncertain future conditions, and the opportunity to use system dynamic modeling to assist policy makers, engineers, and water-decision makers relating to the management of water resources.

ACKNOLWEGEMENTS

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“If you don’t get the water now, you’ll never need it. The dead never get thirsty.”

~ William Mulholland
Los Angeles Civil Engineer

1. INTRODUCTION

The State of California is experiencing exceptional drought conditions that are threatening the availability of water resources for potable and non-potable applications throughout Southern California. During 2022, January and February, which are typically the wettest month in California, have been the record driest months. This drought follows 2021, which was the driest year in California history since 1924 (Becker, 2022). As shown in Figure 1-1, the majority of California is currently experiencing extreme or exceptional drought conditions.

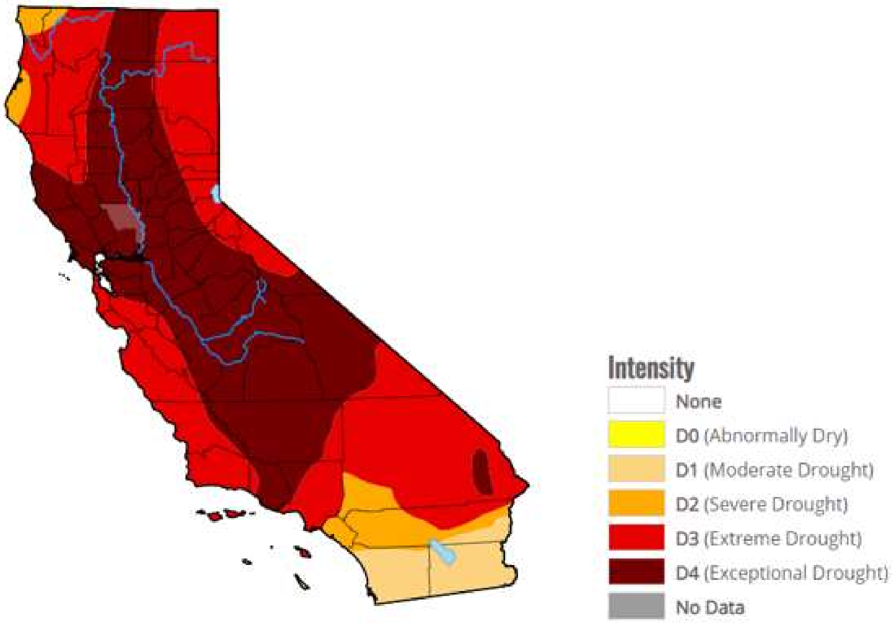


Figure 1-1. California Drought Level (Adapted from U.S. Drought Monitor, Sept. 2021)

California receives an estimated 75 percent of its rain and snow in the watersheds north of Sacramento. However, 80 percent of California's water demand comes from the southern two-thirds of the state (CDWR, 2021). The Central Valley Project, State Water Project, and Colorado River all support Southern California's water supplies. Southern California uses a complex system of local water supplies and imported water to meet water demands. Water infrastructure development, water governance, and management of water resources is multidimensional and is impacted by complex natural and human changes from population, land use, urbanization, climate change, policy decisions, and many other factors.

These issues are especially important considerations for the United Water Conservation District, a special water district located in Ventura County of Southern California to manage the local water supply, including the Oxnard Basin. The District has the mission to better manage, protect, and enhance water supply in the Santa Clara River Valley and Oxnard Plain which is an agriculturally dense region. The District manages water infrastructure and works with regulatory agencies that have direct impacts to the current and future health of the Oxnard Basin, which is currently critically over drafted.

This thesis uses a systems approach to develop a tool to assist policy makers, engineers, and water-decision makers relating to the management of water resources in the Oxnard Basin. The model explores the factors that impact available water supplies, the quality, quantity, and cost of water resources, as well as the timing and role of infrastructure development for managing water resources. The development of the model was aimed at answering the following questions:

- Can a systems dynamic approach be used to understand complex water resource management decisions for the Oxnard Basin?

- What are the drivers of water security in the Oxnard Basin?

- How can water management and implementation decisions be optimized to maximize water security in the Oxnard Basin?

This project contributes directly to the Sustainable Development Goals (SDGs), which are a worldwide guidance set forth by the United Nations in 2015 consisting of 17 goals to address global challenges facing the international community. These goals provide a framework for action to be taken by 2030 to provide a better and more sustainable future. The project contributes directly to the SDGs 2) Zero Hunger, 6) Clean Water and Sanitation, 9) Industry Innovation and Infrastructure, and 13) Climate Action. The project indirectly contributes to the

SDGs 8) Decent Work and Economic Growth, 14) Life Below Water, and 17) Partnerships for the Goals.

The thesis report is organized into the following sections:

- **Section 1:** **Introduction** –Presents an overview of the objectives and context of the project presented in this Report.
- **Section 2:** **Background and Literature Review** –Provides the context of water resource management in Southern California and information on system dynamics and modeling of systems.
- **Section 3:** **Case Study: Application of System Dynamics to the Oxnard Basin**– Describes the context in which the model was applied to the Oxnard Basin.
- **Section 4:** **Methodology** –Describes the steps that were taken in the development of a systems approach and Vensim model.
- **Section 5:** **Results** –Presents the results of the model calibration, model evaluation under climate scenarios, and optimization of the system through proposed infrastructure development alternatives.
- **Section 6:** **Discussion** –Provides a discussion summarizing the findings, the methodological contribution, project limitations, and future opportunities to build upon the presented work.

2. BACKGROUND & LITERATURE REVIEW

This chapter provides background information on the management of water resources including water security, availability, self-sufficiency and water governance as it applies to Southern California, as well as background information on system dynamics and modeling systems.

In the late 1800's and early 1900's, self-taught civil engineer, William Mulholland famously voiced to the public, *"If you don't get the water now, you'll never need it"* (Davis, 1993). He worked as the superintendent of the Los Angeles Water Department in Southern California and evaluated the scarcity of the water using a simple mental model. He estimated that the quantity of water from rainfall and inflow from the Los Angeles River was not adequate to meet the future growth and development demands of the growing city of Los Angeles. The city had grown from 50,000 residents in 1890 to more than 100,000 residents in 1900. He predicted that as the population continued to increase, water consumption would increase, and as a result the available water supplies would not be adequate. He forecasted that if the population could not continue to obtain water, Los Angeles would not survive as a city. Mulholland developed mental model of the water system, as is shown in Figure 2-1.

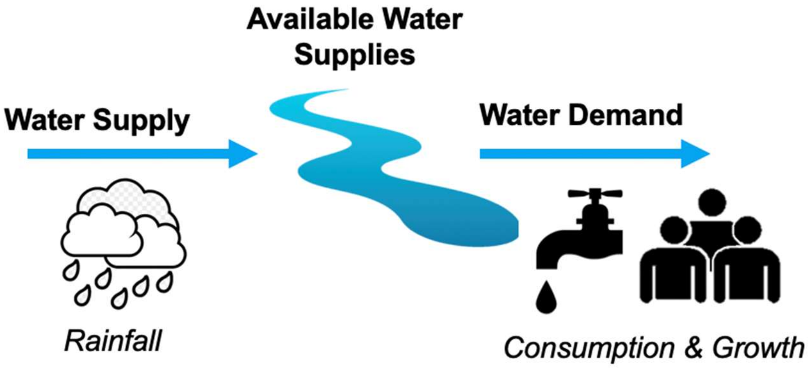


Figure 2-1. Simple Mental Model of Water Supply in Southern California

In Mulholland's position as superintendent he understood some of the complex relationships of water availability, water consumption, and city development. Using his mental model and understanding of the city, he strategized, initiated policy change, and developed infrastructure including the Owen's Valley Aqueduct. This aqueduct was the fourth-largest engineering project to date in American History, and the longest aqueduct in the Western Hemisphere, and was based on his mental model of water supply and demand patterns (Davis, 1993). As a result of this project, Los Angeles was able to continue to grow. The city grew to 575,000 by 1920 and 1.25 million by 1930, with a large portion of the water being imported via the Owen's Valley Aqueduct (Davis, 1993).

Since Mulholland's water decisions Los Angeles has grown from 50,000 residents to 3.9 million residents (Census, 2020), with 23.8 million people living in Southern California. As an arid and desert climate, Southern California continues to face significant challenges when making decisions regarding water resources. Mulholland's project also set the precedent in Southern California of imported water resources, supporting economic growth through water supplies that are not locally available, requiring the import of water to support many communities in Southern California.

2.1Water Security

Water security is defined by the United Nations as, "*the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustainable livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.*" Emerging from this and other available definitions of water security, four main themes emerge: water quality, water availability, water cost, and self-sufficiency (Figure 2-2). Lacking one or more of these themes threatens water security.

Figure 2-2. Key Components Driving Water Security

Water availability indicates that there is adequate water supplies to meet the required demands. *Water cost,* is the ability to provide water at an affordable price. *Self-sufficiency,* is the ability to provide water without reliance on significant external factors and/or the ability to minimize those external factors impact on the water supply. *Water quality* requires that the available water resources are potable, requiring adequate raw water quality and/or the ability to treat the water to meet a standard that is deemed safe for human consumption. These components and how they relate to water security are discussed further in subsequent sections.

2.1.1.1 Water Security Indices

Frameworks have been established to assess water scarcity including the development of indices. These indices relate the availability and access to an adequate quantity and quality of water for the population, with an acceptable level of risk for impacts of hydrometeorological extremes (Calow, 2013). The creation of an index allows for the systematic assessment of water security across scales, locations, and over time (Doeffinger, 2021). The United Nations established the *Global Water Security Index* (GWSI) that evaluates availability, accessibility to services, safety, and management (Arreguin-Cortes, 2020). Scarcity within the GWSI is defined as

$$WSI = \frac{W_w}{A_w - E_w}$$

Where, W_w is the water withdrawal, A_w, is the water availability, and E_w is the environmental flow requirements (Arreguin-Cortes, 2020).

Similarly, the Asian Development Bank (ADB) developed a framework for evaluating water security called the *National Water Security Index* (NWSI). The NWSI has been applied to compare water security between countries and evaluates household, economic, urban, and environmental security and resilience to water related disaster (ADB, 2016). At a national level, domestic water supply security framework was developed to analyze water security in Ethiopia. The framework accounts for water supply, sanitation, and hygiene, which are assessed through twelve indicators. These indicators include water supply, sanitation, and hygiene. This framework applied equal weights to the variables and indicators. The index resulted in a level of water security rated from 0 to 5, with 0 representing the inability to meet water requirements for citizens, and 5 providing an ideal example of a water-secure society (Assefa, 2019).

An assessment was conducted of 107 publications by scholars and practitioners that have identified methodologies to measure and index water security. The findings indicated that the more local the scale and more specific to the water domain, the more meaningful the metrics provided to the understanding of water security (Octavianti, 2020).

Within the United States, Doeffinger (2021) has used a selection of ten sub-indicators with data collected from 2008 to 2018 to evaluate and define water security across the country. This index evaluated sustainability of water usage, water quality, productivity, infrastructure, institutions, people, service, floods, economy, floods, droughts, environment and biodiversity. In the development of the index, indicators were given equal weighting and a sensitivity analysis was conducted. Based on the findings of the sensitivity analysis, a weighting schema was applied, resulting in a larger emphasis on water stress and access to water services. The composite indicator was subdivided into five brackets, with one (1) corresponding to the lowest water security, and five (5) corresponding to the highest water security. While this water security assessment has been conducted across the entire United States, there is no formally countrywide adopted water security index that is used for measuring, evaluating, or comparing water security (Doeffinger, 2021).

Worldwide, the use of an analysis methodology that enables the measurement and communication of water security levels provides a step toward reducing water related risks, and aids future planning. Summarizing water security into an index aids the engagement of stakeholders, especially policy makers, shaping water security into a more tangible and measurable concept (Octavianti, 2020). However, there is the drawback that performance indicators that quantify systems based on subjective and priori determined criteria could result in augmented understanding of the system and other missed and available metrics (Thomas, 2019).

2.1.1.2 Water Security in Southern California

There is currently no adopted metric for evaluating water security that is used within the Southern California or the State of California. California has however developed the Sustainable

Groundwater Management Act which has developed an index for evaluating groundwater supplies. The index assesses reliability (REL), resilience (RES), and vulnerability (VUL). These performance indicators comprise the sustainability index (SI) which is calculated as:

$$SI = REL\ x\ RES\ x\ (1 - VUL)$$

While water sustainability and security are not synonymous, the concept of developing metrices for communicating complicated numerical modeling and hydrogeologic phenomenon to discuss water resources among stakeholders is critical. The index can highlight complex and variable interactions between the groundwater use, climate, and groundwater storage to assess groundwater sustainability. The SI can and has been used to inform management decisions and identify future intervention strategies (Thomas, 2019).

In addition to the evaluation of groundwater using the SI, all forms of water for urban consumption are required to be evaluated regularly. The State of California requires urban water supplies to develop Urban Water Management Plans (UWMPs) every five years that support the suppliers' long-term resource planning. The intention of the UWMP is to ensure that adequate water supplies are available to meet current and future projected water needs. These plans are required by any water supplier that provides over 3,000 acre-feet of water annually, or serves more than 3,000 urban connections. These plans assess the reliability of water sources over a 20-year planning period, evaluate demand management and water shortage contingency plans, and discuss the planned use of recycled water (CDWR, 2022).

The UWMP requires the development of a water shortage contingency plan. This provides a detailed proposal as to how a supplier intends to act in the case of a water shortage. Six standard water shortage levels are identified and correspond to ranges of 10, 20, 30, 40, 50, and greater than 50 percent shortage. The shortage levels are defined based on the water suppliers' water supply conditions such as percent reductions in water supply, changes in groundwater levels, changes in surface elevation, or level of subsidence.

The Sustainable Groundwater Management Act (SGMA) was passed by California legislators in 2104 and provides a framework to help protect groundwater resources for the future. The SGMA requires local agencies to form groundwater sustainability agencies (GSAs) for those in the high and medium priority basins. These GSAs are required to develop and implement groundwater sustainability plains to mitigate overdraft within the next 20 years (DDW, 2021).

2.1 Water Availability

Available water supply is the quantity of water that can be used for human purposes, and is a function of the amount of precipitation, natural ecosystem requirements, and the amount of water that can be stored and or captured. Available water sources are summarized in Table 2-1.

Table 2-1. Water Sources

Type	Storage	Origin
Surface Water	Lakes, streams, rivers, reservoirs, ocean*	Rainfall
Groundwater	Groundwater basins	Infiltration from rainfall/water bodies
Recycled Water	Tanks	Rainfall, grey/blackwater
Imported Water	Reservoirs, tanks	Outside of

**Requires reverse-osmosis treatment to remove salts*

2.1.1.1 Southern California Local Water Resources

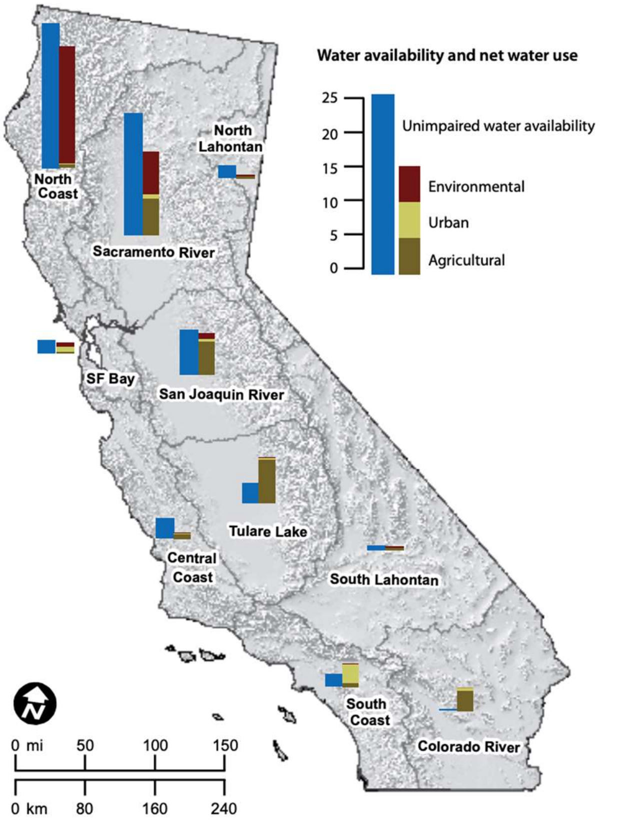
Groundwater accounts for at least one-third of all water use in California (CDWR, 2021). Southern California has minimal local water resources available, when compared to the total environmental, urban, and agricultural demands. Figure 2-3 demonstrates the comparison of available water sources (blue bars) to the required water uses (red, yellow, and green) for each region. The South Coast and Colorado River regions, which make up the majority of Southern California, have significantly higher water demands than water availability. Southern California has supplemented their water supply through the use of alternative treatment and water management methods. These recycled wastewater, urban stormwater, and desalinated seawater and brackish water.

2.1.1.2 Southern California Imported Water Resources

Drought conditions impact the availability of water from the California State Water Project (SWP), which is a state financed water project designed to divert millions of acre feet of water from the Delta, the Colorado River, and the Los Angeles Aqueduct. Twenty-nine contractors purchase water from the SWP and deliver the water to municipalities and other water users. The amount of water available for purchase is dependent on allocations of the total available water supply set by the California Department of Water Resources (DWR). Allocations are dependent on supply (see Section 2.3.1).

2.1.1 Climate Impacts on Southern California Water Availability

Climate change is expected to lead to intensification of the global hydrologic cycle and have direct influences on overall water resource availability (Huntington, 2006). In 2009 and 2013 the California Natural Resources Agency prepared reports to the Governor on California's Climate Adaptation Strategy and produced four climate change assessments, with the most recent issued in August 2018. These climate change assessments evaluated the losses to the Sierra snowpack and water supply. Based on the findings of California's Fourth Climate Change Assessment, the impacts of climate change will disproportionately affect the State. Snowpack, temperature change, and precipitation patterns are anticipated to impact water availability.



SOURCE: California Department of Water Resources, *California Water Plan: Update 2009*, Bulletin 160-09.

NOTE: The map shows annual average values for 1998–2005 in millions of acre-feet.

Figure 2-3. Water Resources in California (California Department of Water Resources, 2009)

Climate Change & Snowpack

The Sierra Nevada snowpack functions as the most important natural reservoir of water in California, slowly releasing approximately 15 million acre-feet of water in the spring and summer to California. The dams and water storage facilities within California have been designed to accommodate the snow melt. However, higher temperatures are resulting in earlier snowpack melt are anticipated to result in earlier and larger releases of water that the existing infrastructure may not be sized to accommodate. The spring snowpack stores approximately 70 percent as much water as the engineered reservoirs can store (Dettinger & Anderson, 2015). Snowpack melt contributes to approximately 70 percent of the total water supply in the Colorado River Basin. Southern California relies on the Colorado River Basin for approximately 55 percent of its water supplies. Regional analyses indicate that climate change has already begun to reduce the fraction of precipitation falling as snow (Knowles et al., 2006) and has diminished spring snow water accumulation in the western United States. Snow water storage, averaged across the western U.S., has declined by approximately 10 percent (Bedsworth, 2018). Based on climate change models, by 2050, the snow water equivalent is estimated to decline to less than two-thirds of its historical averages. By 2100, it is anticipated to decline to less than half the historical median under one scenario, and less than one-third under another scenario. However, the climate models predict that the amount of precipitation is anticipated to maintain stable, however, stronger year-to-year variation in precipitation is anticipated (Bedsworth, 2018). This suggests that existing infrastructure is not adequately sized to capture the earlier snow melt and larger variability of volumes across years.

Climate Change & Temperature

California temperatures (1986-2016) have warmed above temperatures recorded during the first six decades of the 20th century (1901-1960). The annual temperature increases over the majority of the state have exceeded 1°F, with some areas exceeding 2°F. Temperature projections for California are shown in

Table 2-2.

Table 2-2. Temperature Projections for California

Scenario	Early Century 2006-2039	Mid-Century 2040-2069	Late Century 2070-2100
Climate Scenario 1	+2.5	+4.4	+5.6
Climate Scenario 2	+2.7	+5.8	+8.8

Projected increase in annual average maximum daily temperatures under RCP 4.5 (Scenario 1) and 8.5 (Scenario 2). (Pierce et al., 2018)

Climate Change & Precipitation

California has a highly variable climate. Recently there were unusually wet years observed in 2005, 2011, and 2017. However, there were droughts observed from 2001-2004, 2007-2010, 2012-2016, and 2019-present. Paleoclimate measures indicate two spells with several decades of prolonged dryness existed, and climate models suggest that a similar prolonged 'mega-drought' has a higher probability of occurring within the 21st century. The heaviest precipitation occurs in the winter, when storms are fed by streams of water vapor from the Pacific Ocean (Bedsworth, 2018). The climate models project less frequent but more extreme daily precipitation. Year-to-year precipitation is anticipated to become more volatile, and the number of dry years is anticipated to increase (Berg & Hall, 2015; Pierce et al., 2018; Swain et al., 2018).

2.2 Water Self-Sufficiency

Water self-sufficiency is the ability to provide adequate water resources without reliance on an external source or organization. Benefits of water self-sufficiency include:

- **Reduced Water Shortage Risk:** A seismic event or significant decrease in water resources further minimizing or eliminating the amount of available imported water.

- **Energy & Carbon Footprint Reduction:** To transport water long distances requires significant energy including pumping. By reducing the amount of energy required for water transport, energy consumption and carbon footprint can be reduced.

- **Political Control:** Relying on water outside of the area of use requires political action and cooperation from many stakeholders. Self-sufficient water supplies can minimize political tension outside of their jurisdiction. Excess water supplies can also be leveraged with neighboring communities.

- **Reduced Costs:** Significant infrastructure must be maintained to transport as well as the cost of energy to transport the water. The cost of imported water can also be potentially more expensive than locally sourced water.

- **Environmental Impacts Minimized:** Water imports can reduce available water supplies in other regions, having negative impacts on existing ecosystems.

2.2.1.1 Water Self-Sufficiency in Southern California

Southern California does not produce adequate water locally to meet water demands. The region imports a large portion of its water from the Metropolitan Water District, with that water being sourced from the Colorado River Aqueduct (25%), the State Water Project (30%), and local stormwater, groundwater, recycling, and desalination (45%). In 2018, as part of the Resilient Los Angeles Plan, Garcetti introduced the objective to reduce reliance on imported water for Los Angeles from 85% to less than 50% by 2035 (Gold, 2018). Motivation behind Garcetti's plan of a self-sufficiency, as well as other communities is driven by the risk of a seismic event that would cut off water supplies, increased water costs, and political tensions as water sources may become scarcer.

2.2.1.2 Water Infrastructure for Self-Sufficiency

Self-sufficiency, however, comes at a cost of new or expanded infrastructure. Developing new infrastructure can provide additional infrastructure for the capture of existing water resources, as well as expanding to use new water resources. Desalination of ocean water or brackish groundwater is one infrastructure alternative that communities and agencies are evaluating. Ocean and brackish water are available water resources in the area, however, they do not meet water quality standards for potable use. The use of treatment technologies can expand the available water supplies, improve water quality, and improve self-sufficiency.

2.2.1.3 Brackish Water

The extraction and treatment of brackish groundwater for irrigation and potable use provides an alternative for inland water users in Southern California to reduce reliance on imported water from the imported water, while using local groundwater resources that cannot be used due to their high salt concentrations. Extraction of brackish water in some circumstances can also mitigate the impacts of saline intrusion into an aquifer resulting from coastal flux. Saltwater intrusion can occur when wells in close proximity to the ocean can upset the balance between the freshwater and saltwater interface. Under normal conditions, shown by the top figure in Figure

2-4, the fresh groundwater discharging ot the coast prevents the saline water from entering the groundwater table. However, when pumping is added, the ocean water can migrate landward by the process of saltwater intrusion.

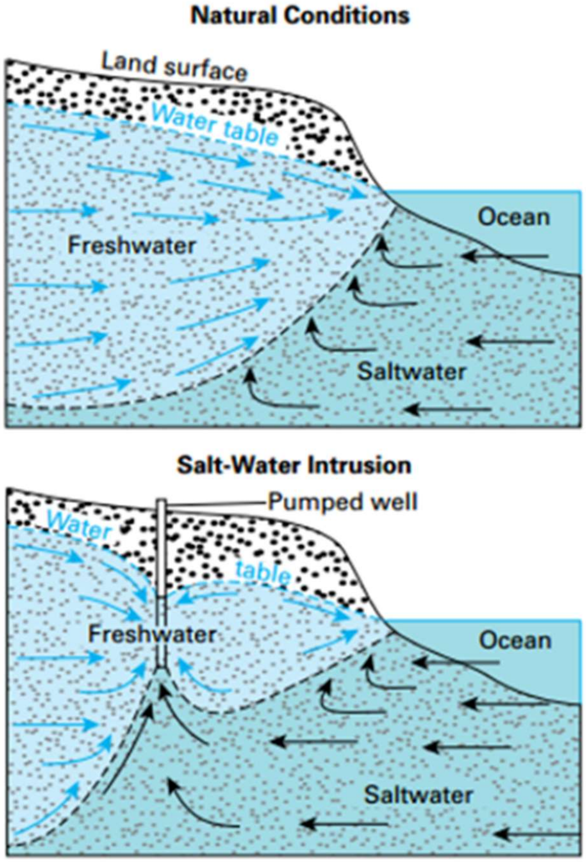


Figure 2-4 Brackish Water Saline Intrusion (USGS)

Reverse osmosis (RO) can be used to treat brackish groundwater; however, it has historically not been used due to the high cost per unit of water, energy demands, and technical complexity. An inland brackish groundwater system is comprised of an aquifer in which water is extracted through a pump. A treatment technology such as RO is used to remove salts and other contaminants, using a membrane. RO is a pressurized, energy intensive, membrane filtration process. The RO membranes have extremely small pores and through multiple mechanisms, the dissolved ionic contaminants in water can be removed. A treated potable permeate water and a reject stream of brine discharge results from the treatment process (Figure 2-5). While the aquifer, treatment, permeate, and brine are each a distinct step in the extraction process of inland brackish groundwater, the components are interconnected.

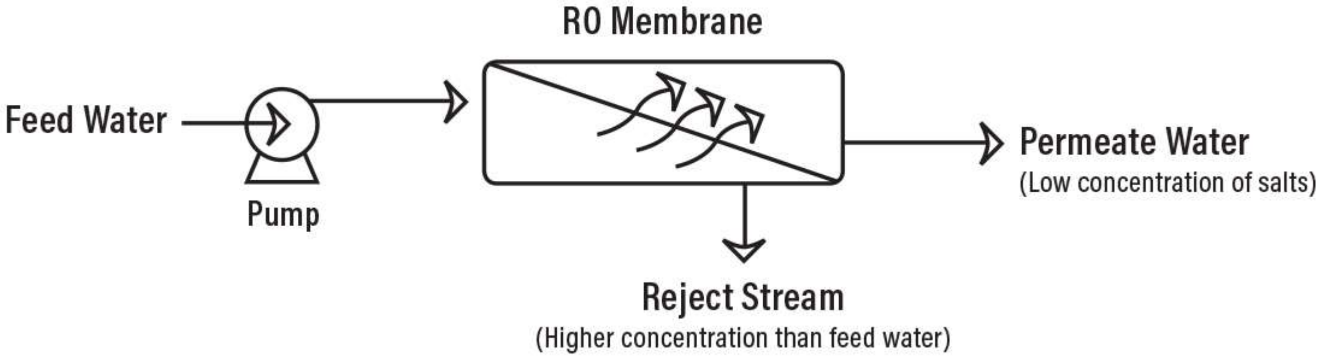


Figure 2-5. Brackish Water Treatment Process (Puretec Industrial)

Major challenges to inland brackish groundwater treatment are the inability to recover a high fraction of the feed water due to poor use of scarce natural resources and the disposal of the concentrate stream, or brine (Crittenden, 2012). Additionally, RO membranes are susceptible to scalants, and depending on the raw water quality, pre-treatment may be required to remove constituents that would cause lower recovery rates as a result of fouled membranes.

Innovation in treatment technology has led to higher recovery rates of brackish water treatment. The recovery rate of a traditional RO system ranges from 40-70%. Closed-circuit reverse osmosis (CCRO), which is a technology provided through DesaliTech^{TM}, offers systems that can recover over 90% of the water treated, minimizing waste. Conventional RO systems run a crossflow process, where the saltiest water collects at the end of the pressure vessel before it is disposed. The CCRO system uses a semi-batch process, which recirculates the feed water until the target recovery rate is achieved. This recirculating allows the entire membrane surface to be exposed to similar salt concentrations and reduces membrane fouling from the scaling potential.

Since the level of treatment in a RO system produces extremely pure water, brackish water that does not have significant contaminants can be blended with raw water. This can reduce the total amount of water that has to be extracted.

Brine Management for Brackish Water Treatment

The amount of brine that is produced from RO or CCRO is related to the recovery rate of the system and the total flow into the system. If the recovery rate of a system is 85%, then 15% of the influent water will become part of the reject stream. For low recovery rates and/or large systems, this can result in significant brine streams.

A variety of methodologies exist for managing brine. These practices include disposal methods such as surface water discharge, sewer discharge, deep-well injection, evaporation ponds, land application, as well as emerging treatment technologies for zero liquid discharge (ZLD) such as membrane and thermal-based technologies. Natural plant-based options are also gaining traction as new emerging technologies.

Site-specific conditions, environmental conditions, and costs are major components that impact the decision-making process for brine management and must be balanced. However, tools for decision-makers in identifying optimal brine management methods that consider the urban water cycle, integrated water systems, and resiliency are not readily available. The lack of information and understanding may lead to difficulties in quantifying the true cost and effectiveness of these brine management systems in protecting the environment and future water supplies.

2.3Water Governance

Water governance includes the formation, establishment, and implementation of water policies, legislation, and institutions that provide a framework for who, how, and when people receive water services. Water governance provides the governing body who makes the decisions and the framework in which the decisions are made, as they relate to water security. Water governance includes the management of available water resources, identifying water quality requirements, and setting water costs. In the 1990's, Google Scholar records had only 47 references to the phrase 'water governance', however by 2014 there were 2,640 references (Woodhouse, 2016). Solutions to water resource problems require the application of scientific principles and an understanding of the social, political and economic conditions in which the problems exist. Management of water resources systems is based on human interventions and highlights the need for both collective and individual action. However, these decisions are becoming increasingly serious and complex. (Simonovic, 2009). Some examples of water governance include:

- **Water Resources:** The decision of which water resource to use as a potable or non-potable water supply.

- **Water Cost:** The pricing framework and annual rate of cost increases for water customers.
- **Water Infrastructure:** Whether to build a new water treatment
- **Water Quality:** What the allowable level of biological, chemical, or physical constituents within the delivered water supply.

2.3.1.1 California Water Governance

There are approximately 3,000 community water systems (CWS) in the state of California. California has a decentralized management of water, relying on local and regional agencies which coordinate with state agencies. State agencies include the California Department of Water Resources (CDWR), California State Water Resources Control Board (SWRCB), Regional Water Quality Control Boards, California Water Commission, the Colorado River Board of California, amongst others. The main types of local or regional water managing entities are cities, county districts, special districts, public utilities, and mutual water companies.

California State Water Resources Control Board (SWRCB) & Regional Water Quality Board

The SWRCB is one of six branches of California EPA, which was established from the Dickey Water Pollution Act of 1949. The SWRCB includes the following divisions with their main responsibilities:

- **Division of Water Quality:** Sets water quality standards, issues permits, conducts surface and groundwater monitoring
- **Division of Water Rights:** Permitting for stream or river water rights
- **Division of Financial Assistance:** Loans and grants for water infrastructure
- **Division of Drinking Water:** Inspections, permitting, and enforcement. Approval of new technologies, accreditations of laboratories, and maintains water quality databases.

There are nine ***regional water quality boards*** within California, with the boundaries of these boards based on watersheds and water quality requirements. These boards are semi-autonomous and are responsible for making decisions that impact water quality including setting standards for issuing waste discharge requirements, determining compliance with requirements, and implementing enforcement actions. These agencies are responsible for water supply management such as identifying water supplies, wastewater treatment, flood control, land use decisions, and groundwater overdraft (Hanak, 2011). Southern California is primarily comprised of the Los Angeles, Santa Ana, San Diego, and Colorado River Basin regional water boards (Figure 2-6).

Figure 2-6. Map of California Regional Water Control Boards (CA SWRCB, 2022)

California Department of Water Resources (CDWR)

The CDWR has the responsibility to prevent and respond to floods, droughts, and catastrophic events, plan for future water needs, evaluate climate change impacts, and ensure public safety as it relates to water resources. The CDWR operate and maintain water storage and supply systems as well as regulate the use of groundwater. The CDWR must apply for water right permits from the SWRCB.

One of the roles of the CDWR is to manage the SWP. Water deliveries and sales of the SWP is not conducted by the CDWR, but by state water contractors. The CDWR issues allocations for the SWP, which is a predetermined water supply volume. These volumes are based on the CDWR and water contractor's initial contract. Due to the hydrologic variability, the actual availability of SWP water varies. Based on the precipitation and snowpack runoff, the SWP allocation can increase or decrease as a percentage of the contractor's maximum contracted allocation. Historical allocations are shown in Figure 2-7. At the beginning of 2022, CDWR allocations limited to only the volume required to cover critical health and safety needs. Due to the increased precipitation in December 2021, these allocations were increased to 15 percent of the requested supplies.

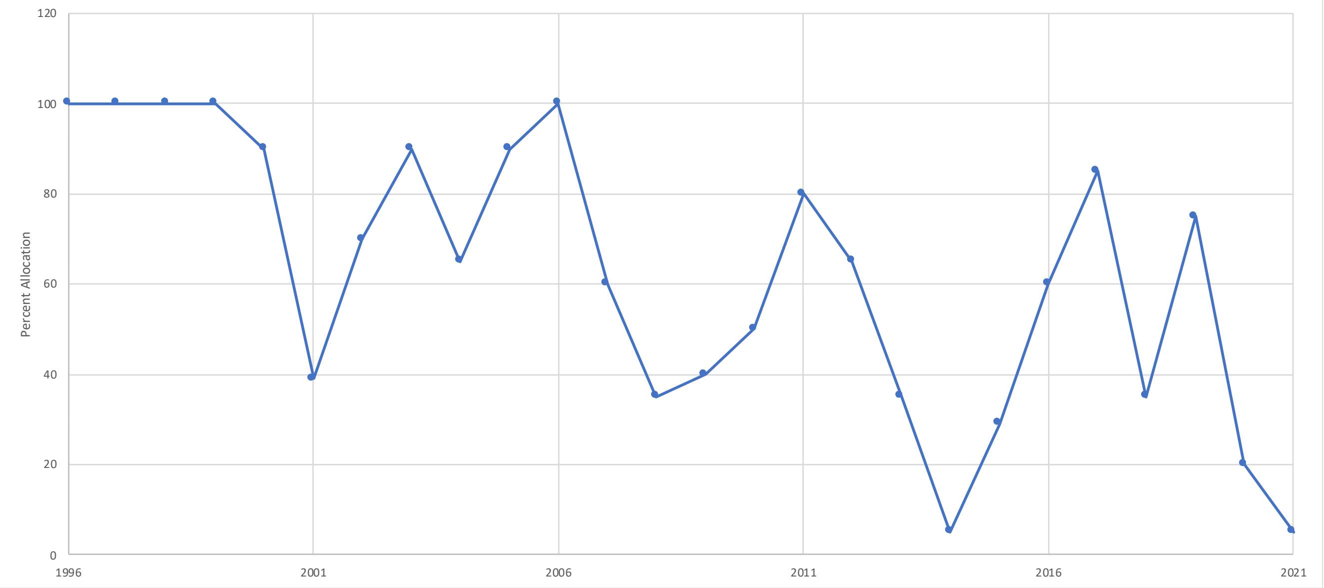


Figure 2-7. CDWR SWP Allocations 1996- 2021 (Data Source CDWR)

State Water Contractors

The State Water contractors (SWC) includes 27 public water agencies that locally manage SWP water. 13 of the 27 SWC are located within Southern California, and account for 63 percent of the total water allocated from the SWP (Lund, 2022). These agencies and their percent of SWP available water is summarized in Table 2-3.

Table 2-3. Southern California State Water Contractors

State Water Contractor	Type of Agency	Percent of Total SWP (%)
Antelope Valley East Kern	Water Agency	3.5
Castaic Lake	Water Agency	2.3
Coachella Valley	District	3.3
Crestline Lake Arrowhead	Water Agency	0.1
Desert Water Agency	Water Agency	1.3
Littlerock Creek	Irrigation District	0.1
Metropolitan	District	45.8
Mojave Water Agency	Water Agency	2.2
Palmdale Water District	District	0.5
San Bernardino Valley	District	2.5
San Gabriel Valley	District	0.7
San Gorgonio Pass	Water Agency	0.4
Ventura County	Watershed Protection District	0.5
SWC Outside of Southern California		36.8

California Special District

California Special Districts are local government agencies that provide essential services to citizens. These districts are formed and governed by local residents to establish or enhance the essential services and infrastructure within a community. There are approximately 2,300 special districts within California, with 537 special districts that manage water resources. Some SWC are special districts, however, not all special districts are SWC.

Cities, Counties, Public Utilities, Mutual Water Companies

The water that is delivered to the end user can come directly from a SWC or a California Special District, however, it is most likely that it will come through a city, county, public utility, or mutual water company. These organizations will collaborate with districts and SWCs to supplement some or all of their water supply.

2.4System Dynamics & Modeling Systems

All decisions that are made are based on models. These decisions are typically mental models that reflect an individual or organization's understanding of relationships within a system.

The field of system dynamics (SD) was created during mid-1950's by Professor Forrester as he identified that social systems are much harder to understand and control than are physical systems and identified methods of developing models to explain the relationship of employment business cycles at General Electric. From the 1950's to late 1960's SD modeling was applied primarily to corporate and managerial problems, however in the late 1960's and early 70's, Forrester began collaboration with John Collins and developed Urban Dynamics. This was the first major non-corporate application of system dynamics and evaluated urban policy implementation (SDS, 2021). Since then, the field of SD has grown with applications such as economics, health care, supply chain management, and the natural and built environment.

SD can be used to evaluate the dynamic complexity of a system. This is achieved by the positive and negative feedback loops between systems and how the connections within the system give rise to system behavior. It allows the study of how those connections influence the overall system and how changing those connections can influence the overall system. SD enables a greater understanding of the interconnections within a system and which may provide the greatest significance to the system behavior. With understanding which interconnections and relationships are most significant it allows for the opportunity for focused action to impact the system in a desired way.

System dynamics models (SDM) are a method of transforming mental models into differential equations that can be used to analyze complex systems that include social and qualitative factors. These models can be used to gain insight into circumstances of dynamic complexity and policy resistance. A SDM includes information on an individual or organization's understanding of the networks of causes and effects that describe how a system operates, as well as the boundaries in which the model operates and exists within. Feedback, the results of our actions, define the situation faced in the future. This new situation alters our assessment of the problem and decisions made in the future. The basis of SD models is primarily the mental model of the relationships.

Forrester states, "*The mental database is tremendously powerful, and has millions of times more information in it than you will find in any books or data series. Unless one uses that database, you are missing what makes the world run. The world does not run on the data series, it does not run on what you read in the books in the newspapers, it runs on what's in people's head and have to be willing to model from that"* (Forrester, 2013).

2.4.1.1 Existing Application of System Dynamics for Water Management

Modeling, can and has been used as tool for estimating economic, ecological, and social impacts prior to making and implementing expensive infrastructure decisions (Simonovic, 2009). Historically, SD has been used by various agencies for water management. Two paradigms drive SD applications for water management, (1) the *complexity paradigm*, and (2) the *uncertainty paradigm*. The complexity paradigm states that water problems in the future will continue to grow in complexity. Domain complexity will continue to increase, with population growth, climate variability, regulatory frameworks, and other factors increasing the complexity of these problems. The *uncertainty paradigm*, states that all elements increase in uncertainty over time and space. The two largest uncertainties in water decision making is hydrologic variability and uncertainty. Hydrologic variability is the temporal and spatial variability of precipitation. There is a lack of knowledge and uncertainty of the increased natural variability of water and how water flows will be impacted in the future, impacting domestic, agricultural and industrial uses. Anticipated, but uncertain local maxima and minima hydrology and hydraulic flows result in uncertainty in design (Simonovic, 2009).

The first published application of system dynamics to water was in 1979, which evaluated water-supply policies on growth in Saudi Arabia's agricultural region (Picardi, 1979). Since Picardi's article more than 1,000 articles related to water and system dynamics have been published. Phan (2020), evaluated these articles and identified that 77% of the system dynamic water models were used to develop and understand a long-term perspective of water-related issues for decision making. Of these long-term perspective models, 23% of these models evaluated long-term applications 50+ years in to the future (Phan 2020). 82% of water SDMs were used to evaluate scenario-based approaches. These were used to answer 'what if' questions by evaluating the effectiveness of various management measures under different scenario conditions (Phan 2020).

SDM have been developed at various scales, from the country to community level. At the country level, the Integrated Water Resources Model for Egypt (IWRME) was developed with a SD approach that evaluates various policies and their long-term effects to inform long-term socio-economic plans at the national level (Simonovic, 2009). On a smaller scale, the Red River basin in Manitoba, Canada was used to evaluate flood management (Ahmad, 2004). On a similar small-scale application, SDM was applied to aquifer storage and recovery analysis for aquifer storage and recovery wells in the context of the Sirik region of Iran (Niazi, 2014).

2.4.1.2 System Dynamic Tools

Several tools are used for the analysis of systems in the process of developing a system dynamics model. These tools include reference modes, model boundary charts, causal loop diagrams, and stock and flow maps.

Reference Modes

A reference mode is a set of graphs and descriptive data that shows the development of the problem over time. These graphs demonstrate how known and observed trends relate to events or actions. These graphs are used to guide model-building and provide a comparison of anticipated patterns against the model stimulated system behavior. Three reference modes, as well as others, were derived to serve as guides for the subsequent model development.

Model Boundary Chart

System dynamics seeks endogenous explanations for phenomenon existing within a system. *Endogenous variables* are those which change based on the interaction with other components within a system, based on the rules of interaction and decisions within a system. *Exogenous variables* are those in which arise or change over time without the variables defined within the system.

Causal Loop Diagrams

A causal loop diagram is a tool that can be used to represent the feedback structure of systems . These diagrams consist of variables that are connected by arrows that denote the influences among the variables. Within the diagram variables are assigned a polarity to describe how the dependent variable changes because of the independent variable. A positive link indicates that an increase in the independent variable causes in increase in the dependent variable, or similarly a decrease in the independent variables causes a decrease in the dependent variable. A negative link indicates that an increase in the independent variable causes a decrease in the dependent variable, or similarly a decrease in the independent variable causes an increase in the dependent variable. All dynamics are a result of the interaction of positive (self-reinforcing) and negative (self-correcting) loops. A positive loop will reinforce or amplify the system, while a negative loop will counteract the and oppose the change within the system.

Stock and Flow Maps

Stocks and flows trace the accumulations of variables throughout the system such as population or quantities of water. Stocks can be used to characterize the state of the system and generate information upon which decisions are made. The stock is represented by a square, where variables accumulate. Flows go either in or out of the stock which influences whether the stock is accumulating or reducing over time.

3. OXNARD BASIN BACKGROUND

This chapter provides a summary of the location and context of the Oxnard Basin that a systems approach was used to understand the drivers of water security.

3.1 Location & Context of the Oxnard Subbasin

The Oxnard subbasin is in Southern California in Ventura County as shown in Figure 3-1. The subbasin is an approximately 90-square mile coastal alluvial groundwater subbasin, with adjoining basins to the north and east. The Pacific Ocean is to the west and southwest. The basin is comprised of the perched aquifer, lower aquifer system, and upper aquifer system. The groundwater basin is currently in a state of critical overdraft. The basin faces challenges of chronic lowering of groundwater levels, reduction of groundwater storage, seawater intrusion, degraded water quality, land subsidence, and depletions of interconnected surface water.

Primary sources of water for the Oxnard basin are precipitation recharge, stream leakage from the Santa Clara River, and artificial recharge from natural and imported water sources. Ventura county receives on average 12 to 20 inches of rain per year. Climate change is anticipated to impact the total amount of rain received and the intensity of storm events. There is also higher probability of post fire flash flooding, debris flows, and high intensity rainfall. The snowpack in the Los Padres National Forest provides snowmelt to Ventura County which feeds the Santa Clara River and its tributaries. This snowmelt is anticipated to decrease by 17 percent und climate change conditions.

The first water wells were drilled in Ventura County during the 1880’s and from the 1900’s to 1950’s development of lands for farming and urban use increased water demands. Beginning in the 1950’s and becoming more progressive over time, regulation and management of water resources has grown.

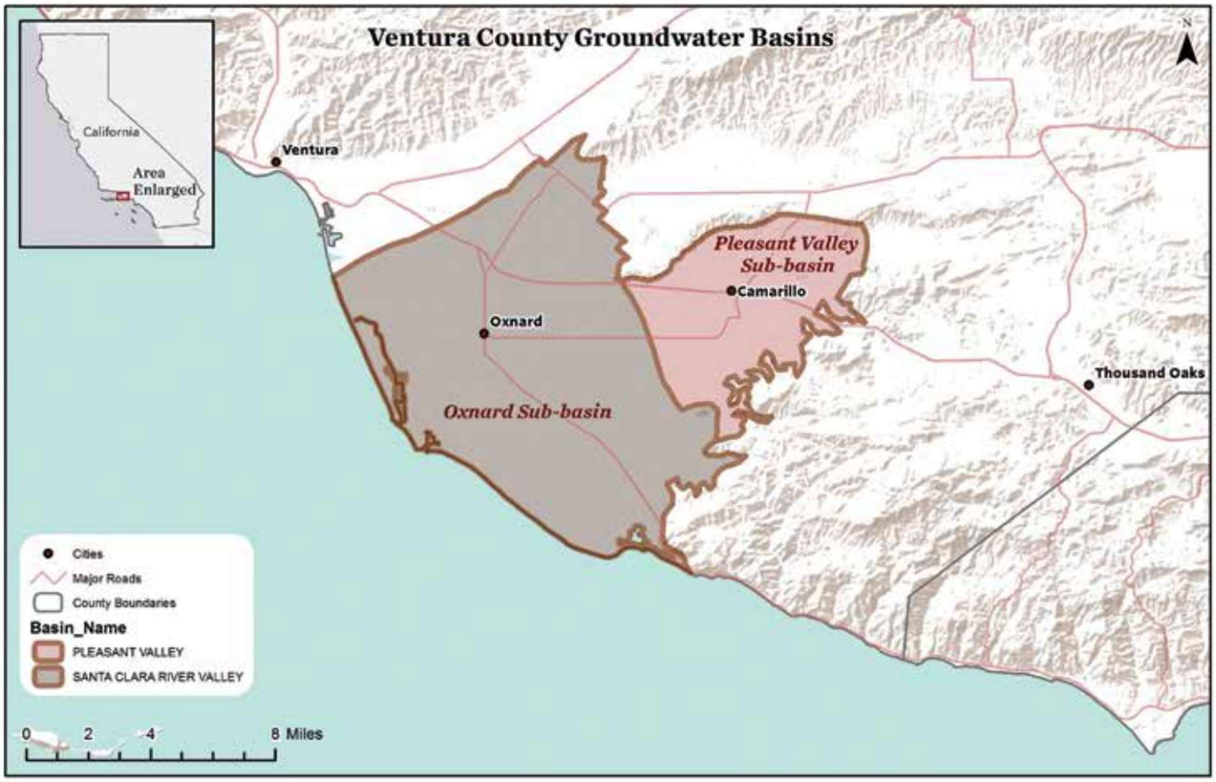


Figure 3-1. Location of the Oxnard Basin

3.2 Stakeholders in the Oxnard Basin

There are many stakeholders that are within the Oxnard basin. Three major stakeholder are water users, the Fox Canyon Groundwater Management Agency (FCGMA), and the United Water Conservation District (UWCD).

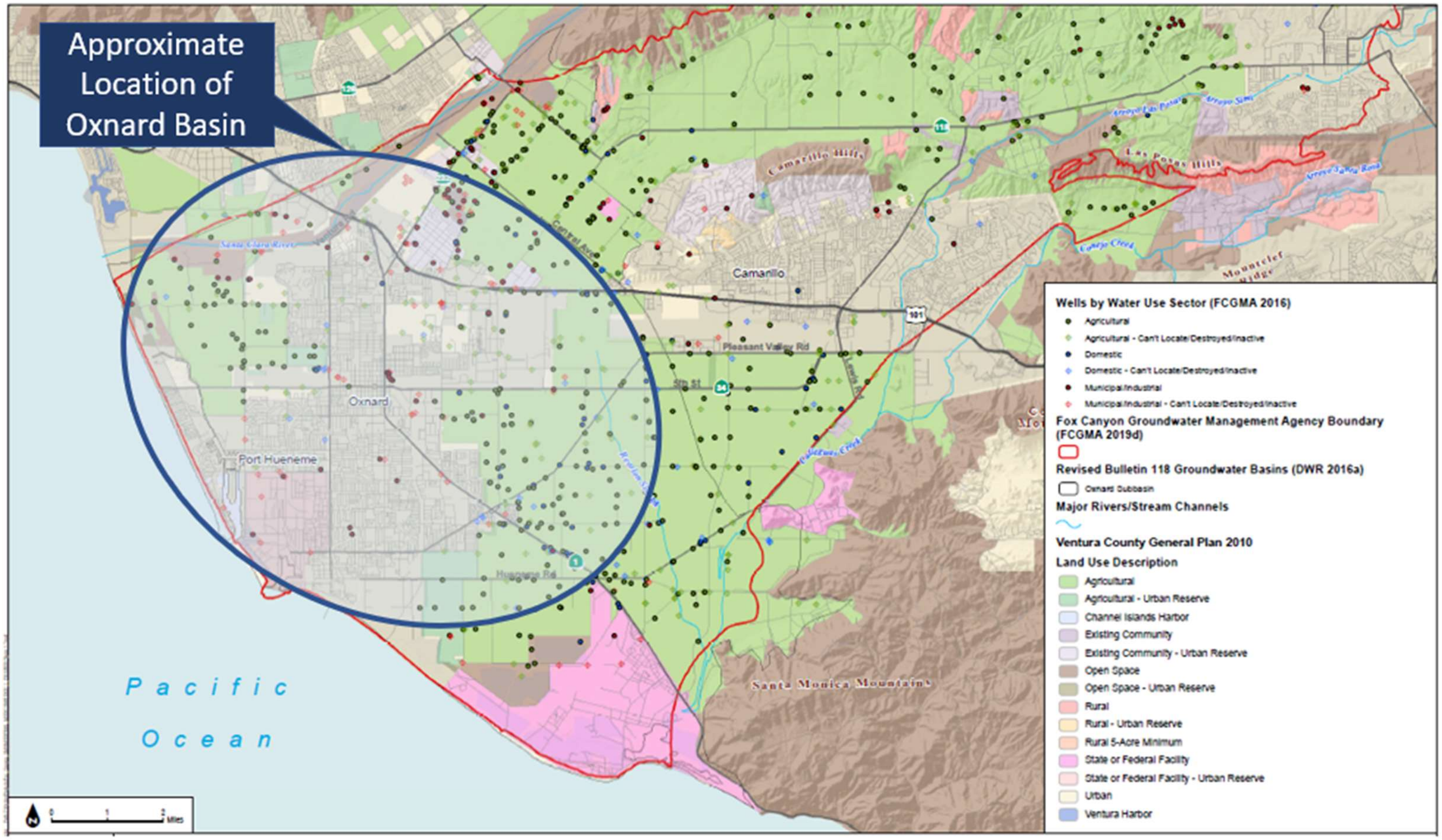


Figure 3-2. Oxnard Basin Wells by Use Sector (Adapted from Dudek, 2021)

3.2.1.1 Water Users

There are three main types of water users in the basin; (1) agricultural, (2) municipal & industrial (M&I)), and (3) domestic. These water users either rely on water from the basin or other available water sources to meet water needs. Due to the limited water supplies and state of overdraft of the Oxnard Basin there are several regulations in place that limit the volume of water use for each type of user.

Agricultural

Agricultural demand accounts for more than half of the water use in the basin. The agricultural areas are shown in Figure 3-3. There are three growing seasons, resulting in agricultural water demand required throughout the year. The highest water demand period is in October, however, this also corresponds with the start of the rainy season.

Agricultural users can obtain their water for irrigation as natural precipitation, private pumping wells, or through an existing distribution system that delivers a combination of pumped groundwater and surface water. Water demands from the existing water infrastructure is dependent on precipitation patterns and water pumping extraction limits that are set forth by the groundwater management agencies.

Municipal & Industrial

M&I demand accounts for the second largest water use in the basin. These demands fluctuate with population growth as well as precipitation. The M&I use is primarily supplied within the existing Oxnard-Hueneme (OH) pipeline distribution system or through private wells.

Domestic

Domestic water users make up the smallest portion of water use in the basin. The domestic use is primarily within the existing Oxnard-Hueneme (OH) pipeline distribution system. This area is fully developed and there is not any additional development that is anticipated along the OH system.

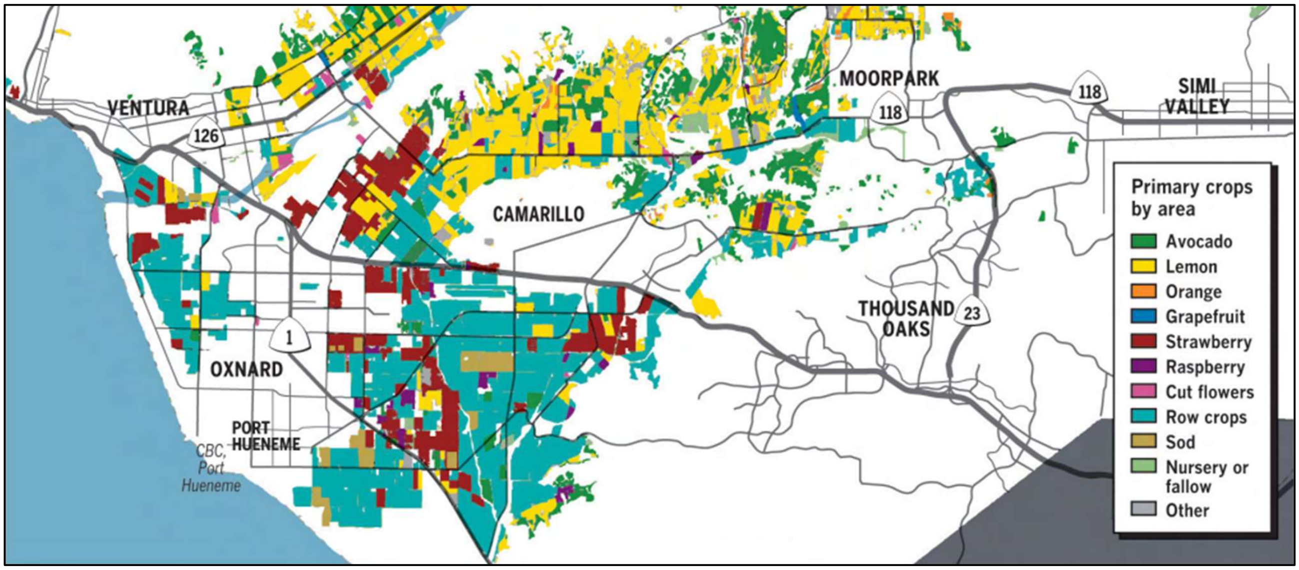


Figure 3-3. Agricultural Users in the Oxnard Basin (Farm Bureau of Ventura County, 2019)

3.2.1.2 Fox Canyon Ground Management Agency

The Fox Canyon Ground Management Agency (FCGMA) is responsible for managing and protecting the confined and unconfined aquifers of four groundwater basins located in Southern Ventura County. The FCGMA is an independent special district and was created in 1982 to oversee the groundwater resources. The mission of the FCGMA is:

> *"The Fox Canyon Groundwater Management Agency (Agency), established by the State Legislature in 1982, is charged with the preservation and management of groundwater resources within the areas or lands overlying the Fox Canyon aquifer for the common benefit of the public and all agricultural, domestic and municipal and industrial users."*

After the founding of the Agency in 1983, FCGMA required all wells within the Agency to register and report groundwater extractions. A fee of $0.50 was levied for each AF of water that was pumped. These fees became the operating budget for the agency, as well as beginning the process of incentivizing decreased water pumping.

The FCGMA then began taking actions in the mid to late 1980's to increase monitoring and develop infrastructure that would mitigate excess groundwater extraction. This included the construction of new pipelines to provide supplemental surface water for irrigation, as well as the construction of a series of clustered monitoring wells to provide water level and water quality data.

In 1987 the FCGMA established the first Groundwater Management Plan. This plan set in action a number of new projects and programs to continue to improve the management of groundwater resources. This GMP has been updated on a regular basis to reflect the current state of the basin and identify new projects and management strategies to improve water resource management.

The FCGMA has passed several ordinances that have aimed to improve groundwater management. Ordinance No. 3 required flowmeters to be installed on wells that extract more than 50 AF of groundwater per year. This was later modified to all groundwater wells not used for domestic purposes, increasing the ability to monitor and quantify the groundwater extractions. Similarly, Ordinance No. 5, passed by the FCGMA, established a system of scheduled extraction reductions. This required a series of 5% pumping reductions every 5-years to reduce pumping demands with the goal of reducing pumping demands by 25%. This developed a credit system to encourage cutbacks in pumping and a penalty system for excess pumping beyond annual allocations. The ordinance has been adopted over time to improve or define water management plans and methods.

In February of 2015, the FCGMA passed the Emergency Ordinance E which prohibited the construction of any new pumping wells in Ventura County. This Emergency Ordinance remains in place and as a result significant pumping growth from agricultural users is not anticipated.

The FCGMA uses groundwater elevations as the primary metrics for progress in groundwater sustainability. The agency recognizes that sustainability can be achieved over cycles of drought and recovery, as long as impacts to the subbasin ae not significant or unreasonable. This suggests that on a year-by-year basis the groundwater levels may decline during drought periods, but must return to pre-drought levels in the wetter years following the drought years.

3.2.1.3 United Water Conservation District

The United Water Conservation District (UWCD, the District) is located a special water district located in Ventura County. It was originally formed as the Santa Clara Water Conservation district in 1927 and became a public agency in 1950. The mission of the District is:

> *"UWCD shall manage, protect, conserve, and enhance the water resources of the Santa Clara River, its tributaries and associated aquifers, in the most cost-effective and environmentally balanced manner."*

While the District's main objective is to maintain the health of the groundwater basins, the District is also a wholesale urban water supplier that cities of Oxnard, Port Hueneme Water Authority (PHWA), Ventura, Santa Paula, and Fillmore, as well as Naval Base Ventura County and several mutual water districts, farms, and individual pumpers. Port Hueneme Water agency is the largest water purveyor from the District.

The District maintains a significant amount of infrastructure in the region and has collaborated closely with the FCGMA to develop and implement projects that improve water resource management impacting the Oxnard Basin. Additional information on the District's infrastructure and operations is discussed in ***Section 3.3 District's Primary Infrastructure in the Oxnard Basin***.

3.2.1.4 Oxnard Basin Water Costs

Cost of water within the basin depends on the water source that is used. Water costs are used for operating budgets of water management agencies such as the FCGMA and the District. The District has an annual budget of approximately $40 million which is funded through groundwater pumping charges, property taxes, and water delivery charges.

For irrigation, which accounts for more than 50% of water demand in the basin, the least expensive water source is free precipitation. The second least expensive water supply is pumped groundwater, within the allowable limits. Once groundwater is required beyond the FCGMA extraction limits the cost of water drastically increases, incentivizing the use of alternative water supplies. The next least expensive water supply after pumped groundwater is surface water deliveries from the UWCD infrastructure (further discussed in ***Section 3.3 District's Primary Infrastructure in the Oxnard Basin***). The most expensive water sources are groundwater beyond the extraction limits set forth by the FCGMA and alternative water supplies (AWS).

AWS which include water sources such as recycled water and reverse osmosis treated water are currently not available in the system, however, they may be available as early as 2024. These require new infrastructure to be developed and have high treatment requirements. AWS in the Oxnard Basin is further discussed in ***Section 3.5 Future Anticipated Projects to Improve Water Security in the Oxnard Basin.***

3.3 District's Primary Infrastructure in the Oxnard Basin

The primary infrastructure in the Oxnard basin, which is managed by the District includes groundwater wells, the Santa Felica Dam, the Freeman Diversion, recharge basins, and distribution systems for water delivery. Figure 3-4 presents a map with the key infrastructure that is further discussed in this section.

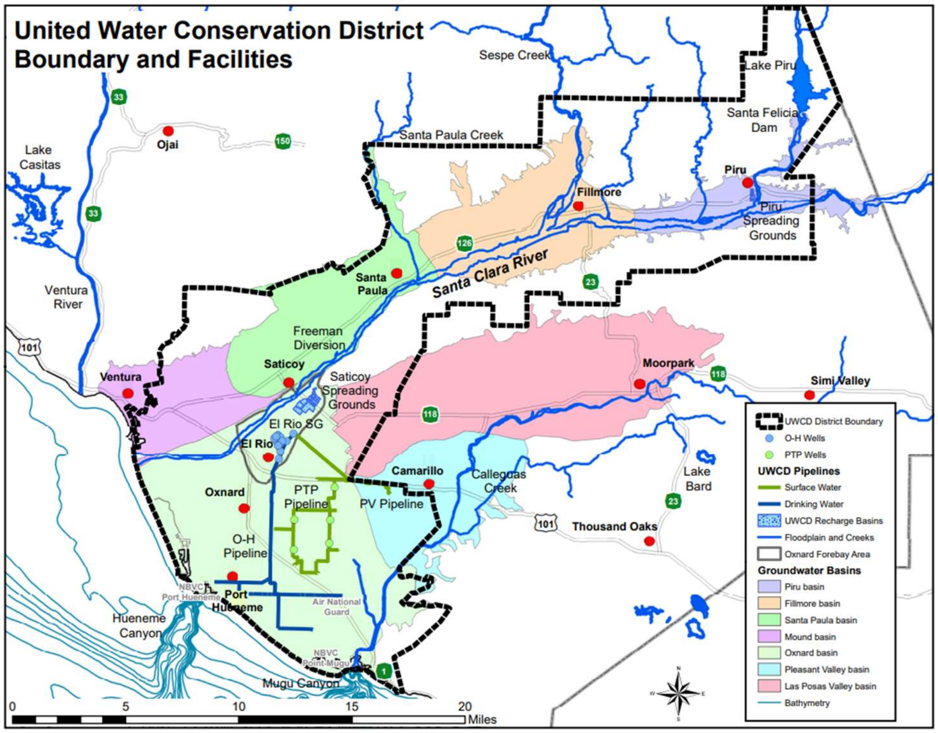


Figure 3-4. Existing Primary Infrastructure Managed by UWCD in the Oxnard Basin (UWCD, 2019)

3.3.1.1 Groundwater Infrastructure

The District's primary water supply is groundwater. Twelve groundwater wells are used to extract the groundwater and are treated at the El Rio Treatment Plant. Groundwater pumps are used when surface water diverted from the Santa Clara River is unavailable.

3.3.1.2 Surface Water Infrastructure

Surface water infrastructure directly impacting the Oxnard basin includes Lake Piru, the Santa Felicia Dam, and the Freeman Diversion.

Lake Piru & Santa Felicia Dam

The District captures water from the Santa Clara River Valley. Lake Piru, which is northeast of the Oxnard Basin, was formed from the creation of the Santa Felicia Dam in 1955. The purpose of the dam construction was to capture and store winter runoff from Piru Creek and to release controlled amounts during dry periods. Lake Piru has a capacity of 82,000 AF of water and can receive water from Pyramid Lake, which is part of the SWP network. The water is released from Pyramid Lake and is conveyed through an existing river to Lake Piru. The water released from Santa Felicia Dam enters the Santa Clara River, mixing with existing natural flows. The Santa Clara River discharges to the ocean with an intermittent flow regime.

Freeman Diversion

To capture freshwater that would otherwise be discharged to the ocean the Freeman Diversion is used. The Freeman Diversion was constructed between 1988 and 1991 and is located 10-miles north of the Pacific Ocean and the diverted water is conveyed for potable use or for artificial recharge. Diversions from the river are limited to maintain flows to support the river ecology. The current allowable maximum diversion rate is 375 cfs, with 38 cfs of surface water for direct water deliveries. Approximately 12% of the water diverted at the Freeman Diversion is delivered to Pleasant Valley Conservation Water District (PVCWD). On average 9,600 AFY is delivered to PVCWD.

3.3.1.3 Imported Water to the Oxnard Subbasin

The groundwater recharge basins are recharged by percolating surface water which is diverted from the Santa Clara River. This volume of water can be increased by using imported water supplies provided by the State Water Project (SWP). SWP is more costly than natural runoff but provides the ability to recharge additional water that would otherwise not be available. There are also benefits to upstream basins resulting from the release of additional water into the Santa Clara River. State water that can be released from either Pyramid Lake or Castaic Lake to the Santa Clara River. These increased river flows are then diverted at the Freeman Diversion. Flows from the Freeman Diversion can be used directly as surface water when there is demand or alternatively recharged at the artificial spreading grounds. Water from the SWP is either purchased as part of the Table A allocations or Article 21.

Table A Allocations

The Ventura County Flood Control District (VCFCD) contracted with the State of California for 20,000 AFY of SWP for Ventura County. The District has 5,000 AFY of Ventura's 20,000 AFY Table A SWP water, with 1850 AFY of that water leased on a permanent basis to the Port Hueneme Water Agency (PHWA). The total amount of water that the District receives depends on the total amount of water that is allocated on an annual basis, as set forth by the SWP. The District's annual importation of State Water accounts for a small fraction of the total water supplies in the basin, but is used to increase the recharge of groundwater beyond what is naturally available. From the initiation of the project to the present, on average allocations have been 50% of the total Table A volume.

Article 21

The District also has the ability to purchase excess SWP water through Article 21. This allows excess SWP water to be purchased at a discounted rate for the purpose of groundwater recharge. UWCD receives surplus State Water Article 21, when it is available. The availability of this water is uncertain and not guaranteed.

3.3.1.4 Artificial Recharge of Surface Water to Groundwater

The District has four groundwater recharge basins (Saticoy, Noble, Rose, and El Rio), which are spreading grounds that facilitate artificial recharge by percolating surface water.

Saticoy Basin

The Saticoy Basin was constructed in 1945 and covers 116 acres. It is comprised of 12 sub recharge basins. The percolation rate in some of the sub recharge basins is 15 ft/day due to the geology and operational practices. During very wet years the Saticoy basins have been able to percolate as much as 54,000 AF.

Noble Basin

The Noble basin was constructed in 1995 to recharge additional water diverted from the river during wet periods. It is comprised of 3 recharge basins and covers 120 acres. On average it recharges 4,750 AF per year. This basin has lower percolation rates than other available basins and as a result lower quality water with high turbidities is diverted here, preserving the performance of other basins.

Rose Basin

The Rose basin is adjacent to the Noble Basin and is connected through a pipeline. The basin can provide 121 acres of surface area for recharging. Use of this recharge basin is limited to years when significant groundwater mounding does not exist beneath the Saticoy Recharge Facility.

Ferro Basin

The Ferro Basin is currently not in service, channels need to be constructed to bring this recharge basin online. It was created from a 183-acre gravel mine and provides the opportunity for future diversions of high flows. Use of this basin assumes that the District can secure a permit that would increase their instantaneous diversion rate.

3.3.1 Water Distribution Systems

The District has two primary distribution systems, one for irrigation and one for domestic use. The Oxnard-Hueneme (OH) system is used to convey the potable water to the City of Oxnard, PHWA, and other mutual companies. Water for the OH system is treated at the El Rio facility to meet potable drinking water standards. The system includes 8 miles of transmission, with 4 miles added by Mugu Lateral and serves 43 square miles.

In addition to the potable OH system, water is conveyed to the Pumping Through Pipeline (PTP) for irrigation purposes. The PTP pipeline was constructed in 1986 in partnership with the County of Ventura and delivers water to an area of approximately 4,400 acres. It is designed to convey diverted river water to agricultural pumpers in the east-central area of the Oxnard plain to reduce the amount of pumping in the area. When surface water is unavailable, 5 wells that produce water from the lower aquifer system are used to supplement the surface water supplies. System demands are dependent on agricultural demands. This water is not treated and does not meet drinking water standards. The PTP system can convey both surface and pumped groundwater. Average deliveries of water from the PTP system are 5,800 AFY.

3.4 Water Quality in the Oxnard Basin

Water quality in the Oxnard Basin is influenced by contamination from agricultural chemicals, runoff industrial sites, spillage from tanker trucks carrying hazardous chemicals. Saline intrusion as well as iron and manganese contamination also impact the water quality of the basin. The existing water quality is presented in Table 3-1 and the water quality goals for drinking water and agriculture are presented in Table 3-2.

Table 3-1. Minimum, Maximum, and Average Water Quality for Surface and Groundwater in Oxnard Basin Area for TDS, Chloride, Sulfate and Boron

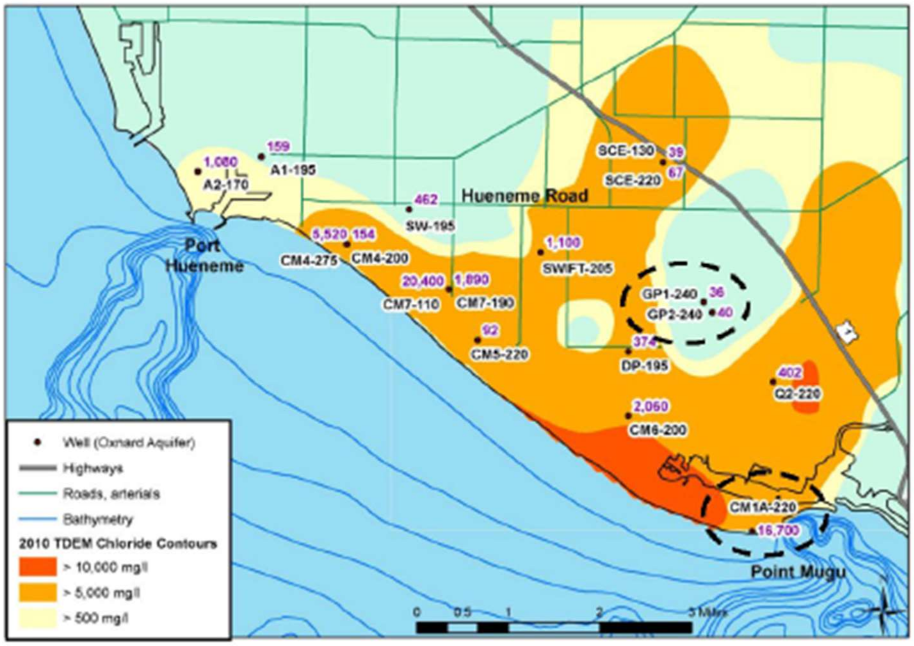
Water Source	TDS (mg/L)			Chloride (mg/L)			Sulfate (mg/L)			Boron (mg/L)		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Surface Water												
Surface Water	699	1480	1134	22	102	61	264	757	493	0.3	1	0.7
Pumped Groundwater												
Saticoy Wells	713	2040	1082	27	120	60	270	920	462	0.5	0.9	0.6
PTP Wells	645	1020	879	36	69	45	163	450	337	0.2	0.6	0.4
OH Wells	928	1150	1031	40	56	47	301	510	444	0.0006	0.7	0.5
Average of Groundwater	762	1403	997	34	82	51	245	627	414	0.23	0.73	0.50

Table 3-2. Water Quality Goals

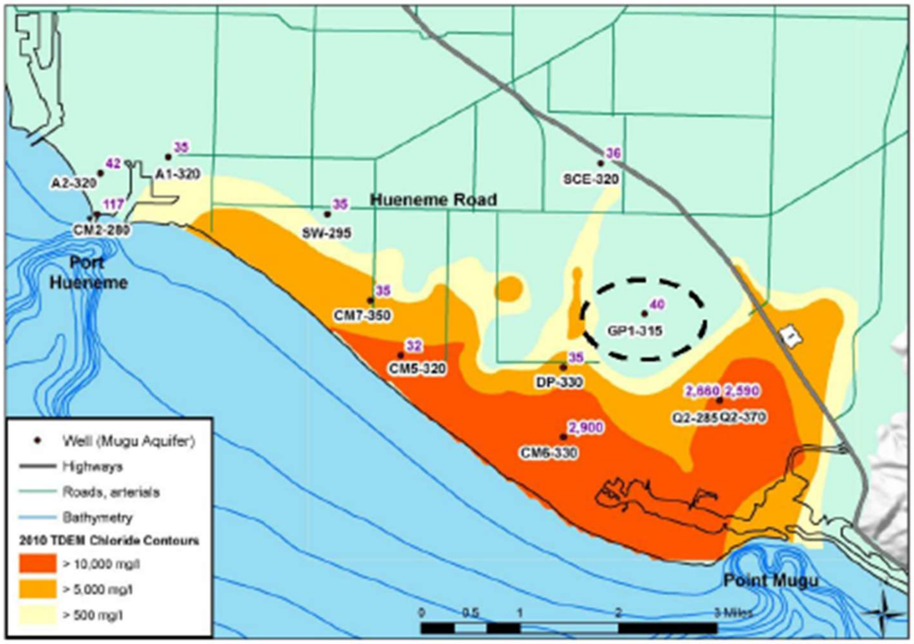
Constituent	CA DDW Standards (mg/L)	Agricultural Goals (mg/L)
TDS	500	<450
Chloride	250	<80
Sulfate	250	N/A
Boron	1	<0.5

3.4.1.1 Saline Intrusion

Decades of groundwater overdraft has caused intrusion of seawater from the Pacific Ocean into the Oxnard Basin Upper Aquifer System. The Upper Aquifer system consists of three aquifers including the Semi-perched, Oxnard, and Mugu Aquifers. The seawater intrusion threatens the ability for continued use of groundwater in this area. Figure 3-5 identifies the current extent of saline intrusion in the area.



Oxnard Aquifer



Mugu Aquifer

Figure 3-5. Saline Intrusion of the Oxnard Basin (Adapted from UWCD, 2021)

3.5 Future Anticipated Projects to Improve Water Security in the Oxnard Basin

There are currently several infrastructure developments and policy changes that are being evaluated to improve water security in the Oxnard basin. Three of the largest ongoing efforts are the implementation of a brackish water treatment plant, the expansion of the Freeman Diversion, and the use of recycled water.

3.5.1.1 Brackish Water Treatment in the Oxnard Basin

The District is currently completing Phase 1 feasibility analyses on the construction of a brackish water treatment plant to mitigate seawater intrusion and provide additional water sources to the region. The Extraction Barrier and Brackish Water Treatment Project (EBB-Water) Project. The District received a DWR Prop 1 Planning Grant ($122,563) to evaluate extraction barrier wells to minimize seawater intrusion in the Oxnard Basin. The extraction wells and treatment plant to be located at the Naval Base Ventura County Point Mugu. The project is anticipated to be completed by 2025. The facility is anticipated to have a 48% recovery rate, with 52 % being discharged as brine. Overtime the recovery of the system is anticipated to increase to 60%. The total amount of treated brackish water for delivery is still being identified through the design process. It is estimated that brackish treatment extraction values may range from 5,000 AFY to 10,000 AFY.

3.5.1.2 Freeman Diversion Expansion

The District is currently working on a phased approach to increase the capacity of the Freeman Diversion to increase the volume of surface water that can be captured from the Santa Clara River. Climate prediction models anticipate less frequent but higher intensity storm events. By increasing the capacity of the diversion, the District can maintain or increase the ability to recharge surface water. The District is currently working on Phase 1 of the Freeman Diversion Expansion which includes removing bottlenecks and increasing the settleability of sediments. This phase of work is anticipated to be completed by 2025.

Phase 2 of the project involves further increasing the ability to spread large amounts of water over shorter periods of time. This includes expanding to use two additional former gravel pits as recharge basins and increasing their water rights for instantaneous diversion. The District is working on negotiations to increase their water right from 375 cfs to 750 cfs by 2035. The exact capacity of the project is currently unknown but it is estimated to potentially provide an additional 7,400 AF of diversions, relative to the current diversion capacity. The Phase 2 of the project is anticipated to take between 2 and 10 years for implementation and is anticipated to cost $31 Million (2018 USD). Operation and maintenance (O&M) costs are anticipated to be $4,300/AFY.

3.5.1.3 Recycled Water

The District is also currently engaged in projects that will provide recycled water to the PTP irrigation system. The recycled water would originate from the City of Oxnard's Advanced Water Purification Facility (AWPF) and would be conveyed to the PTP system to agricultural users. This would be high quality recycled water that could supplement existing water supplies. These potential future recycled water supplies are summarized in Table 3-3.

Table 3-3. Potential Future Recycled Water Supplies

Source	Anticipated Volume of Water (AFY)	Type of Water
City of Oxnard's Advanced Water Purification Facility	7,000	Advanced treated recycled water
Camrosa Water District's Conejo Creek Diversion	15,683	City of Thousand Oaks Hill Canyon Wastewater Treatment Plant (HCTP) disinfected tertiary recycled water during dry weather periods
Camrosa's Water Reclamation Facility	1,450	Disinfected tertiary recycled water
Camarillo's Water Reclamation Facility	4,450	Disinfected tertiary recycled water

3.6 Existing Modeling Efforts for the Oxnard Subbasin

UWCD has developed the Ventura Regional Groundwater Flow Model which is a MODFLOW numerical groundwater flow model. This model was peer reviewed and has a base period of 1985 to 2015. This model has been used for evaluating net changes in groundwater storage. Additionally, a surface water model is used to evaluate the surface water flows for the region. Based on existing reports and discussions with UWCD staff, there is no existing

4. METHODOLOGY

To characterize the long-term water supply for the Oxnard water supply, a system dynamics (SD) approach was used. This chapter section describes the methodology that was used to design and evaluate a system dynamics model for the Oxnard Basin.

The systems relationships that exist around water resource management in the Oxnard Basin are complex. The five primary steps outlined in Figure 4-1 were used to develop an understanding of the complex systems relationships. These steps included (1) articulation of the problem, (2) development of a dynamic hypothesis, (3) development and design of a system dynamics model using Vensim, (4) model testing and (5) evaluation of specific scenarios and policies using a case study. These five primary steps are discussed in detail in the subsequent sections of this chapter.

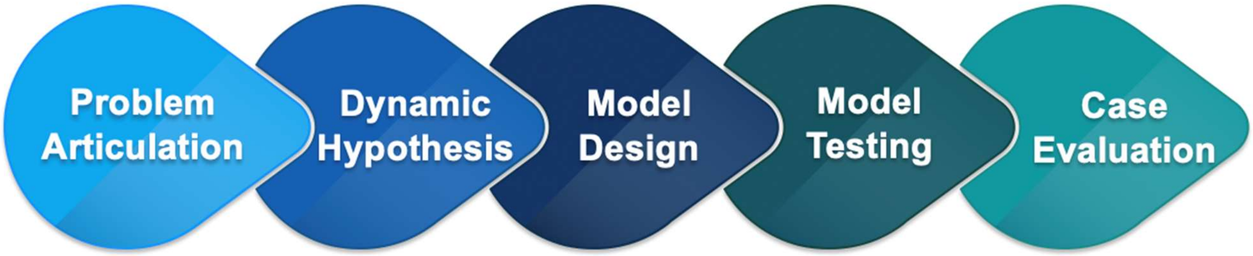


Figure 4-1. Five Primary Steps in System Modeling

The modeling steps are presented as a linear process; however, the model development was and continues to be an iterative process as demonstrated by Figure 4-2. Investigation into the dynamic hypothesis (Step 2) led to re-evaluation and rearticulation of the problem (Step 1). Similarly, model design (Step 3) led to re-evaluation of the dynamic hypothesis (Step 2), as variables were identified and relationships were understood. As the case is evaluated (Step 5), the problem can be further articulated and built upon. The iterative relationship between Step 5 and Step 1 is discussed in ***Section 6. Discussion***, as part of future next steps.

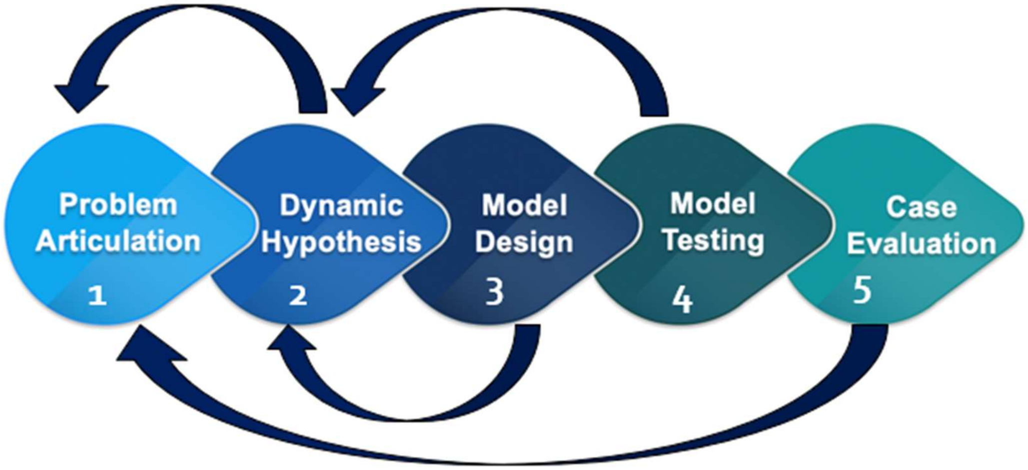


Figure 4-2. Iternative Steps in System Modeling

4.1 Problem Articulation

Problem articulation includes the identification of the problem, identification of key variables, identification of the time horizon and understanding how variables have performed in the past and may perform in the future.

4.1.1.1 Problem Identification

Problem identification identifies what the problem is and why it is a problem. This model addresses the problem of water security in the Oxnard Basin and aims to understand:

- Can a systems dynamic approach be used to understand complex water resource management decisions for the Oxnard Basin?
- What are the drivers of water security in the Oxnard Basin?
- What factors affect the water supply?
- How can water management and implementation decisions be optimized to maximize water security in the Oxnard Basin?

The objective of the modeling is to design a model that simulates the available water supply in the Oxnard Basin and then systematically modify variables and schedules of construction to observe the effect of various scenarios on the available water supply, measured as water security and self-sufficiency.

For the purposes of this study**,** *water security* is defined as the ability to meet water demands with the available local and imported water resources available. This requires both sufficient water resources as well as the capacity and infrastructure to accommodate the local and imported water resources.

For the purposes of this study **s***elf-sufficiency* is defined as the ability for a community to meet its water demand using local water resources and does not need to import water from an outside source, such as a neighboring community or from the SWP.

4.1.1.2 Key Variables

The key variables and components that relate to the problem of water security and self-sufficiency in the Oxnard Basin were identified. The key variables identified as having a relationship to a community's water scarcity and self-sufficiency include capital costs, technology, population, water quality, infrastructure, climate change, water cost, water demand, and local and imported water supplies are summarized in Figure 4-3.

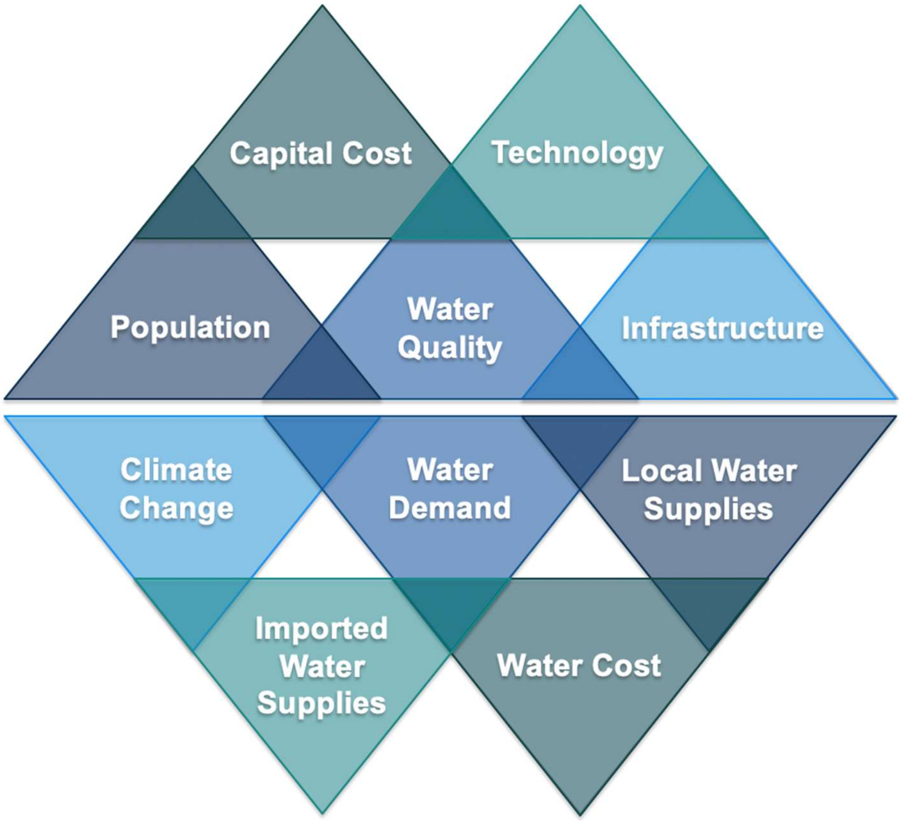


Figure 4-3. Key Variables

4.1.1.3 Time Horizon and Discretization

Mental models tend to evaluate cause and effect relationships as local and immediate. However, in dynamically complex systems, cause and effect relationships are distant in time and space and may result in a delay between the action and the observed effect of the relationship. The time horizon is the simulation start and end period for the model. The key variables such as infrastructure, population, and climate change have relatively slower response time. As a result, for this analysis the period of 1985 through 2100 was identified with a timestep of 1 year. This time period extends far enough back in history to show how the current conditions evolved, as well as extends far enough into the future to capture delayed and indirect effects of actions relating to water resource management and infrastructure decisions. A limitation of this timestep is that the model is unable to reflect large seasonal variations.

Seasonal variation was not incorporated into the model. There are typically three growing seasons during the year, requiring water year-round for irrigation purposes. The existing PTP system sees the highest demands in October, as shown by Figure 4-4. However, these demands can be met by both precipitation, water supplied from the PTP and pumped groundwater. The rainy season is from October 12 to April 29 in Ventura County, which also suggests that some of the demand can be met by natural precipitation.

Monthly fluctuations in demand are anticipated to shift use of water supplies. If the required irrigation exceeds the available surface water supplies, the water will be pumped. Since the purpose of the model is to evaluate the water balance on a long time scale, this is not anticipated to have a significant impact on the results. This may have some impact on the requirements for using pumped water in place of surface water, but it is assumed for the purposes of this research that surface water that is not used will be recharged.

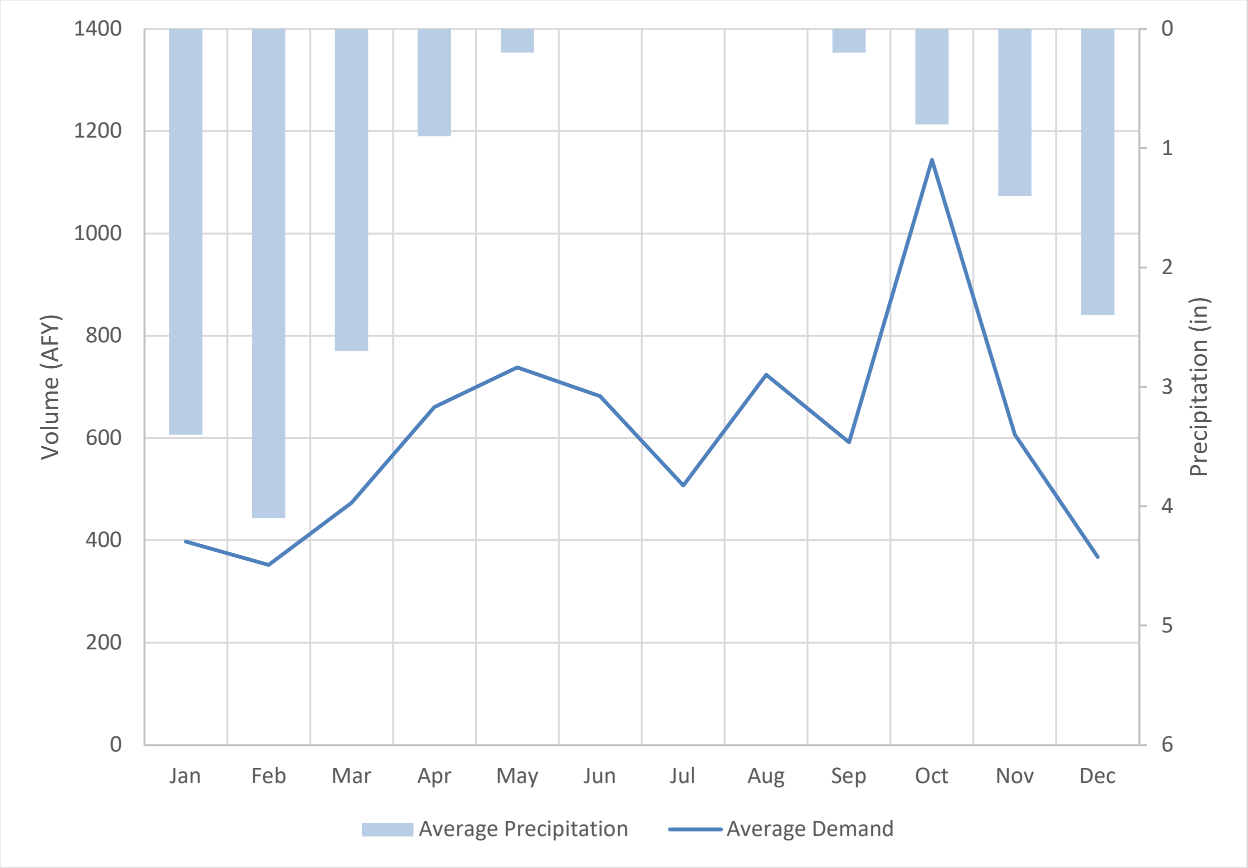


Figure 4-4. Monthly Average Demand and Precipitation in PTP System from 2006-2020

4.1.1.4 Reference Modes

Reference modes were used as a tool during model development. The first set of reference modes (Figure 4-5) assumes that water security is constantly high and shows the observed trends in a community or region where water security is high for population, water demand, and water cost. These reference modes indicate that when water security is being met population grows. When population grows and water security is maintained, the demand for water will increase. Water cost will also increase over time due to economic factors such as inflation, capital improvement, and operation and maintenance costs.

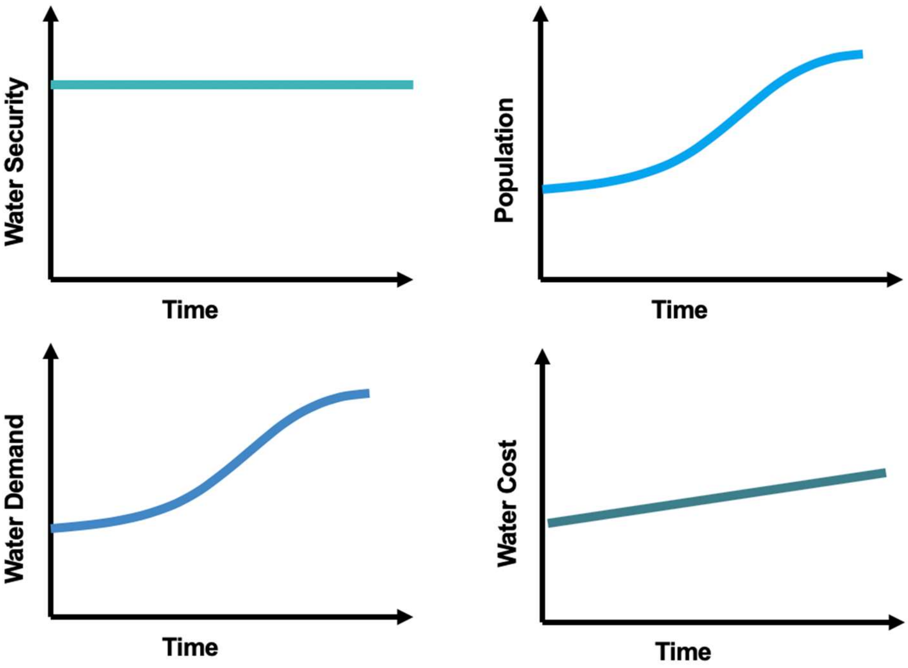


Figure 4-5. Reference Modes for Sustained Water Security

The second set of reference modes (Figure 4-6) shows the observed trends for the same variables but indicates when water security is in decline.

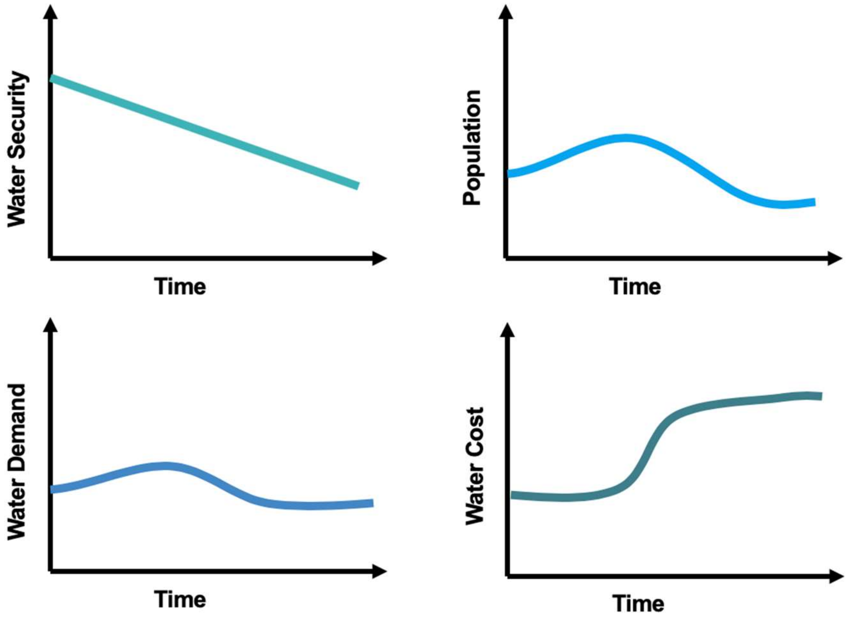


Figure 4-6. Reference Modes for Decreased Water Security

In addition to the reference modes presented in Figure 4-5 and Figure 4-6, additional reference modes were developed that served as tools during the model design (further discussed in ***Section***

4.3 Model Design***)*** to compare anticipated reactions and model simulated reactions from changes within the system.

4.2 Dynamic Hypothesis

The next step in model development the formulation of an initial hypothesis. This evaluates the current theories of the problematic behavior, which in the case of this study is the availability of water. The dynamic hypothesis provides an explanation of the dynamics characterizing the problem in terms of the underlying feedback stock and flow structures of the system. To develop a dynamic hypothesis for this evaluation a model boundary chart, causal loop diagrams, and stock and flow maps were developed.

4.2.1.1 Model Boundary Chart

A model boundary chart was developed to summarize the scope of the model and identify which key variables are included endogenously and exogenously and which variables are excluded from the model. The model boundary chart is presented in Table 4-1.

Table 4-1. Endogenous, Exogenous, and Excluded Variables for Model Development

Endogenous	**Exogenous**	**Excluded**
Water Security	Population Growth/Decline	Grant funding for infrastructure
Water Scarcity	Groundwater Basin Capacities	Recycled Water
Water Quality	Precipitation	Seasonal Variability
Water Cost	Water Quality Regulations	Instantaneous capacities
Infrastructure Development	Imported Table A Allocations	Land use & development
Surface Water Storage Capacities	Imported Article 21	Economic growth
Natural Recharge • Stream Leakage, Subbasin Inflow, Precipitation Recharge, Coastal Influx, Return M&I, Return Agricultural	Pleasant Valley Diversions	
Incoming Surface Water • Santa Clara River Flows	EBB-Water Recovery Rate	
Oxnard Basin Demands • Irrigation, M&I, Domestic	EBB-Mugu Navy Demands	
Subsurface Outflow • Stream Leakage, Subbasin Outflow, Evapotranspiration, Coastal Flux Out, Tile Drains, Subsurface Outflow	M&I Per Capita Demands	
Freeman Diversion Capacity	Unincorporated In/Outflows	
	FCGMA Regulation	
	Upper Basin Recharge Percentage	

4.2.1.2 Stock and Flow Maps

Stock and flow maps were developed. The primary stock within the model is the groundwater supplies for the Oxnard Basin. The amount of water that is available is dependent on the magnitude of inflow into the basin versus the magnitude of outflows and extractions from the basin. This relationship is demonstrated in a stock and flow diagram in Figure 4-7. Stock and flow maps were used for the Oxnard basin groundwater and population.

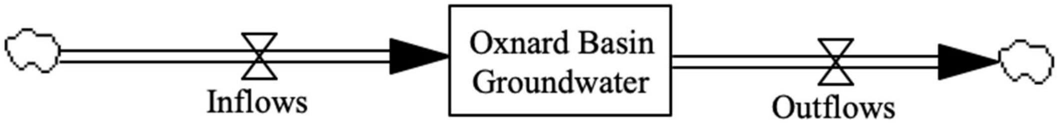


Figure 4-7. Stock and Flow Diagram for Oxnard Basin Groundwater

4.3 Model Design

Using the combination of the dynamic hypothesis including the model boundary chart, causal loop diagrams, and stock/flow maps the model was designed. The full model is shown in Figure 4-11 (water balance portion) and Figure 4-12 (water security portion) and is further described in the subsequent sections of this report. The model was designed using three types of data:

(1) **Measured:** These were values measured by existing measurement devices, detailed historical records, or metrics in the Oxnard Basin.
   a. Examples: Precipitation, imported SWP water, population

(2) **Existing Modeled:** for variables that existing surface water or groundwater models.
   a. Examples: Tile drains, coastal flux, precipitation recharge

(3) **Report Documented:** The UWCD and FCGMA have extensive documentation on the operation of the infrastructure and operations within the Oxnard Basin. This report documentation was used to understand how existing systems may influence and impact each other. These reports were also used to identify historical regulations that may have impacted the relationship between variables over time.
   a. Examples: Freeman Diversion Capacity, FCGMA Regulations

Using the measured, existing modeled, and report documented data it was the information was evaluated to identify relationships between the variables. The equations used in the model are summarized in Appendix A. Scatterplots were used to identify linear relationships between two variables. For example, a linear relationship was identified between precipitation and precipitation recharge, as demonstrated by Figure 4-8. The R^2 value was 0.86, indicating a strong correlation between variables. However, for example, a strong linear relationship does not exist between artificial recharge and pumping as these are independent from each other. This lack of relationship was demonstrated by the low R^2 value of 0.31 as shown in Figure 4-9. Plotting existing measured data against each other provided insight into existing relationships and how to quantify the relationships between variables with strong relationships.

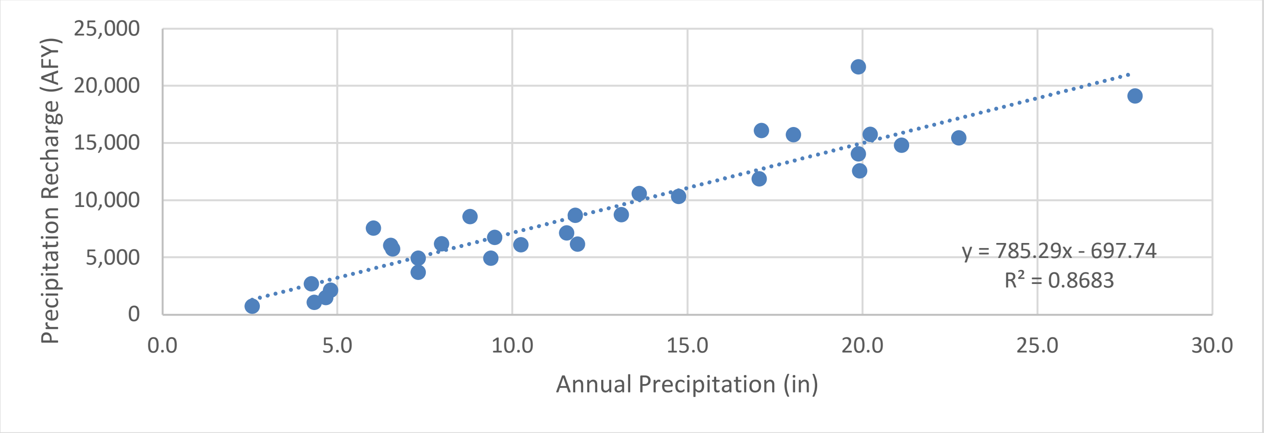


Figure 4-8. Example of Variables with Linear Strong Corelation

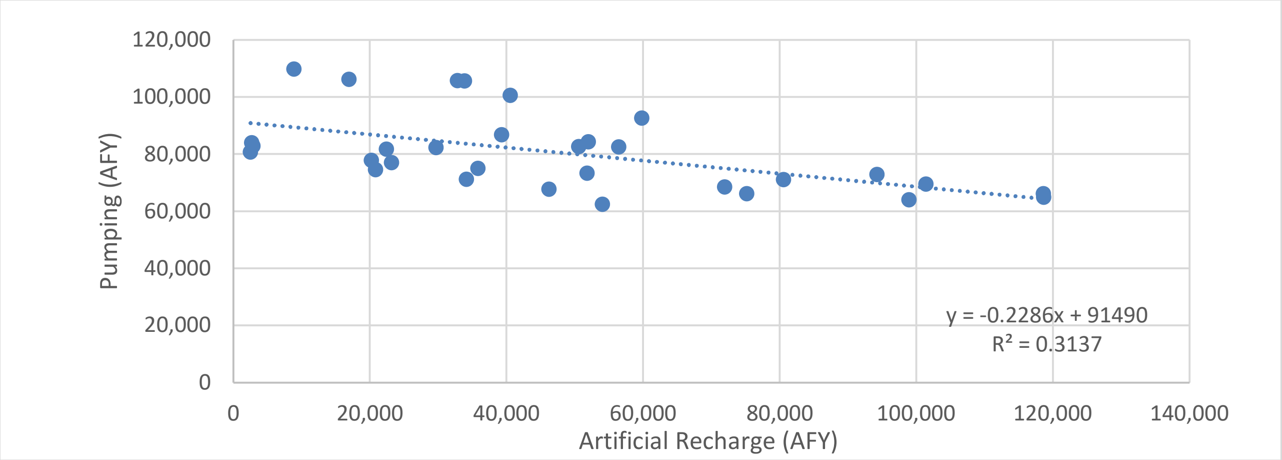


Figure 4-9. Example of Varaiables with Poor Linear Correlation

In some cases, linear relationships existed but changed over time. In these instances, the data was evaluated to see if an infrastructure or policy change may have caused a shift in the relationship between two variables. For example, this was seen in the relationship between irrigation and precipitation. Irrigation demand and precipitation had a strong correlation between 1985 and 1990, and then between 1996 and 2015. However, plotting the entire period (1985-2015) resulted in a poor correlation. It was observed in the data that following 1990 there was a steep decline in water demand and then a new relationship between irrigation and water demand existed. Evaluating this measured data with report documentations suggested that the FCGMA regulation passed in 1991 likely impacted the water use. As a result, the model was adjusted to include the FCGMA regulation.

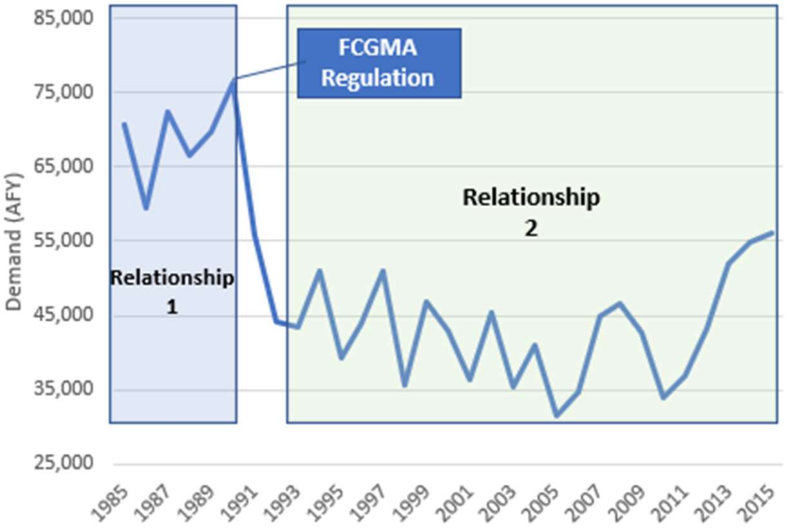
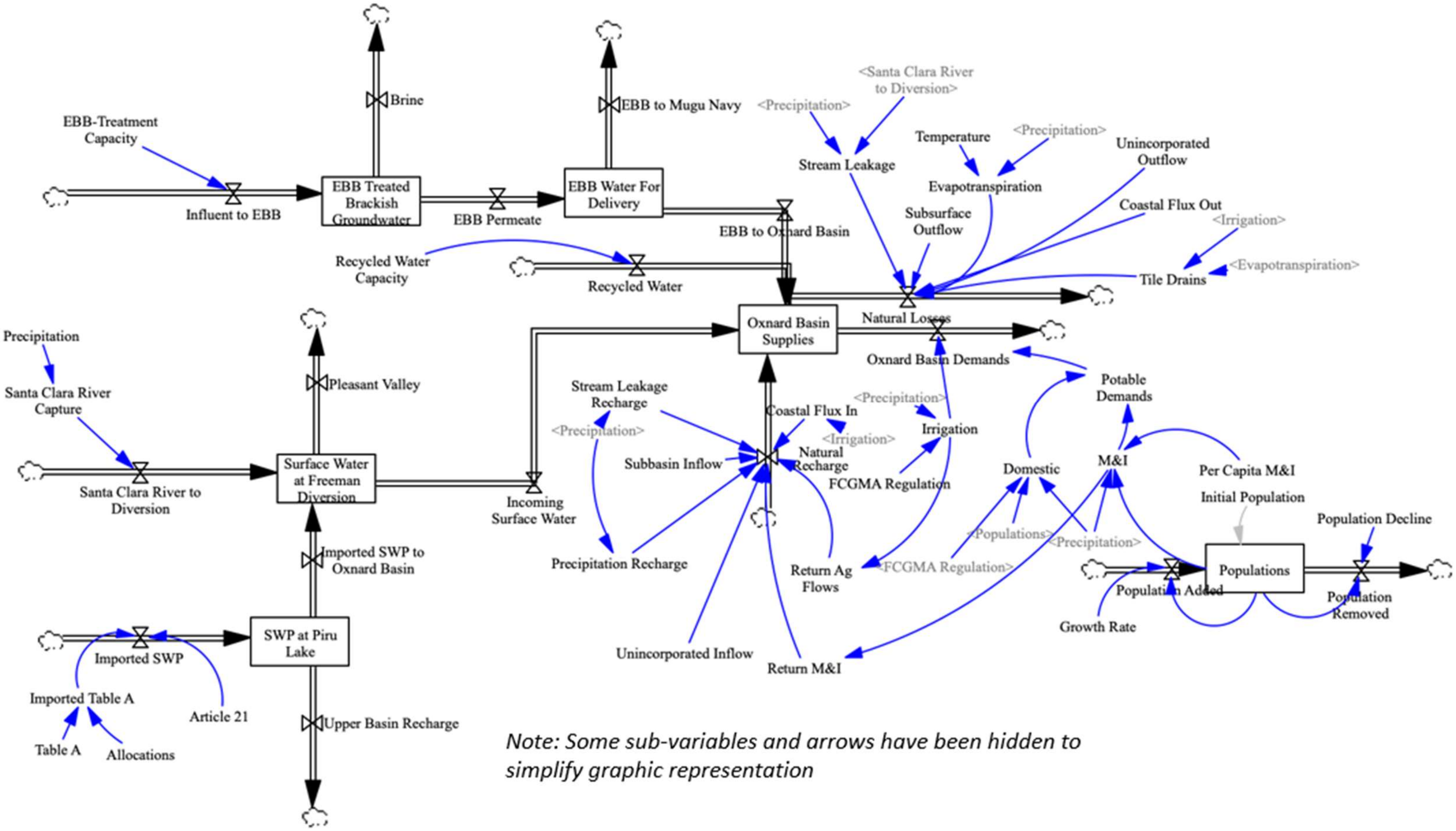


Figure 4-10. Change in Precipitation and Irrigation Regulation with FCGMA Regulation

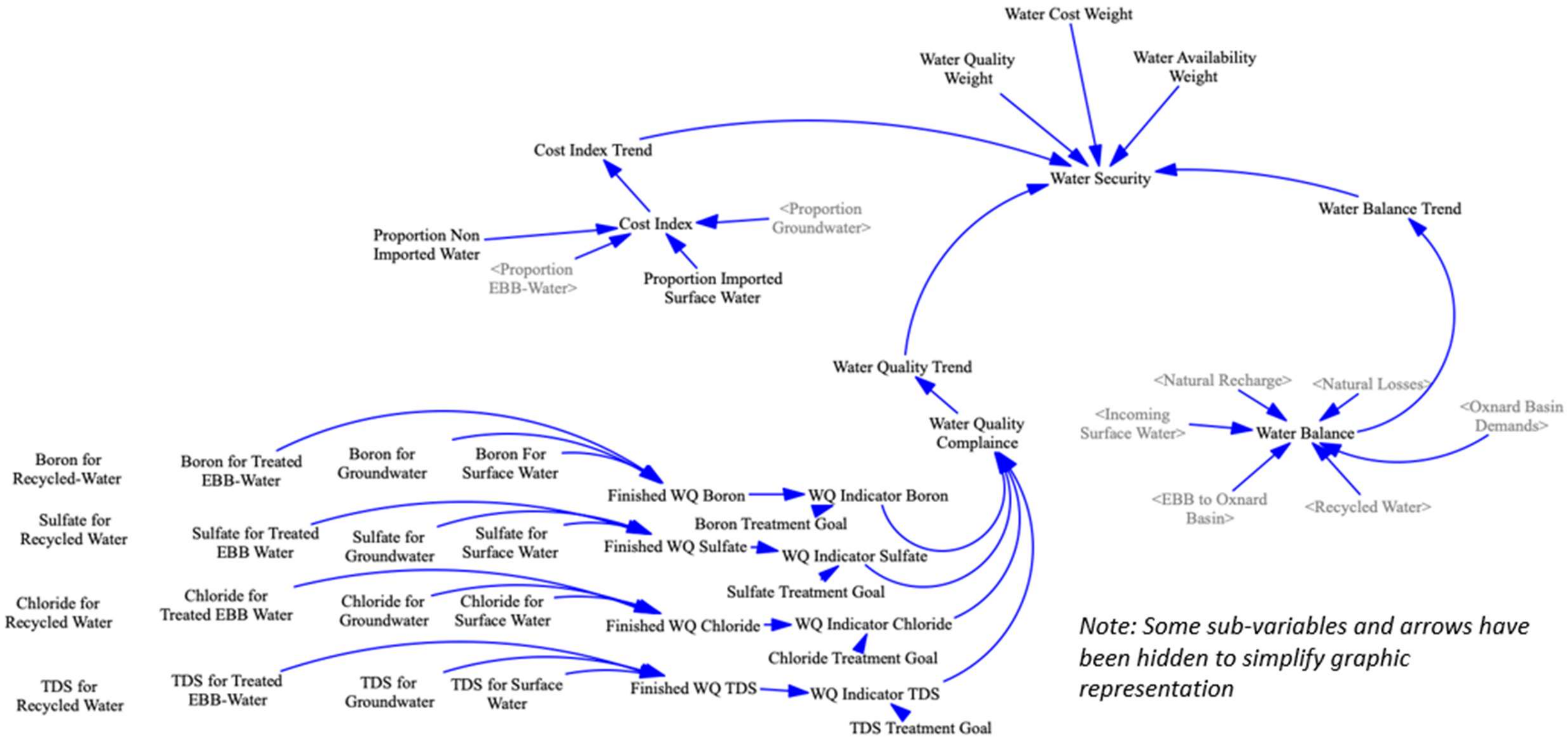
In some instances, more than one variable had an impact on a single variable. In this case a multiple linear regression (MLR) was developed. For example, tile drains which are the runoff from irrigation water have a relationship between both agricultural demand (which is dependent on precipitation) and evapotranspiration. For variables that used MLR, the R^2 was evaluated, and a 3-D scatterplot was developed to visually inspect the relationship between the variables, as shown in Figure 4-13.

Using both the causal loop diagrams and stock and flow maps in conjunction with the observed relationships between variables the model was developed to draw relationships between variables. The model developed include four main parts; (1) System inflows, (2) system outflows, and (3) water security.



Note: Some sub-variables and arrows have been hidden to simplify graphic representation

Figure 4-11. Water Balance Portion of System Dynamic Model for Evaluation of the Oxnard Basin



Note: Some sub-variables and arrows have been hidden to simplify graphic representation

Figure 4-12. Water Security Portion of of Sysetm Dynamic Model for Evaluation of the Oxnard Basin

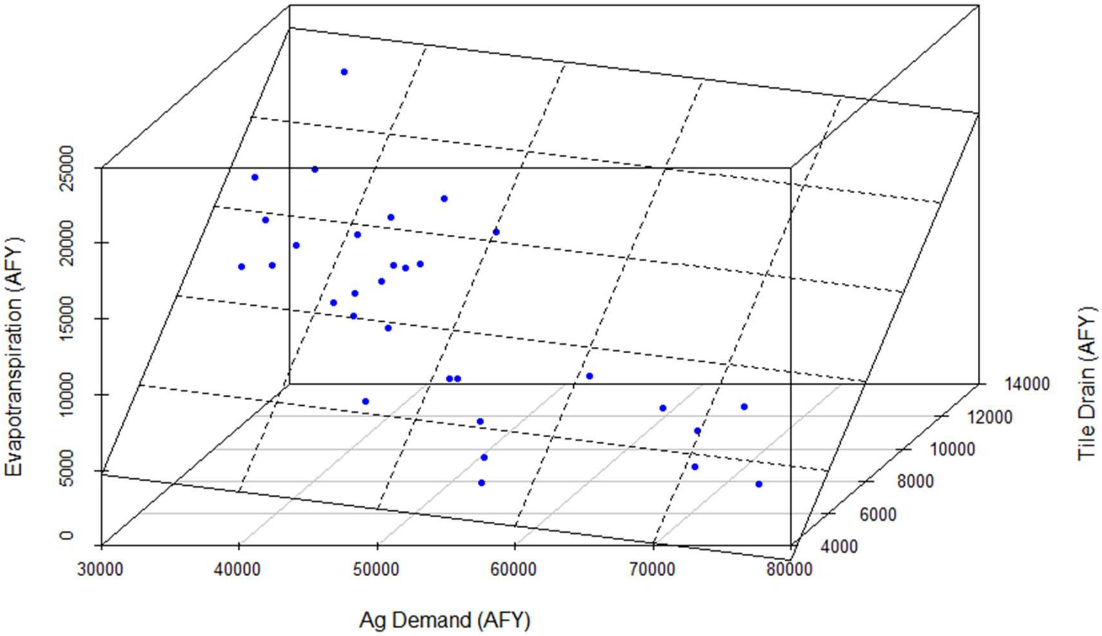


Figure 4-13. Multivariate Linear Regression 3-D Scatterplot for Tile Drains with Agricultural Demand and Evapotranspiration

4.3.1.1 System Inflows

The modeled system inflows are comprised of surface water inflows, natural inflows, and new anticipated inflows from the EBB-Water and recycled water projects. The surface water inflows (Figure 4-14) is comprised of the Santa Clara River inflows which are driven by precipitation and the capacity of the Freeman Diversion to divert flows. A portion of these diverted flows are lost to the Pleasant Valley Basin. The SWP Allocations A and Article 21 water contributes to flows of the Santa Clara River when released from the Santa Felicia Dam. A portion of these flows are lost to the upper basins, as well as Pleasant Valley Basin. The remaining flows are conveyed to the Oxnard Basin.

The natural inflows are comprised of stream leakage, subbasin inflow, precipitation recharge, unincorporated inflows, coastal flux, return agricultural (irrigation) flows, as well as return M&I flows (Figure 4-15). These flows are driven by other variables such as precipitation, irrigation, and M&I. The variables in orange shown in Figure 4-15 represent variables that have feedback from the demand side of the water balance (irrigation and M&I demands).

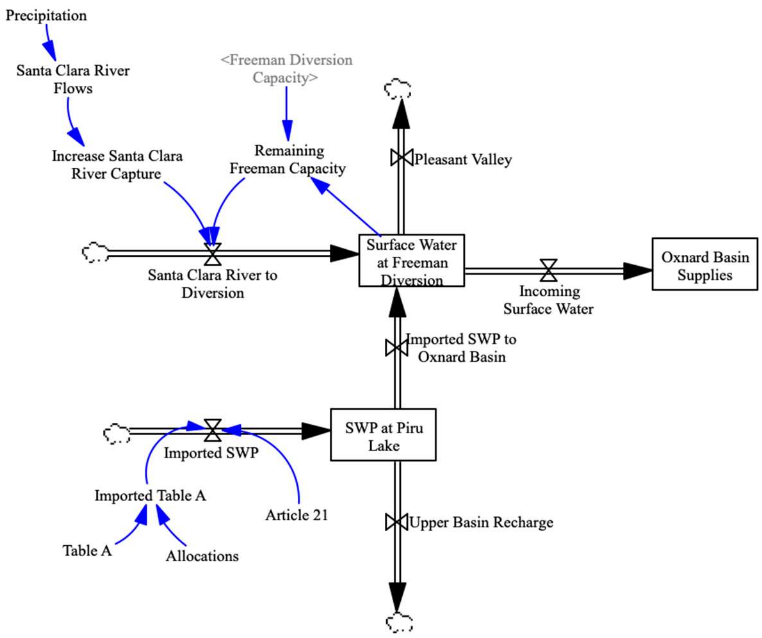
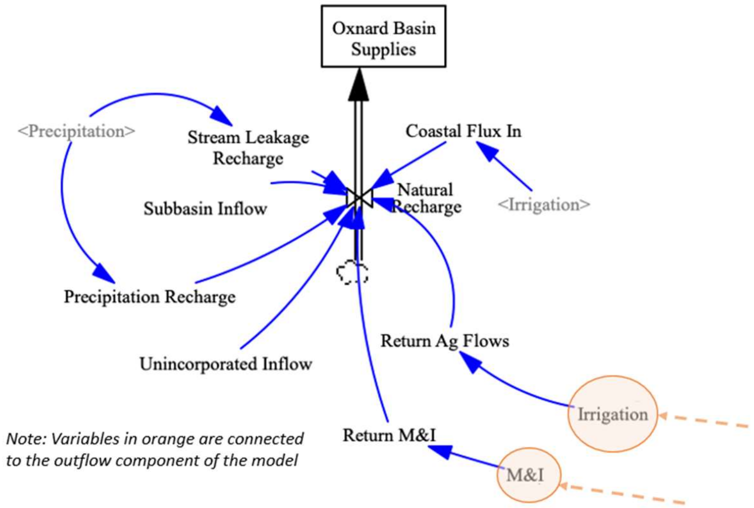


Figure 4-14. Model Configuration for Surface Water Inflows



Note: Variables in orange are connected to the outflow component of the model

Figure 4-15. Model Configuration for Natural Recharge

The new projects which include the EBB-Water and recycled water plant were also included in the supply side of the model (Figure 4-16). The recycled water is a function of the anticipated annual capacity. A step function is used to increase the recycled water capacity based on the anticipated year that the system can receive recycled water as well as how much volume can be conveyed. The EBB-Water infrastructure was modeled similarly using a step function to add brackish groundwater into the system based on the anticipated year that the system would be completed, as well as the anticipated treatment capacity of the project is not equivalent to the water that can be delivered, as a portion of the water is lost to the brine. The system recovery rate and a change in the system recovery rate was modeled. The brine reflects the water that is lost to waste due to the inefficiency of RO treatment. The permeate water is the treated water for conveyance. A portion of that water is anticipated to be consumed by the Mugu Naval base, while the remainder is anticipated to serve the Oxnard Basin.

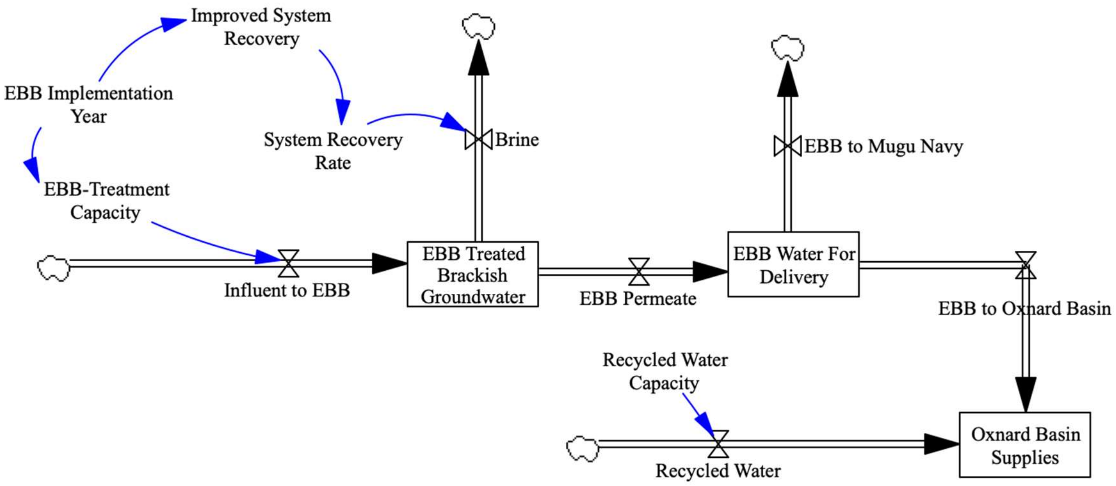


Figure 4-16. Model Configuration for New Project Flows

4.3.1.2 System Outflows

The system outflows are comprised of demands in the basin for human consumption or use as well as natural losses. As shown in Figure 4-17, basin demands are comprised of potable and irrigation demands. Irrigation are influenced by FCGMA regulations and precipitation. Potable demands are comprised of domestic and M&I demands. Population growth, which is modeled as a stock and flow influences both domestic and M&I demand. It is assumed that there is no relationship between population growth and irrigation demands due to FCGMA regulations that prevent future extraction wells from being constructed. This assumption also assumes that farmland will not be converted to support future housing developments.

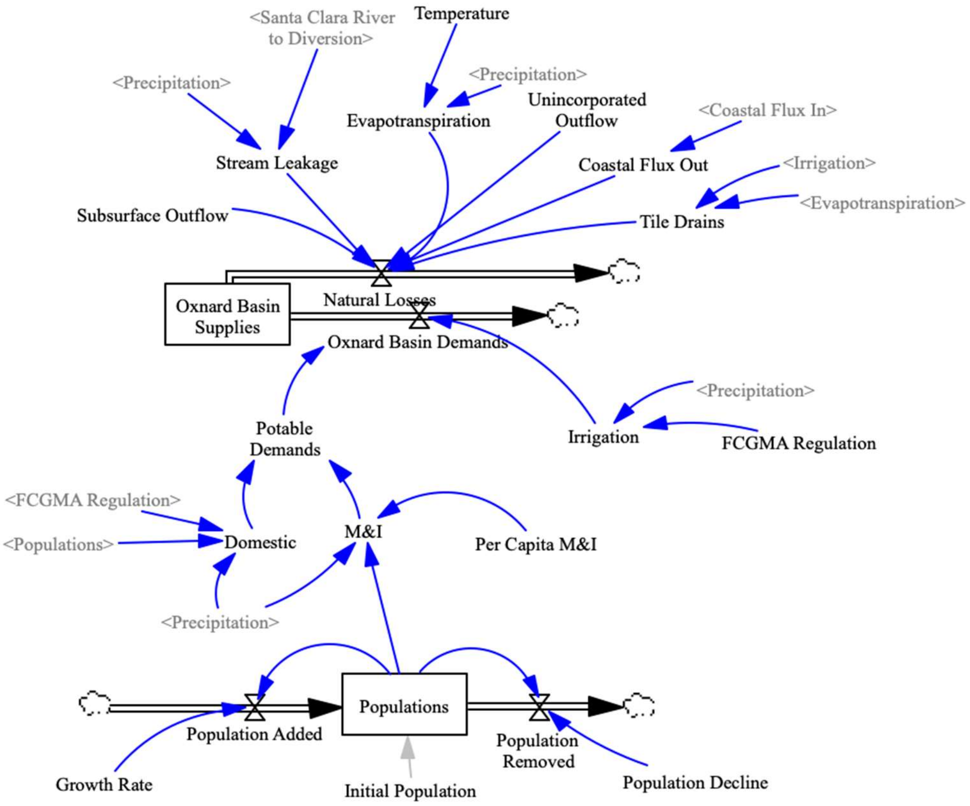


Figure 4-17. Model Configuration for System Outflows

4.3.1.3 Water Security

The water security component of the model is comprised of feedback from the water balance component of the model, water quality, and water cost. The water balance feedback is calculated from the system inflows and outflows previously discussed. The water quality portion of the model, shown in Figure 4-18, used the historical average water quality for each water source and the portion of water from the water balance. This assumes that water quality by water source will not significantly change over time within the basin. This water quality calculation was a feedback into the calculation of water security through the evaluation of the water quality compliance over a 3-year period. The water security portion of the model (Figure 4-19) used feedback from the water quality trend, water balance, and cost to calculate the water security. This is represented as an index value that different weighting values that can be assigned.

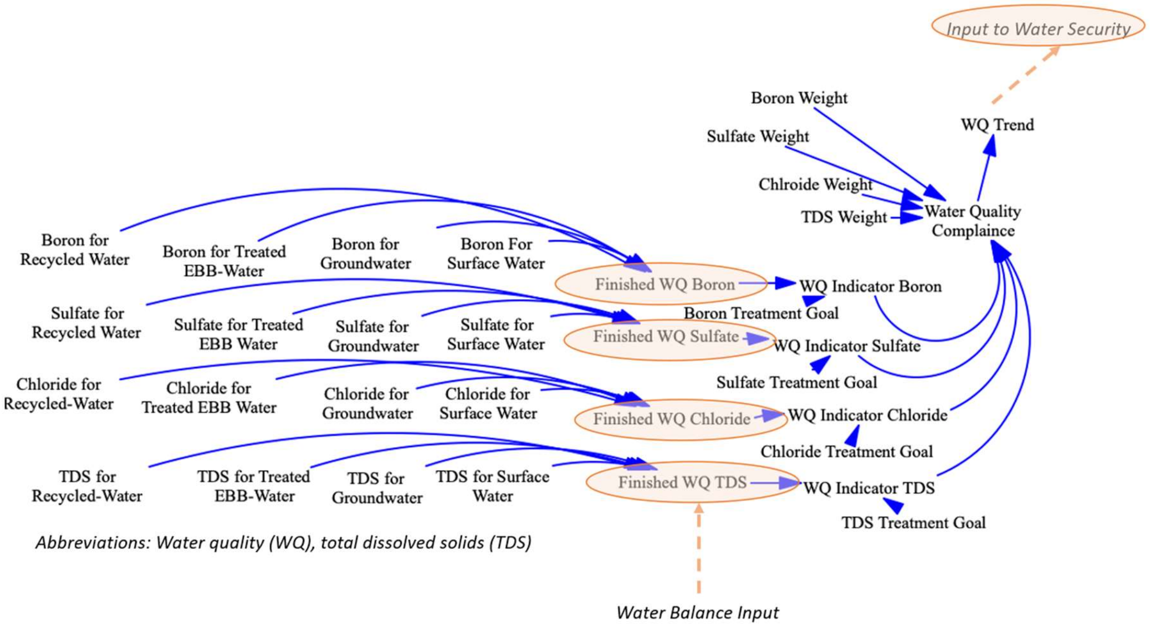


Figure 4-18. Model Configuration for Water Quality

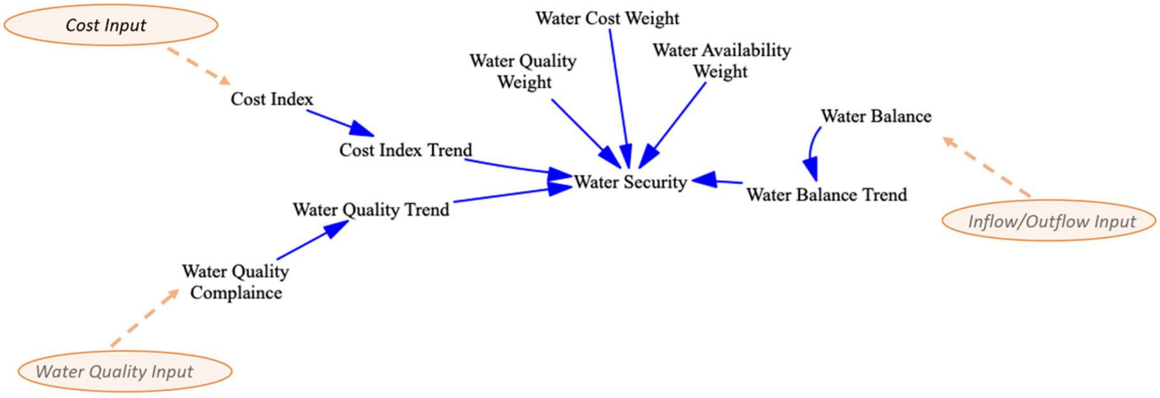


Figure 4-19. Model Configuration for Water Security

4.4 Model Testing

The model behavior and calibration were conducted using existing data. A sensitivity analysis was then conducted to evaluate the model's sensitivity to exogenous variables.

4.4.1.1 Model Behavior and Calibration

Model calibration is the process of adjusting model parameters so that the model predictions more closely replicate observed patterns in a system. The model is run using a set of input data and then the metered and modeled responses are compared to evaluate the ability for the model to produce historical events. Using the comparison of the model and metered results, through the process of model calibration, the model parameters can then be adjusted so that the model can more closely replicate the observed response over time. The results of model calibration are discussed in detail in ***Section 5.1 Model Behavior & Calibration.***

4.4.1.2 Sensitivity Testing

Sensitivity testing was conducted using the sensitivity tool within the Vensim software to evaluate exogenous variables. The non-timeseries exogenous variables included population growth rate, the M&I per capita demand, the pumping demand, and natural inflows and outflows. Time-series exogenous variables such as precipitation and imported water were evaluated as part of the scenario evaluation, discussed in subsequent sections of this report. The intent of the sensitivity analysis was to understand the variability in the model based on several assumed model variables. Individual sensitivity analyses were conducted for each of the forementioned variables and then a combined sensitivity analysis was conducted.

The Vensim sensitivity analysis tool allows for hundreds of simultaneous simulations to be carried out at a time to evaluate how a change in the variable impacts the overall model. Vector sensitivity analyses were conducted. The vector generates a sequence of numbers from minimum to maximum by increment, uniformly increasing by a specified tolerance.

The results of the sensitivity analysis produce sensitivity graphs that present the confidence bounds for the simulations. Confidence bounds are computed at each point in time by ordering and sampling the simulation runs. This indicates that at a confidence bound of 50%, a quarter of the runs had a value above the top of the 50% bound and a quarter of the runs had a value below the bottom of the 50% bound.

4.5 Case Evaluation

Once the model calibration and sensitivity testing were completed the model was used to evaluate different climate scenarios and infrastructure implementation scenarios.

4.5.1.1 Climate Scenario Evaluation

The climate scenario evaluation considered changes in precipitation and imported water from Table A allocations and Article 21. These were input as time-series data while maintaining other variables constant. Additional information on the climate scenario evaluations can be found in the results section of this report, ***Section 5.3 Section Climate Scenarios.***

4.5.1.2 Infrastructure Implementation Scenario Evaluation

Three alternative infrastructure implementation scenarios were evaluated. These included:

- **EBB-Water Project—**Increasing the available water supplies through the treatment of brackish groundwater
- **Freeman Diversion Expansion—**Increasing the available surface water diversions through the expansion of the Freeman Diversion capacity as well as increasing surface water storage capacities.
- **Recycled Water—**Adding the use of recycled water to the basin as a new water supply to the system.

These alternatives were simulated under several climate precipitation scenarios. The evaluation also assumed that SWP Table A water would remain at an average of 50% allocations and that Article 21 water would not be available.

For each of these alternatives the water quality, cost, and water availability were evaluated and compared against each other. A composite ‘water security’ value was derived from the water quality, cost, and availability values and served as a further comparison metric.

<u>EBB-Water Project</u>

The EBB-Water project which will treat brackish groundwater was added to the model to evaluate how the impact of the additional highly pure water would impact water security. The project has a planned implementation of approximately 2025. Implementation of the project in 2025 was modeled as well as a delay in implementation to 2027, 2030, 2040, 2050, and no implementation.

Freeman Diversion Expansion

The Freeman Diversion Expansion which will increase the capacity of Santa Clara River flows that can be captured was evaluated with the model by adjusting the percentage of precipitation capture. Implementation of the project was evaluated under different future precipitation scenarios, anticipated percentage change in river flow capture, and by varying the year of implementation of the project.

Recycled Water

The addition of recycled water as a water supply to the Oxnard Basin was evaluated. Implementation of recycled water was evaluated under different future precipitation scenarios, anticipated recycled water flows, and by varying the year of implementation of the project.

Combination of Projects

The impact of implementing multiple projects within different timeframes was evaluated. This was used to evaluate the impacts that the multiple projects would have concurrently. Implementation of a combination of the three projects (EBB-Water, Freeman Diversion, and recycled water) were evaluated in several combinations and implementation schedules.

5. Results

This chapter provides an analysis of the results from the model which include the base model behavior and calibration results and the sensitivity analysis conducted on the base model. Additionally, several climate and infrastructure implementation scenarios were modeled using the calibrated base model. The results of these scenarios are presented.

5.1 Model Behavior & Calibration

The base model, which is described in ***Section 4.3 Model Design***, was calibrated to available data from the Groundwater Sustainability Plan (GSP) Report, population statistics, and other available resources. Model calibration is the process of adjusting model parameters so that the model predictions more closely replicate observed patterns in a system. The model was run using a set of input data and then the metered and modeled responses are compared to evaluate the ability for the model to produce historical events from 1985 to 2015. Calibration plots were developed and are presented to show the difference between model predicted and measured variables.

5.1.1.1 Basin Inflows

The basins inflows were evaluated overall and by each inflow source. These included incoming surface water that was either recharged or directly used in the system as well as natural sources of recharge such as precipitation recharge, stream leakage, or coastal influx, amongst others.

The overall inflow comparison for measured and modeled is shown in Figure 5-1. The average and total inflows were within less than 5% of each other for the period.

Inflows that contributed to the overall system inflows were evaluated. All natural inflows, shown in Figure 5 2 had a 6 percent difference between the average measured and modeled value. The natural inflows included the precipitation recharge, unincorporated inflows, subbasin inflows, stream leakage, and coastal flux.

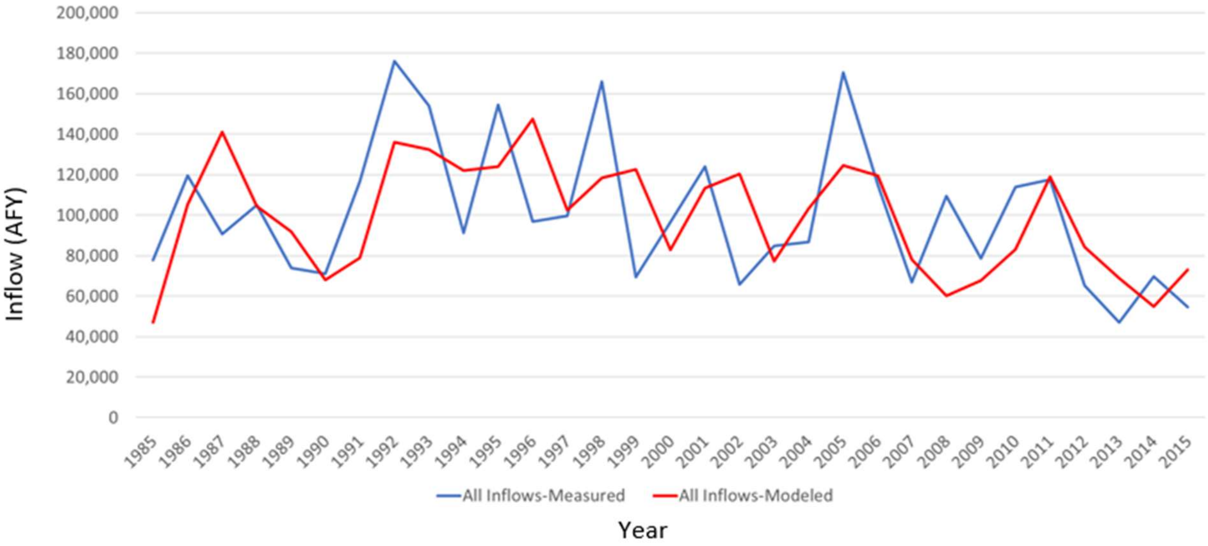


Figure 5-1. System Inflows Calibration Plot

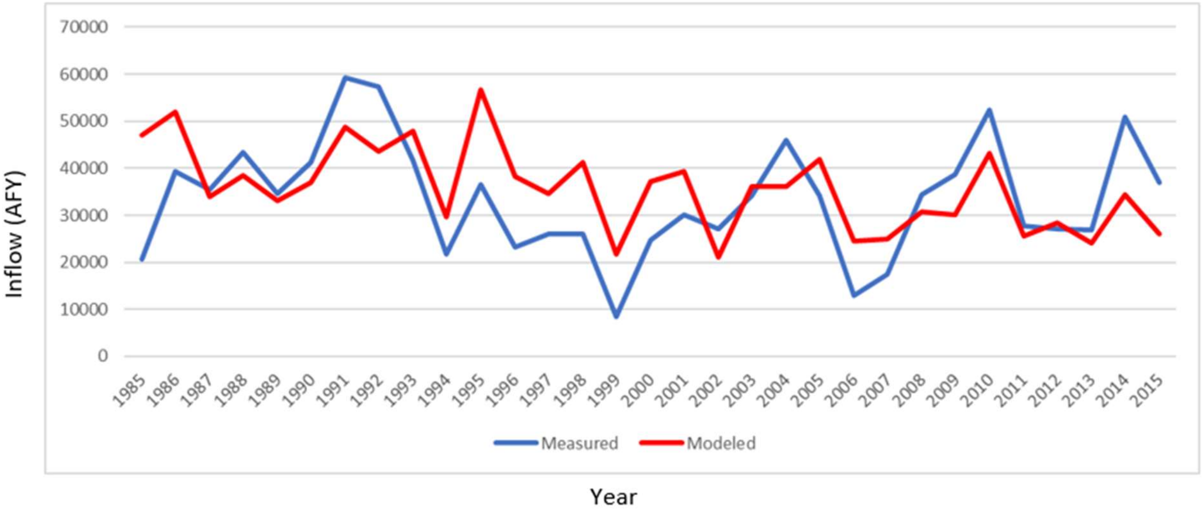


Figure 5-2. All Natural Inflows Calibration Plot

Precipitation recharege was calcualted by the model based on the measured amount of precipitation. The model was able to nearly reproduce the measured precipitation recharege, with a less than 1% difference bewteen the modeled and measured average and total precipitation recharge. Precipitation recharge, however, is not a physically measured condition, as it can not be direclty measured. The 'measured' precipitation recharge is a model predicted value. As a result, this suggests that the system dyanmic model created for this application has a similar estimation of the precipitation recharge to the existing groundwater model.

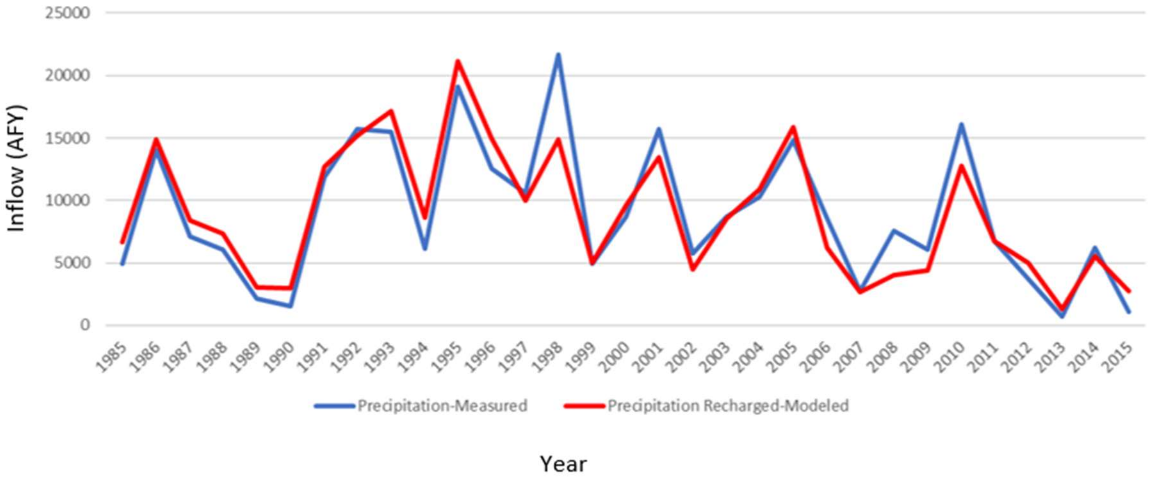


Figure 5-3. Precipitation Recharge Calibration Plot

The river stream leakage 'measured' value was similarly estimated by the existing groundwater model. The system dynamics model was able to reasonably reproduce the

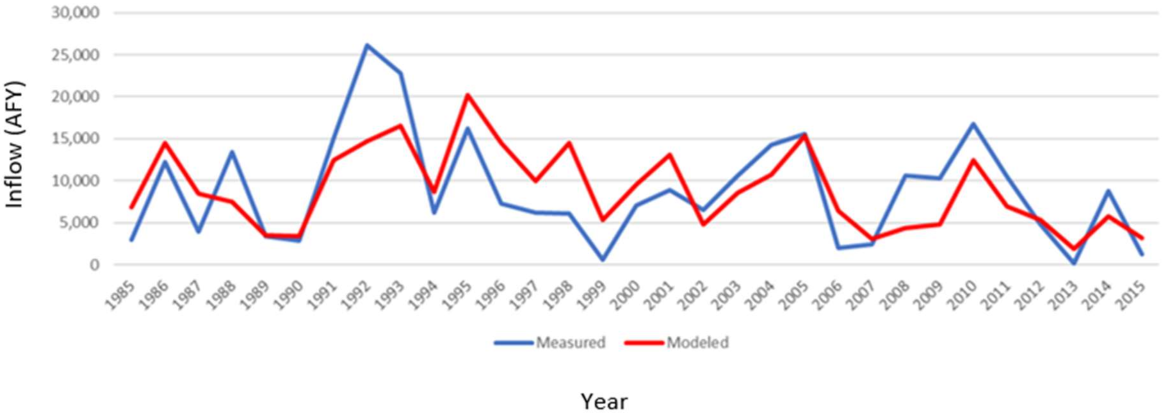


Figure 5-4. River Stream Leakage

There was a poor correlation between the coastal flux modeled and measured values. Strong correlations between coastal flux and other variables were not identifiable. Large amounts of coastal flux occurred between 1988 and 1993, as well as between 2013 and 2015. The model is able to predict an average coastal flux value, but is unable to reproduce the high fluxes during those two periods.

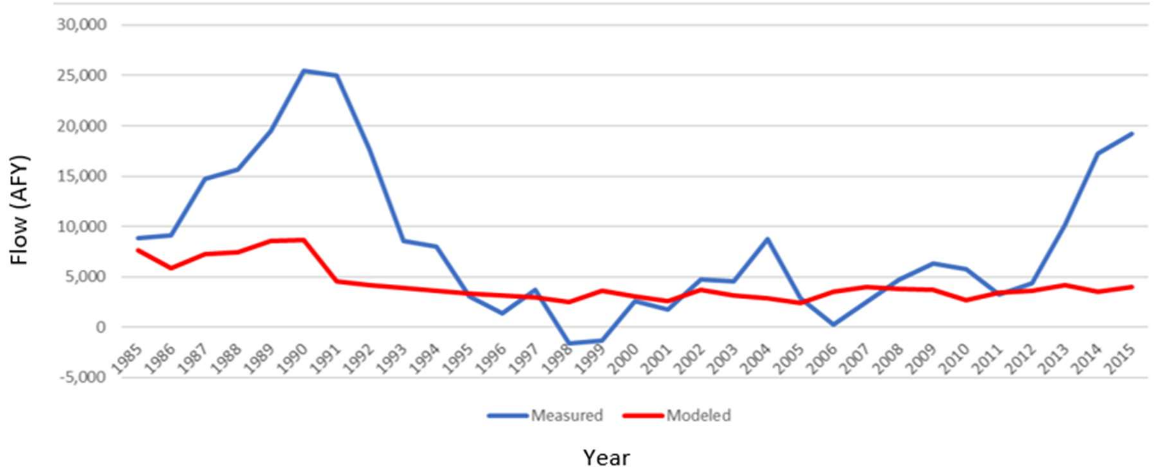


Figure 5-5. Coastal Flux Calibration Plot

Incoming surface water from the Freeman Diversion accounts for water that has been diverted from the Santa Clara River for either use in the PTP or OH systems. This diversion water can either reduce the amount of required pumping by end-users by being used directly as surface water, or it can be recharged into the groundwater basin. The Freeman Diversion includes natural river flows, as well as imported water from the SWP and Article 21. These values also account for a percentage of the water that is diverted away from the Oxnard Basin to other basins, such as the Pleasant Valley Basin. The modeled versus measured Freeman Diversions to the Oxnard Basin are shown in Figure 5-6.

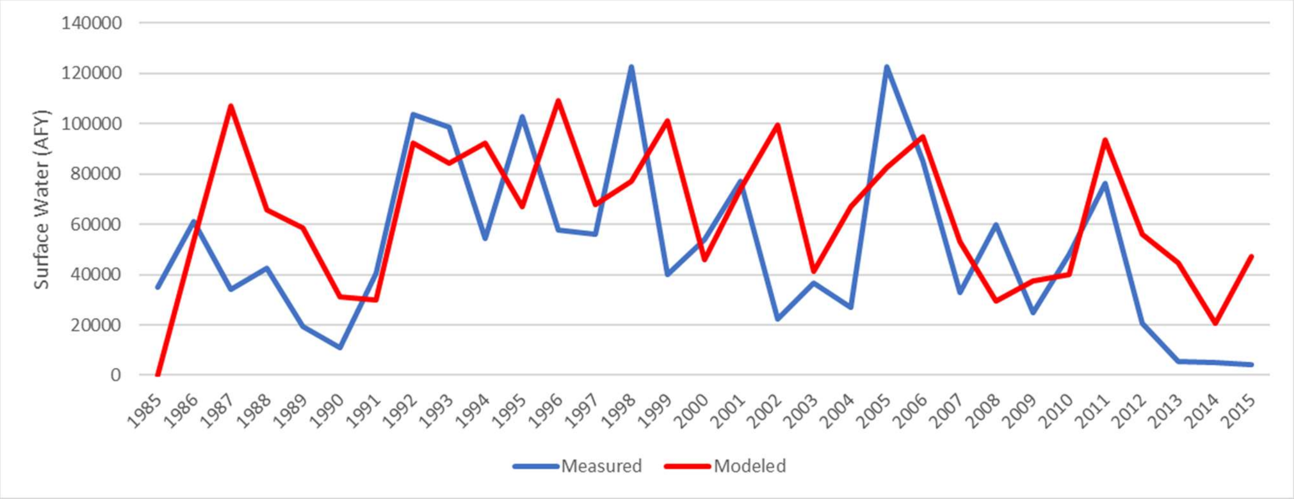


Figure 5-6. Freeman Diversion Calibration Plot

5.1.1.2 Basin Outflows

The basins outflows were evaluated overall and by each inflow source. These included natural losses such as subsurface outflow, evapotranspiration, stream leakage, tile drains, and costal flux out. Basin demands were also accounted for which included domestic, M&I, and irrigation demands.

The overall outflow comparison for measured and modeled is shown in Figure 5-7. The average and total outflows were within less than 5% of each other for the period. The simulated outflows are lower than the modeled outflows for the period of 1995 to 2005. This variation is primarily due to the under predicted variables tile drains and evapotranspiration during this period.

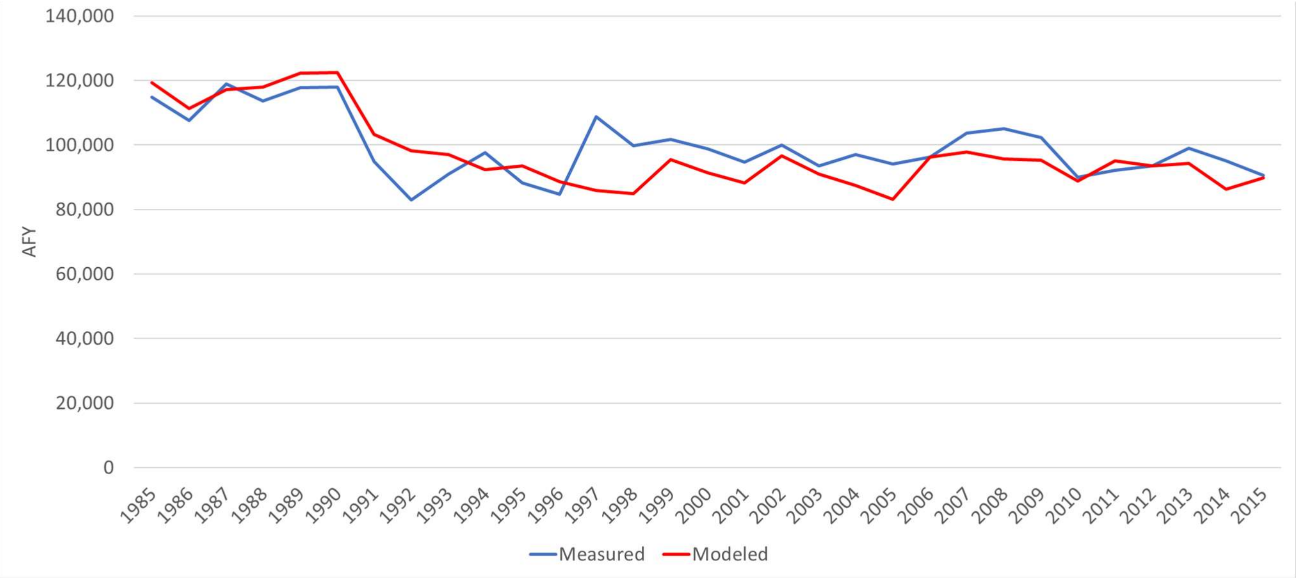


Figure 5-7. System Outflow Calibration Plot

The basin demands for human use included domestic, M&I, and irrigation. The modeled average and total demands were within 2% of the measured demands for the period. There was some variation between the demands, particularly between 1990 and 2000, as shown by Figure 5-8. However, overall, the model was able to reproduce the measured demands during the calibration period.

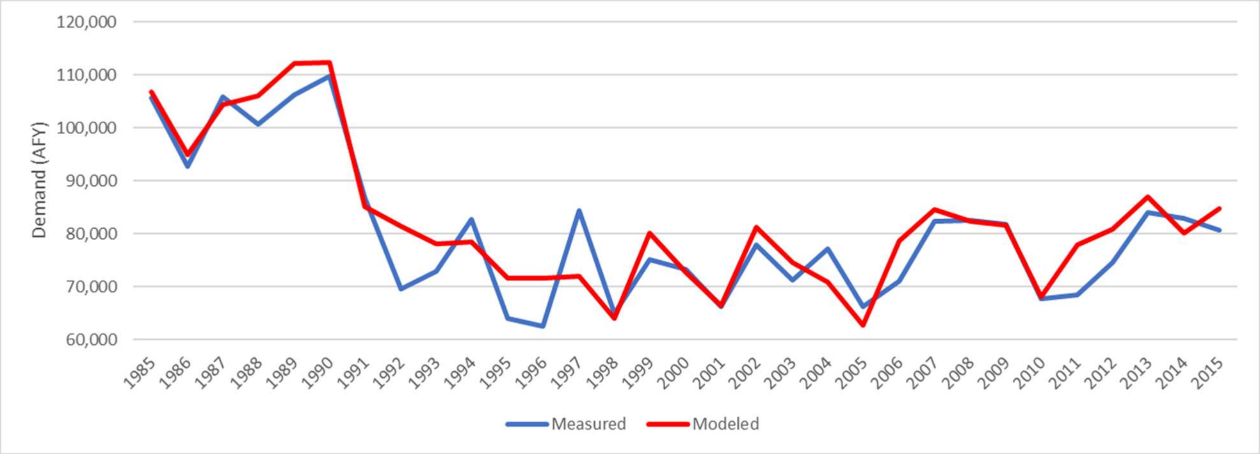


Figure 5-8. Demand Outflow Calibration Plot

The irrigation demands, which were primarily driven by precipitation, had a strong correlation between the model and measured values, as shown by Figure 5-9. The average and total modeled and measured values for irrigation were within 1 percent of each other.

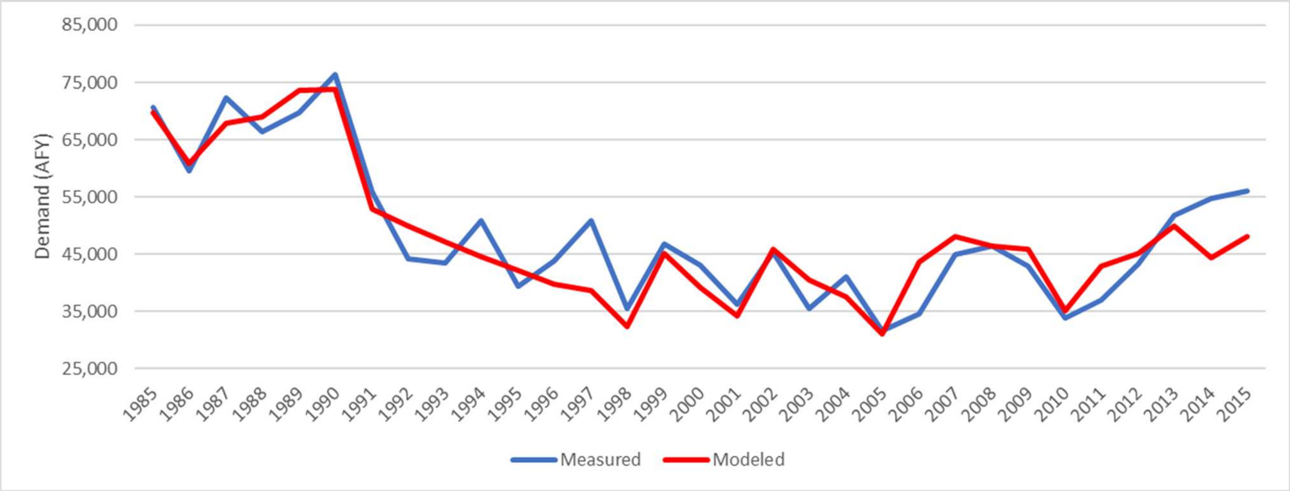


Figure 5-9. Irrigation Demand Calibration Plot

The M&I demands were generally able to be reproduced by the model as shown by Figure 5-10. This relationship was based on precipitation and population growth. The model missed the large variation that occurred in the mid to late 1990's, and generally trended higher than the measured values in the 1980's-90's and 2010-2015. However, overall, the model was within 10% of the average and total value for the calibration period.

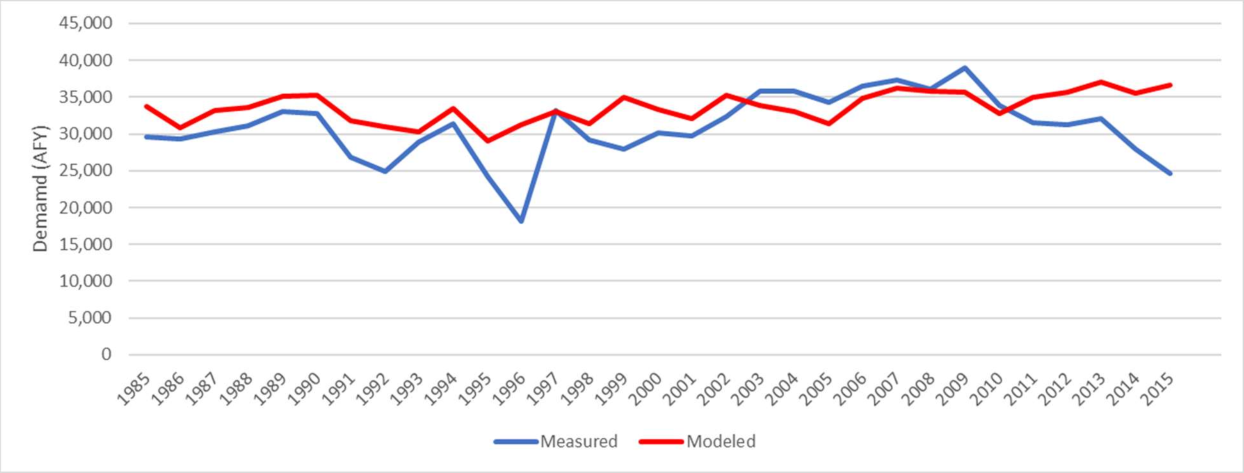


Figure 5-10. M&I Demand Calibration Plot

The domestic demands had significant variations from 1985 to 1993 that the model was not able to replicate, as shown by Figure 5-11. This may have been a result of a policy change or loss of a significant domestic user. However, the total volume of water was able to be generally modeled and the period from 1993 to 2015 was similar. The domestic demand also accounted for the smallest demand of the outflows and as a result this does not have significant impacts on the overall water balance results for the system.

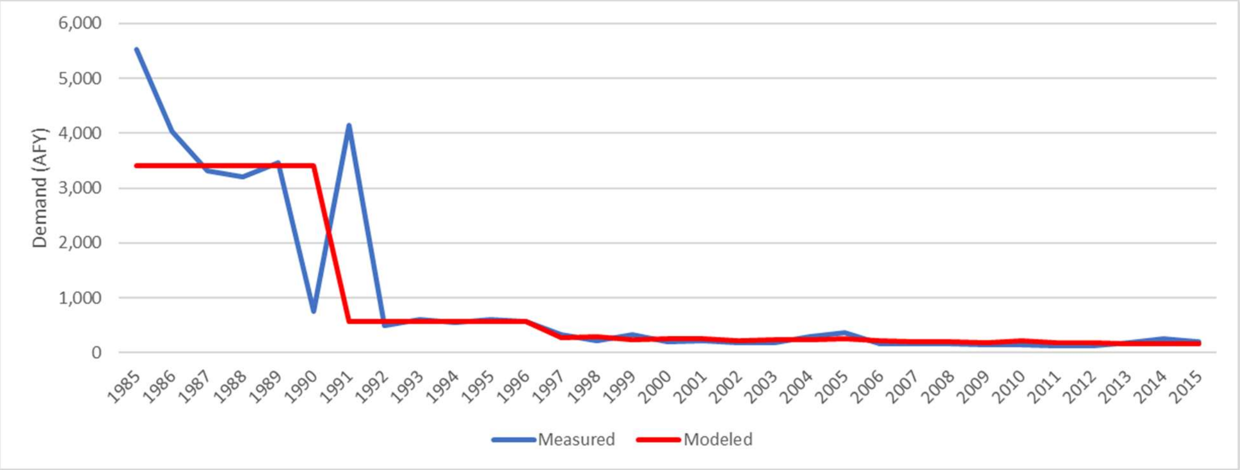


Figure 5-11. Domestic Demand Calibration Plot

The model was able to reproduce the measured evapotranspiration outflows, as shown by Figure 5-12. The modeled and measured average and total were within 1percent of each other. Similar to precipitation recharge, 'measured' evapotranspiration was a modeled value provided by an existing model. The strong correlation between modeled and measured values indicates a strong correlation between the existing model.

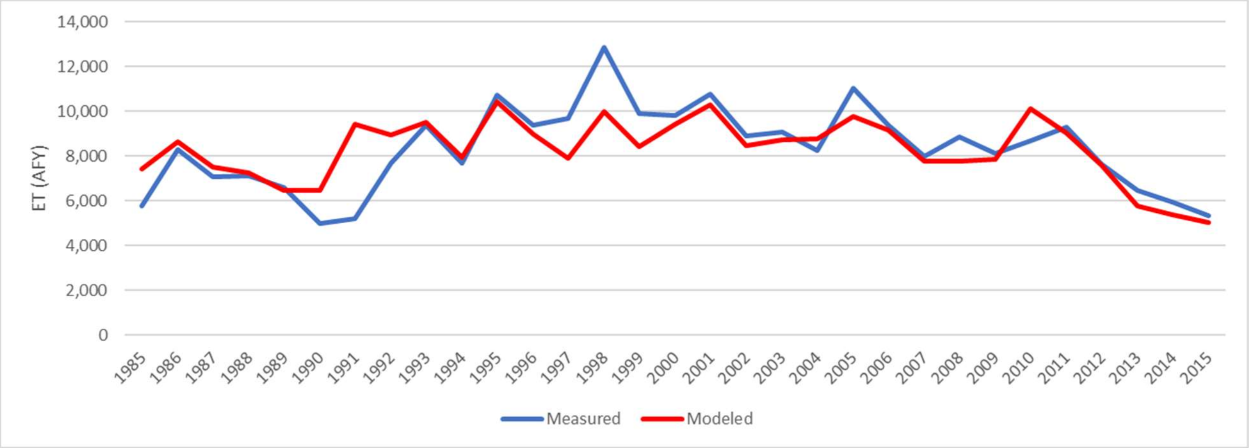


Figure 5-12. Evapotranspiration Calibration Plot

The model was able to reasonably reproduce the measured tile drains outflow, as shown by Figure 5-13. The modeled and measured average and total tile drain outflow was within 3 percent. The 'measured' tile drains were a model estimated value from the existing groundwater model, as the inflow from tile drains cannot be directly measured.

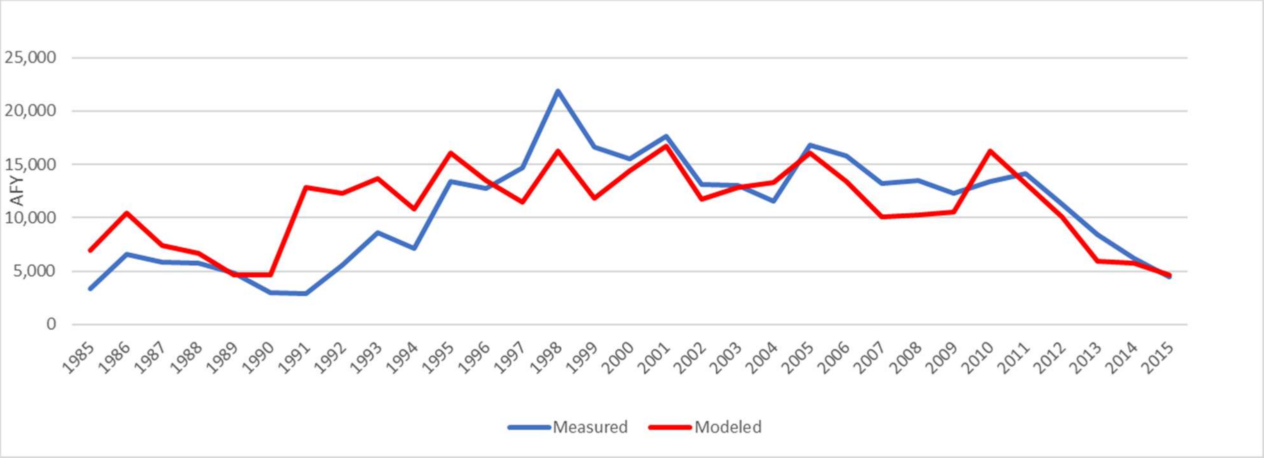


Figure 5-13. Tile Drains Calibration Plot

5.1.1.3 Additional Variables

Other variables that were included in the model but were not directly influencing supply and demand included precipitation, temperature, population, and FCGMA regulations. Precipitation and temperature were model inputs and as a result there was no modeled or measured differences. The FCGMA regulations impacted irrigation use and were calibrated in conjunction with the irrigation parameter previously discussed.

Population was estimated for the model using a constant growth rate. This growth rate was estimated from available measured population data. The comparison of measured and modeled population is shown in Figure 5-14. There was a less than 1% difference between measured and model predicted values for the minimum and maximum values for population. The average population for model and measured results were within 2 percent of each other. There is a slight increase in population in the early 1990's that the model does not capture, however by the early 2000's the model is near the measured values. As a result, the population is reasonably calibrated.

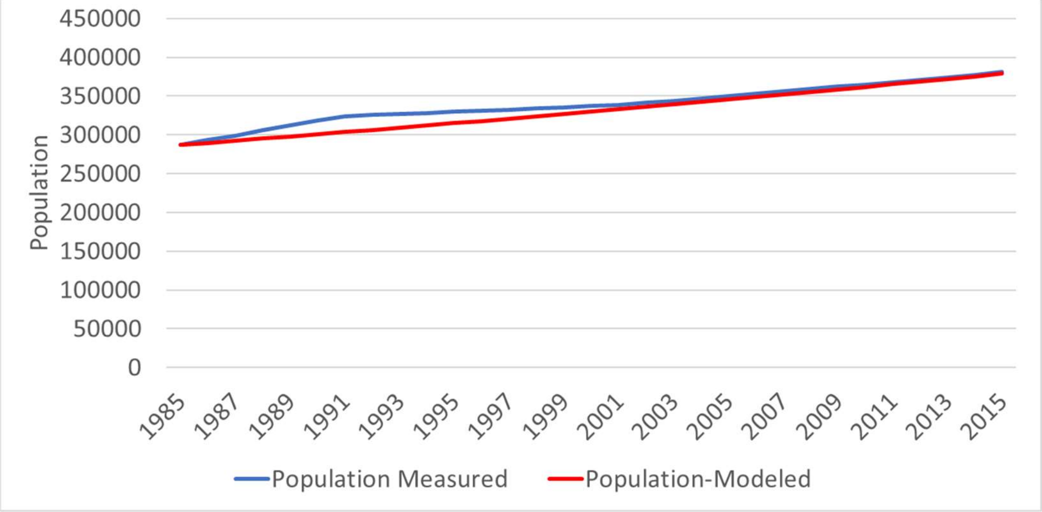


Figure 5-14. Population Calibration Plot

5.1.1.4 Water Balance

The water balance is the comparison of the total inflow versus outflow from the system. This includes inflows and outflows of the model, as summarized in sections 5.1.1.1 through 5.1.1.3. The cumulative water balance for the calibration period is represented by the modeled Oxnard Basin Groundwater stock (Figure 5-15). The available volume of groundwater in 1985 is unknown, and as a result the model results presented show a cumulative change from 1985. The measured versus modeled cumulative water balance is shown in Figure 5-16 for the calibration period of 1985-2015. The model and measured basin assumes a do not assume an initial groundwater basin supply (1985) and measures the total change in the groundwater supplies over time in reference to 1985. Based on the plotted results, the model can follow the measured trend, where the basin is in overdraft between 1985 and the mid-1990's. The model slightly over predicts the number of years of overdraft but follows the general trend of increasing supplies between the late 1990's and mid 2000's. Between 2012 and 2015 the measured groundwater supplies begin to reduce again. The model can predict this reduction, however, it does not have as steep of a decline. condition.

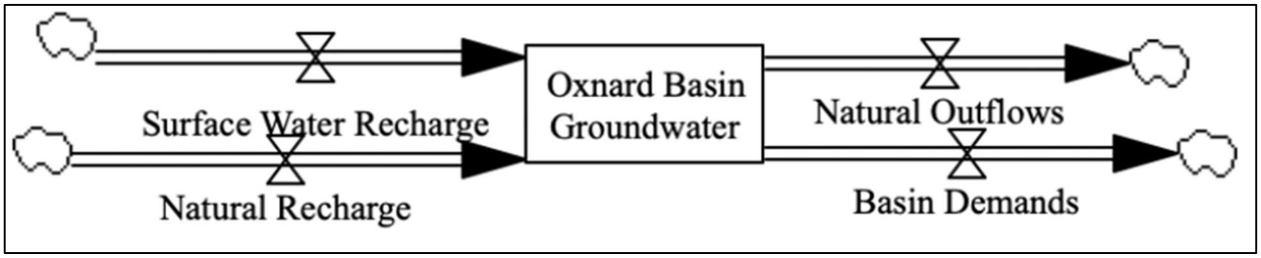


Figure 5-15. Oxnard Basin Groundwater Balance

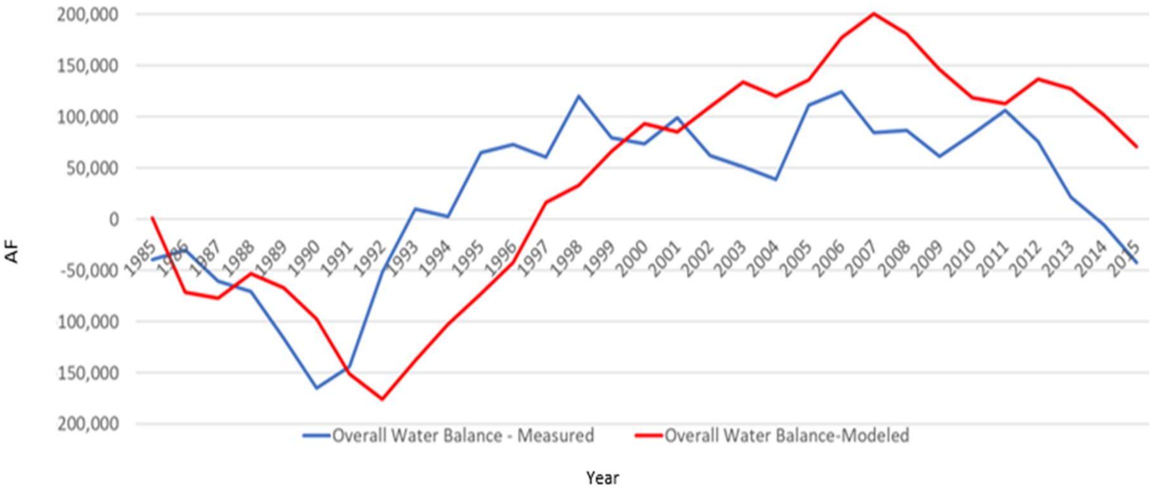


Figure 5-16. Oxnard Basin Cumulative Water Balance Calibration Plot

The model was the evaluated on a year-by-year basis for the water balance, based on the net inflows and outflows from the system. The model generally was able to predict whether more water was going in or out of the basin each year, as demonstrated by Figure 5-17. There were some fluctuations that were not captured by the model. In addition, the model underestimates the available water in the early 1990's. This difference is likely due to the difficulty in estimating the water volume that was contributed by the coastal flux. However, in general the model results were similar to measured data.

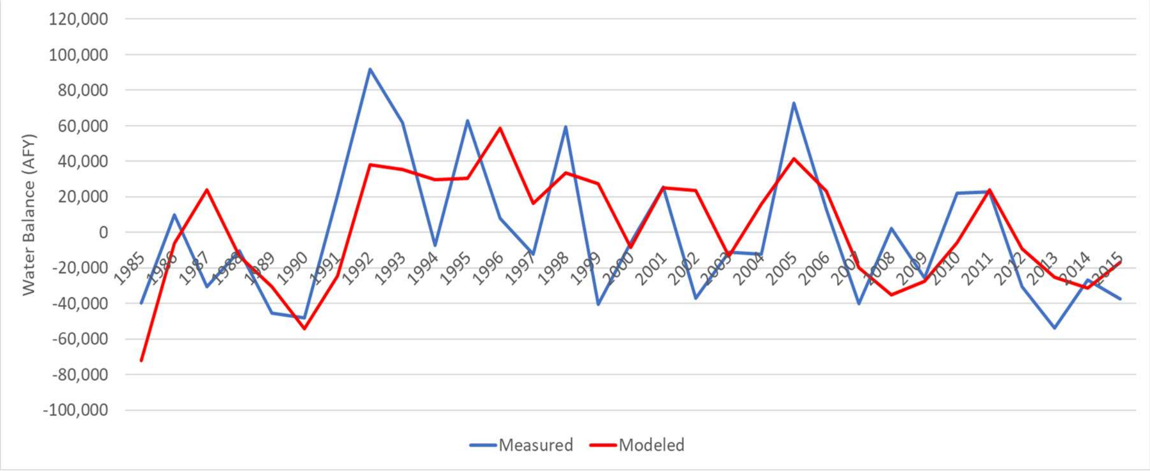


Figure 5-17. Water Balance on Year-By -Year Basis Calibration Plot

The ability of the model to match the net gains or losses from the basin were evaluated in binary, with 0 indicating a net loss and 1 indicating a net gain. The net gain or loss on a yearly basis is shown in Figure 5-18. This plot indicates that for the 31 years that were simulated, 16 modeled years had a net gain. This was near to the measured value of 18 years with net gains. 21 of the 31 years simulated matched the measured net gain/loss from the basin.

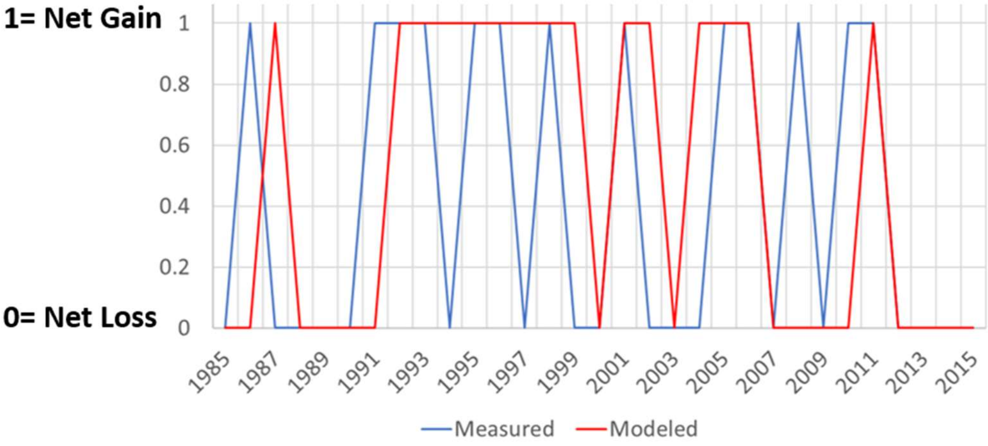


Figure 5-18. Water Balance Net Gain/Loss Calibration Plot

5.1.1.5 Summary of Calibration

Based on the evaluation of these calibration plots, the model is well calibrated for the period of 1985 to 2015, with the ability to generally predict the year-by-year fluctuations in groundwater variance, evaluated based on the inflows and outflows of the system, as reported by the GSP (2019). The model can show the general net change in the water basin from 1985 based on the model inputs which include precipitation, temperature, and imported water.

5.1.1.6 Calibrated Model Limitations

While the model is able to generally reproduce the measured values observed in the calibration period of 1985 to 2015, there are some limitations to the model. These include seasonality, policy change, and uncertain values based on existing modeling efforts.

Seasonality

A limitation of the model is the ability for it to measure the seasonal variations that exist within the Oxnard Basin. Justification for excluding seasonality was discussed in ***Section 4.1.3 Time Horizons***. The model assumes that on an annual basis the water uses will be distributed. However, water storage and capture may be impacted by this assumption. For example, if most of the precipitation were to occur within a 1-month timeframe, the ability to capture, distribute, and percolate those flows may be limited and as a result water may be lost to the ocean that could have been otherwise recharged to the basin.

Policy Change

FCGMA policy changes were incorporated into the model, however, not all policy changes were included. Other policies, regulations, or economic factors may have contributed to the system behavior. Incorporating these policy changes would require further collaboration with stakeholders to understand how historically the system behaved to these changes. Understanding these historical change may provide insight into future policy behavior reactions.

Uncertain Model Values

Uncertainty, which is caused by variability results in fluctuations in the potential outcome. Two forms of uncertainty within this water balance modeling are stochastic variability and uncertainty due to a lack of knowledge. On the latter, there is a significant lack of knowledge on the exact quantity of water that is entering and existing the system as a result of natural inflow and outflow. These fluctuations cannot be easily measured and level data from monitoring wells have been used to estimate these values along with other system information.

The existing groundwater model that the UWCD uses to evaluate the basin groundwater conditions uses level data to approximate these parameters and the degree to which an event occurs. Further evaluation of these uncertain values against the model may provide insight into the ability for the model to predict under extreme conditions.

5.2 Sensitivity Analysis

The sensitivity analysis was conducted using the base scenario which used a future predicted temperature, precipitation, Table A allocations, and no Article 21 water. The intent of the sensitivity analysis was to understand the variability in the model based on several assumed model variables. These variables evaluated as part of the sensitivity analysis included the population growth rate, the M&I per capita demand, the pumping demand, and natural inflows and outflows. Individual sensitivity analyses were conducted for each of the forementioned variables and then a combined sensitivity analysis was conducted.

The subsequent graphs presented in this section that were produced as part of the sensitivity analysis present confidence bounds. These confidence bounds are computed in each point in the simulation by sampling all of the simulation runs. This shows the confidence that the model will produce a value within a range. A higher confidence value, such as 95% presented as the area in blue within the graph, results in a higher likelihood of the model being within the indicated range.

5.2.1.1 Sensitivity Analysis for Population

The assumed growth rate of the model is 0.93% based on available population statistics. Several factors over time, however, can influence population growth, such as economic opportunities, water availability, affordability and availability of housing, amongst others. Two growth sensitivity tests were conducted. The first assumed a maximum growth rate of 5%, which is significantly higher than the existing growth rate of less than 1%. The second sensitivity analysis assumed a more conservative maximum growth rate of 1.5%.

The sensitivity analysis using a 5% growth rate indicated a significant increase in anticipated demand by 2100. This resulted in a near-mirrored decrease in the basin's cumulative water balance, as illustrated by Figure 5-19. This also demonstrates that the model is sensitive to a high growth rate. It is unlikely that the system would be able to support this level of growth without significant changes to the system, suggesting that the model is sensitive to the growth rate.

Similarly, a lower growth rate was evaluated that evaluated a range of 0-1.5% growth. The resulting population growth and basin cumulative water balance are shown in Figure 5-20.

These results indicate that within a smaller growth rate the system can overtime have a compounding impact on the availability of water supplies by 2100. With a higher growth rate, the system demands exponentially increase over time and as a result the year-by-year recharge I decreased faster so that earlier in the simulation there is more water being extracted than input to the basin.

5.2.1.2 Sensitivity Analysis for M&I

Based on the calibration of the model, the per capital M&I consumption was estimated to be 81.7 gpd per person. A 10% increase and decrease was used to evaluate the impact of M&I on the model. A 10% decrease in M&I could reflect a change in water savings behavior, while a 10% increase in M&I could reflect a shift towards more water intensive M&I activities.

Table 5-1. M&I Sensitivity Values

Gallon per day per person	Acre Feet per Day per Person	Value
73.53	0.082	10% decrease
81.7	0.092	Existing
89.87	0.101	10% increase

The growth of M&I demand is shown in Figure 5-21 indicates that the model is not very sensitive to the M&I per capita demand, when compared to the model's sensitivity to the population growth rate. The small impact can be observed by the narrow confidence bands.

5.2.1.3 Sensitivity Analysis for Agricultural Pumping

Since agriculture accounts for more than 50% of the demand of the water in the Oxnard Basin, a sensitivity analysis was conducted to see the impact of raising or lowering pumping by 25%. The results of increasing or decreasing the pumping had moderate to high impacts on the model, as shown by Figure 5-22.

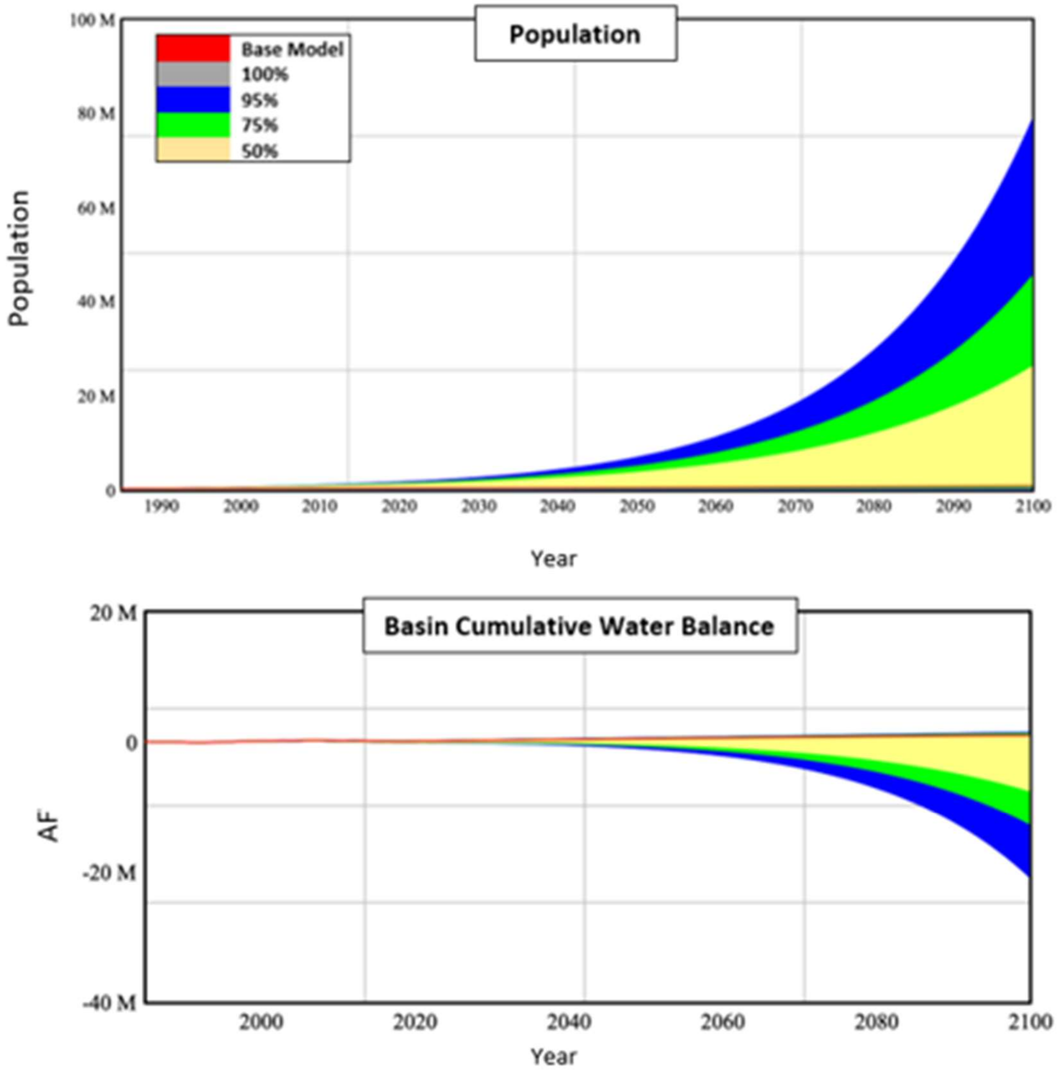


Figure 5-19. Population Sensitivity Analysis with a Maximum Growth Rate of 5%

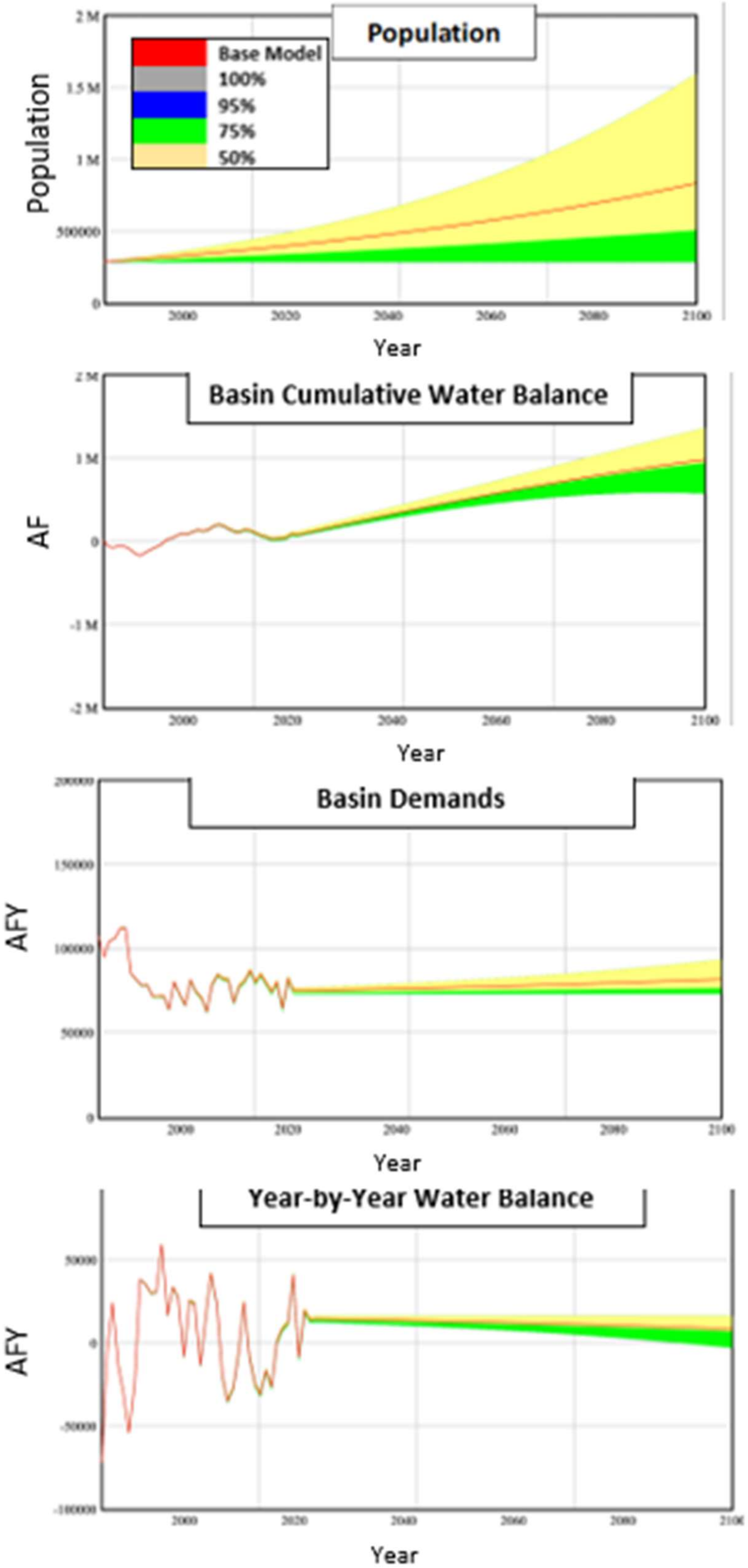


Figure 5-20. Population Sensitivity Analysis with a Maximum Growth Rate of 1.5%

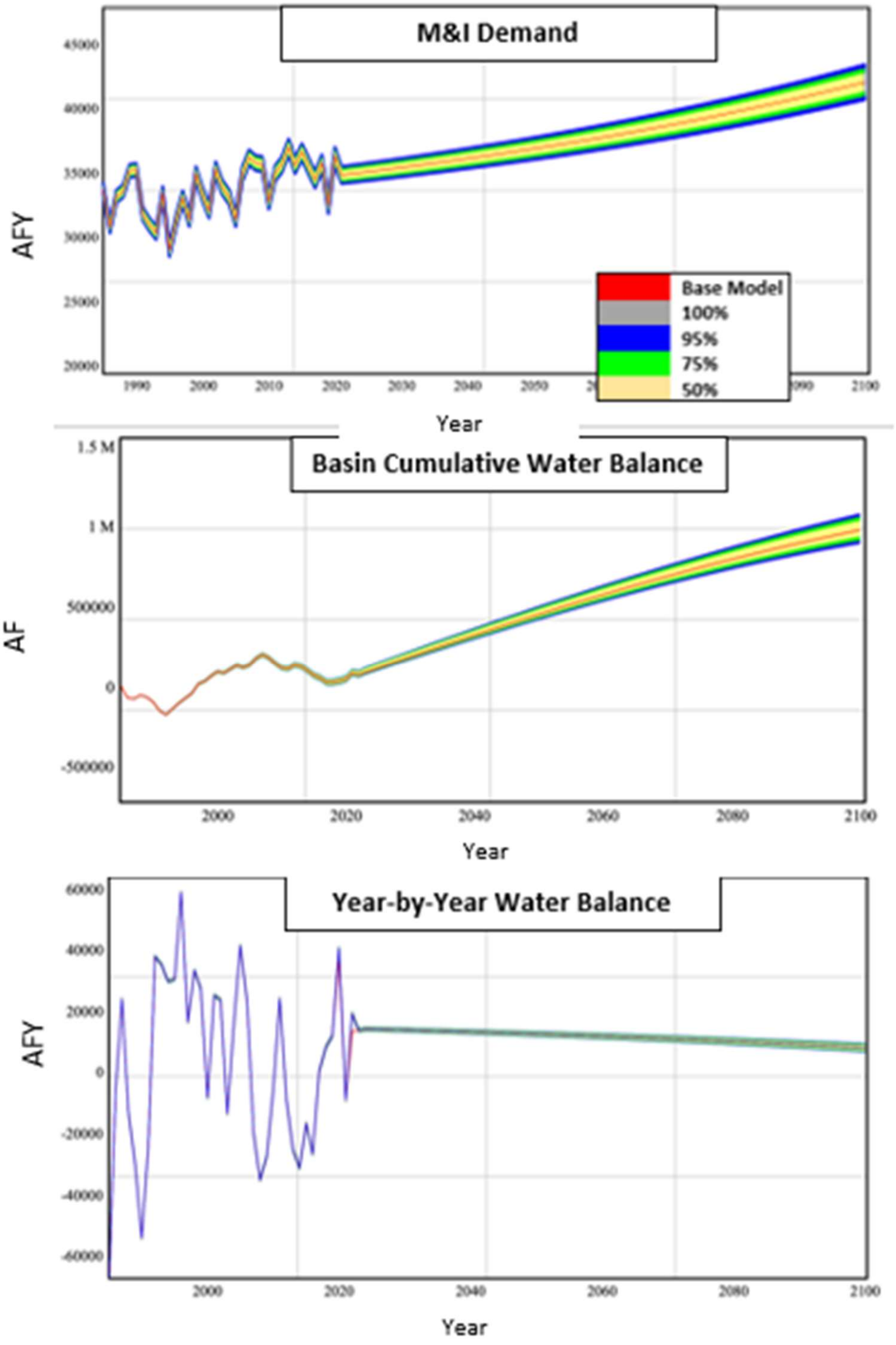
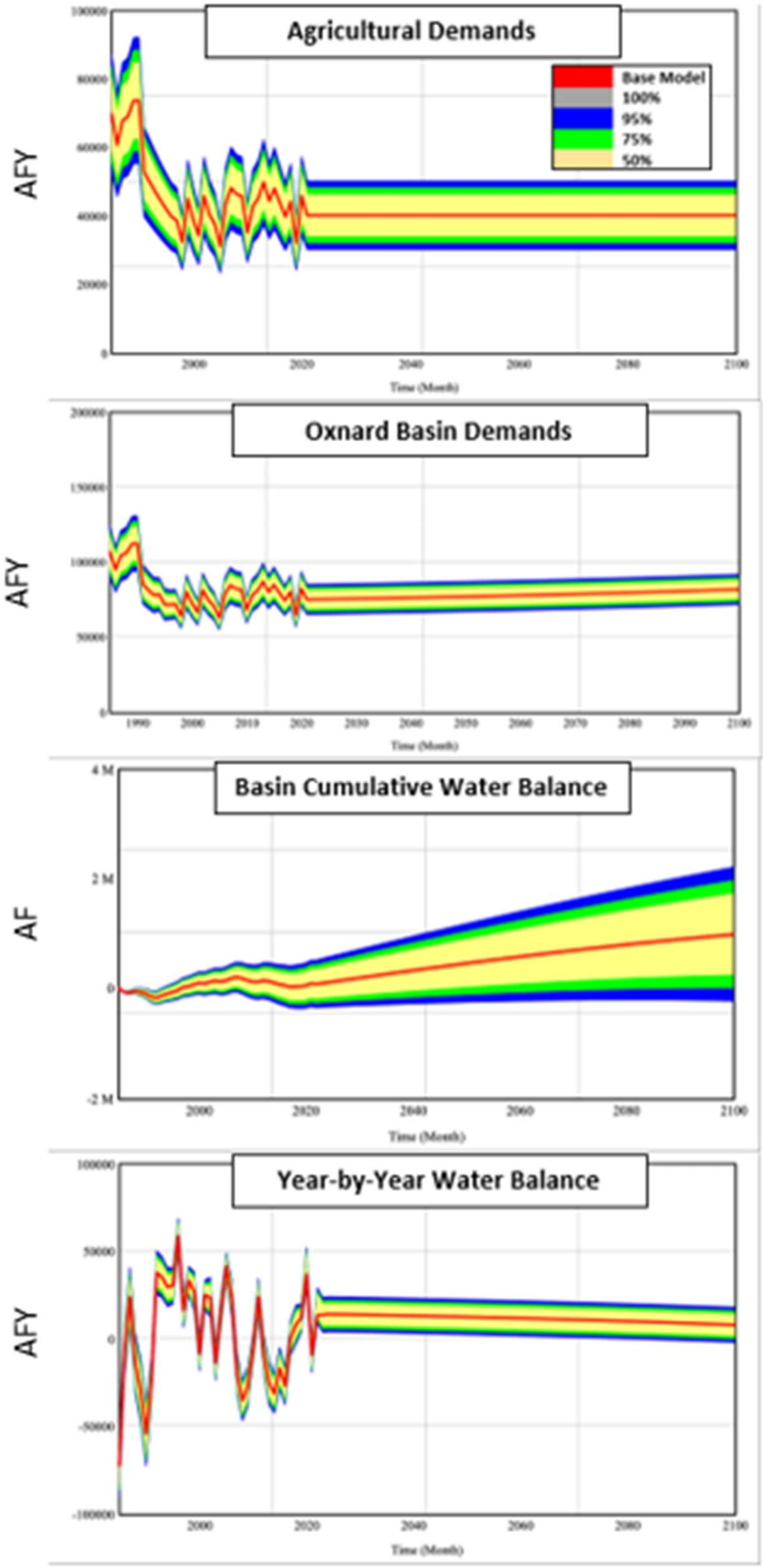


Figure 5-21. M&I Per Capita Demand Sensitivity Analysis



Agricultural Demands

Oxnard Basin Demands

Basin Cumulative Water Balance

Year-by-Year Water Balance

Figure 5-22. Agricultural Demand Sensitivity Analysis

5.3 Climate Scenarios

Climate scenarios were used to evaluate potential future scenarios of precipitation, Table A water allocations, and Article 21 water.

5.3.1.1 Precipitation Variation

Eleven potential future precipitation patterns were derived based on anticipated climate projections using various methods. These precipitation projections were used to extend the 1985 to 2015 calibration period to simulate potential scenarios to evaluate how the system may respond.

Climate estimates for Ventura County estimate a 2 to 5 percent decrease in average annual precipitation, however existing simulated future precipitation models demonstrate considerable disagreement (Oakley, 2019). Based on precipitation data from the area, the average precipitation from 1985 to 2020 was 12.13 inches. Reducing average precipitation by 2 or 5 percent results in 11.89 and 11.52 inches, respectively. The first three precipitation scenarios (P-01, P-02, and P0-3) used the average, 2% reduced average, and 3% reduced average precipitation for the future forecast.

Climate predictions, however, also predict that the intensity and duration between extreme wet and extreme dry conditions will also increase. Drought periods lasting five years (P-04) and ten years (P-05) were modeled. The precipitation for the 5- and 10-year droughts were the annual precipitation from measured drought period from 2012 to 2016. During non-drought years the 2% average decreased precipitation was used.

While the use of average precipitation can show the general amount of precipitation that is anticipated in the system, precipitation is inevitably varied and it is anticipated that precipitation will fluctuate from year to year. Stochastic rainfall generators (SRGs) are a helpful tool for providing in-depth analysis of precipitation. STORAGE (STOchastic Rainfall Generator) was used to generate potential future precipitation scenarios under different anticipated climate predictions. STORAGE is a VBA macro in MS Excel that uses a modified version of the Neymann-Scott Rectangular Pulse to estimate the precipitation pattern. The software uses average annual precipitation and the number of dry days in a period to generate a precipitation pattern on a 5-minute basis. The 5-minute data was then aggregated to the annual basis and was used as an input to the model. Using this stochastic method to generate precipitation patterns average precipitation conditions (P-07), 2% and 5% increases in average precipitation (P-08, P-09), and 10 and 15% increases in average number of dry days (P-10, P-11) were developed. These stochastic precipitation scenarios represent a limited set of traces.

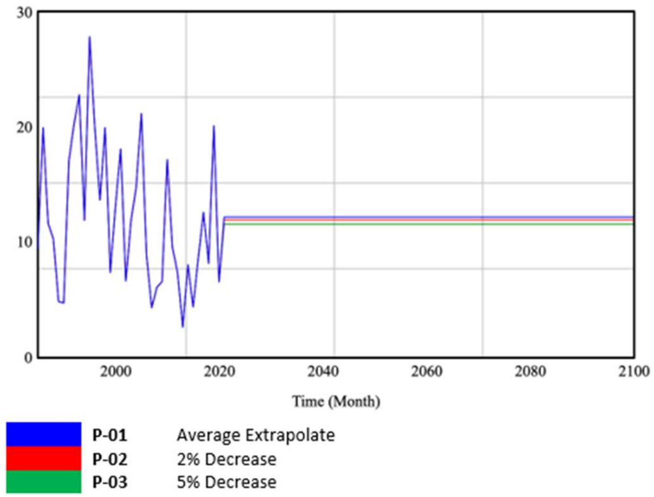
A summary of the precipitation scenarios is described in Table 5-2 and the hyetographs are shown in Figure 5-23. The precipitation statistics for each of these scenarios is presented in Table 5-3.

Table 5-2. Precipitation Climate Scenarios

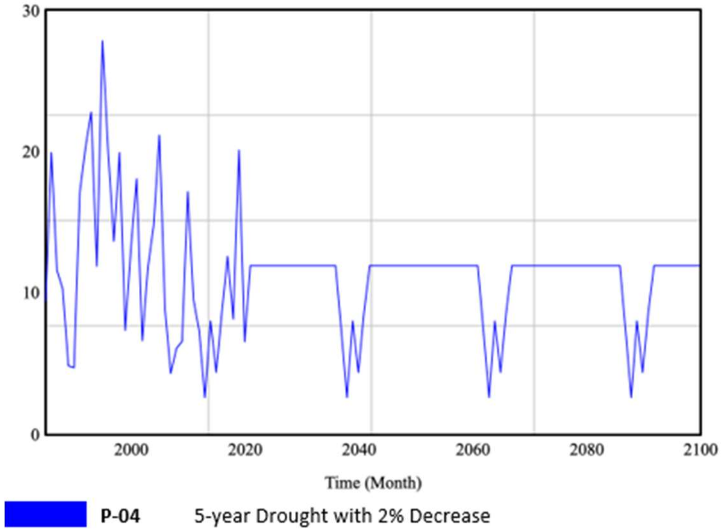
ID	Name	Description
P-00	Existing Historical precipitation	Existing, only used for 1985-2020
P-01	Average Extrapolate	12.13 inches annually from 2021 to 2100
P-02	2% Decrease	11.89 inches annually from 2021 to 2100
P-03	5% Decrease	11.52 inches annually from 2021 to 2100
P-04	Drought lasting 5 years with 2% Decrease	Drought lasting five years every 20 years, and 2% decrease average annual precipitation
P-05	Drought lasting 10 years with 2% Decrease	Drought lasting ten years every 20 years 2% decrease average annual precipitation
P-06	Drought lasting 5 years with Wet Year	Drought lasting five years followed by a year with higher than average precipitation
P-07	Stochastic Existing Average	STORAGE calculated using existing precipitation average and existing 36 average dry days
P-08	Stochastic 2% Decrease	STORAGE calculated using reduced average by 2% and existing 36 average dry days
P-09	Stochastic 5% Decrease	STORAGE calculated using reduced average by 5% and existing 36 average dry days
P-10	Stochastic 5% with Dry Day Increase	STORAGE calculated using reduced average by 2% and increase by 10% in average dry days
P-11	Stochastic 5% with High Dry Day Increase	STORAGE calculated using reduced average by 2% and increase by 15% in average dry days

Figure 5-23. Precipitation (in) Hyetographs by Scenario

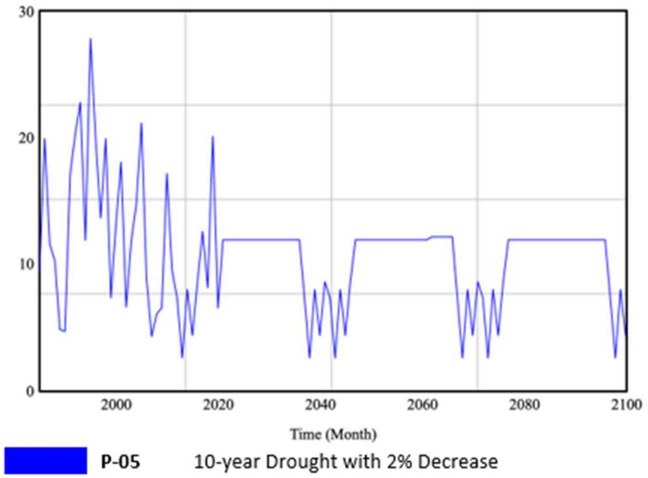
P-01, P-02, P-03



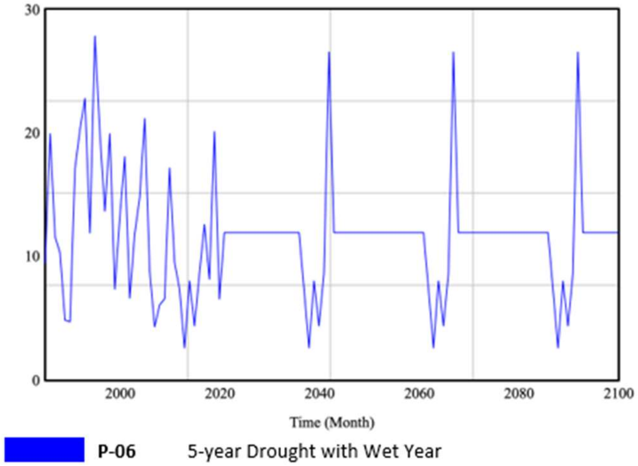
P-04



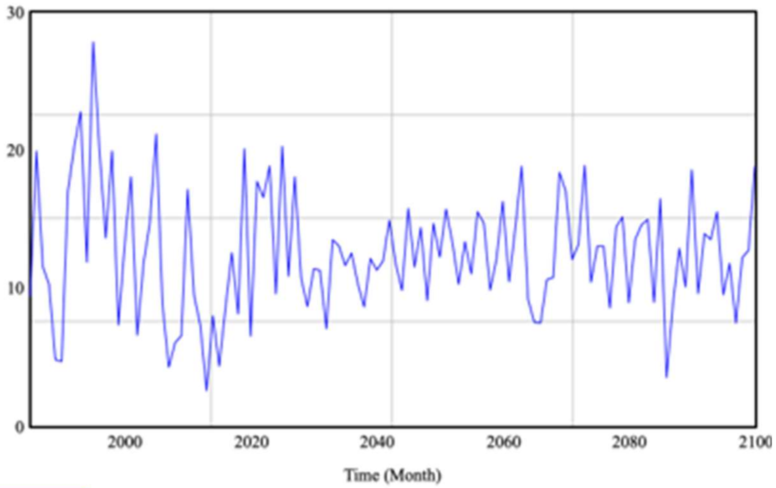
P-05



P-06

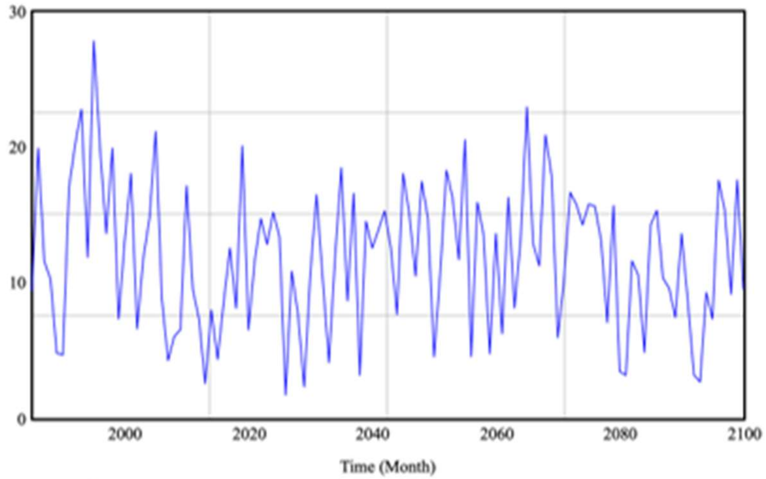


P-07



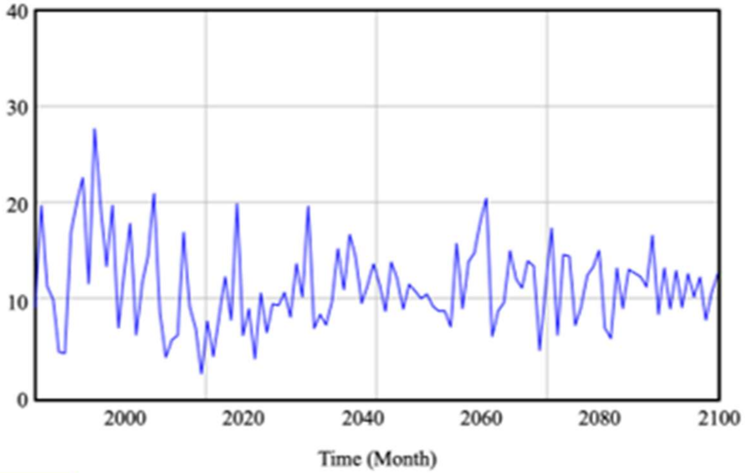
🟦 **P-07** Stochastic Existing Average

P-08



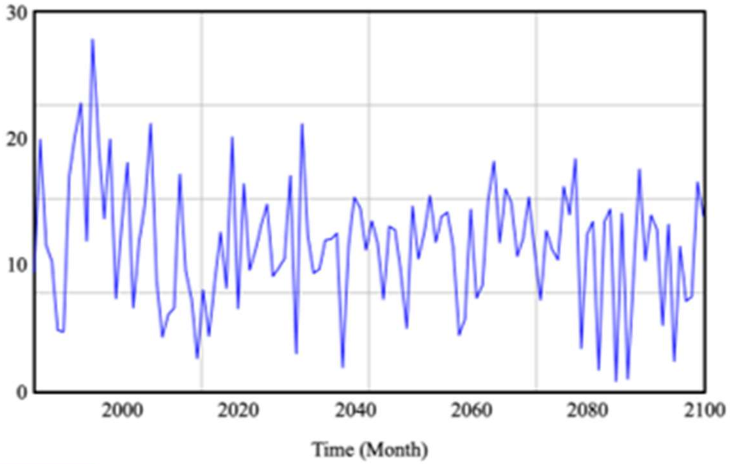
🟦 **P-08** Stochastic 2% Decrease

P-09



🟦 **P-09** Stochastic 5% Decrease

P-10



🟦 **P-10** Stochastic 5% with Dry Day Increase

P-11

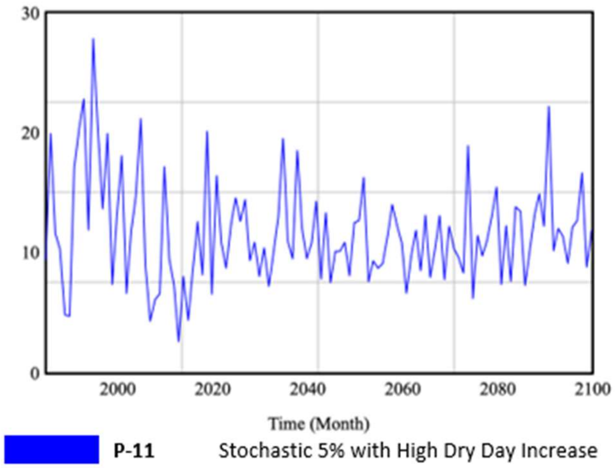


Table 5-3. Statistics for Precipitation Scenarios (1985-2100, inches)

ID	Name	Total	Maximum[1]	Minimum[1]	Mean	Median	Standard Deviation
P-01	Average Extrapolate	1407	12.13	12.13	12.13	12.13	3.50
P-02	2% Decrease	1388	11.89	11.89	11.96	11.89	3.50
P-03	5% Decrease	1358	11.52	11.52	11.71	11.52	3.51
P-04	5 years of Drought with 2% Decrease	1301	11.89	2.56	11.22	11.89	4.09
P-05	10 years of Drought with 2% Decrease	1249	12.13	2.56	10.76	11.89	4.38
P-06	5 years of Drought with Wet Year	1345	26.50	2.56	11.60	11.89	4.76
P-07	Stochastic Existing Average	1447	20.24	3.52	12.48	12.07	4.46
P-08	Stochastic 2% Decrease	1377	22.93	1.71	11.87	11.83	5.36
P-09	Stochastic 5% Decrease	1352	20.61	4.11	11.65	11.16	4.45
P-10	Stochastic 5% with Dry Day Increase	1339	21.09	0.77	11.55	11.78	4.99
P-11	Stochastic 5% with High Dry Day Increase	1344	22.15	6.16	11.58	10.88	4.35

(1) Maximum and minimum precipitation represent the period of 2021-2100

Average Precipitation Scenarios

The first three precipitation scenarios (P-01, P-02, and P0-3) which used the average, 2% reduced average, and 3% reduced average precipitation for the future forecast were evaluated. The year-by-year change in water added or removed from the basin remained above 0 between 2021 and 2100, as shown in Figure 5-24.

The cumulative water balance is the total amount of flow being added or removed from the system over time and is represented in the model by the Oxnard Basin Groundwater stock. The cumulative water balance in the Oxnard Basin was evaluated under the three average precipitation scenarios and is shown in Figure 5-25. Under all precipitation scenarios and the assumption that other variables in the system maintain constant, the total basin supplies are anticipated to increase over time. However, under the 5% scenario less than 700,000 AF will accumulate, while under a maintained average precipitation nearly 1 MAF will accumulate. Figure 5-25 also has an asymptotic curve, which is driven by the increase in outflows over time, as suggested by the decreasing availability of water over time in Figure 5-24. These graphs suggest that a long-term sustained change in average precipitation can have a significant impact on potential total amount of water accumulating within the basin.

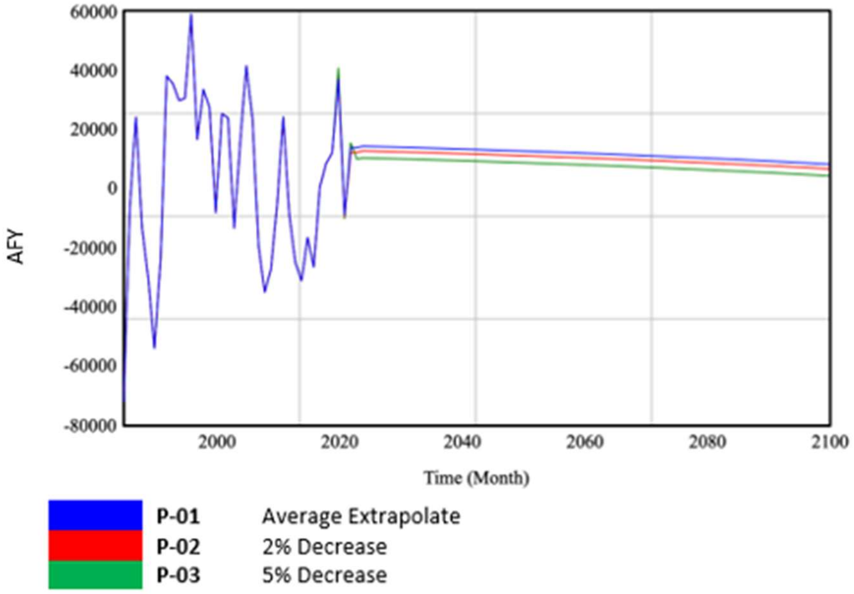


Figure 5-24. Water Balance on Year-By -Year Basis Under Average Extrapolated, 2% Decrease, and 5% Decrease Precipitation Scenarios

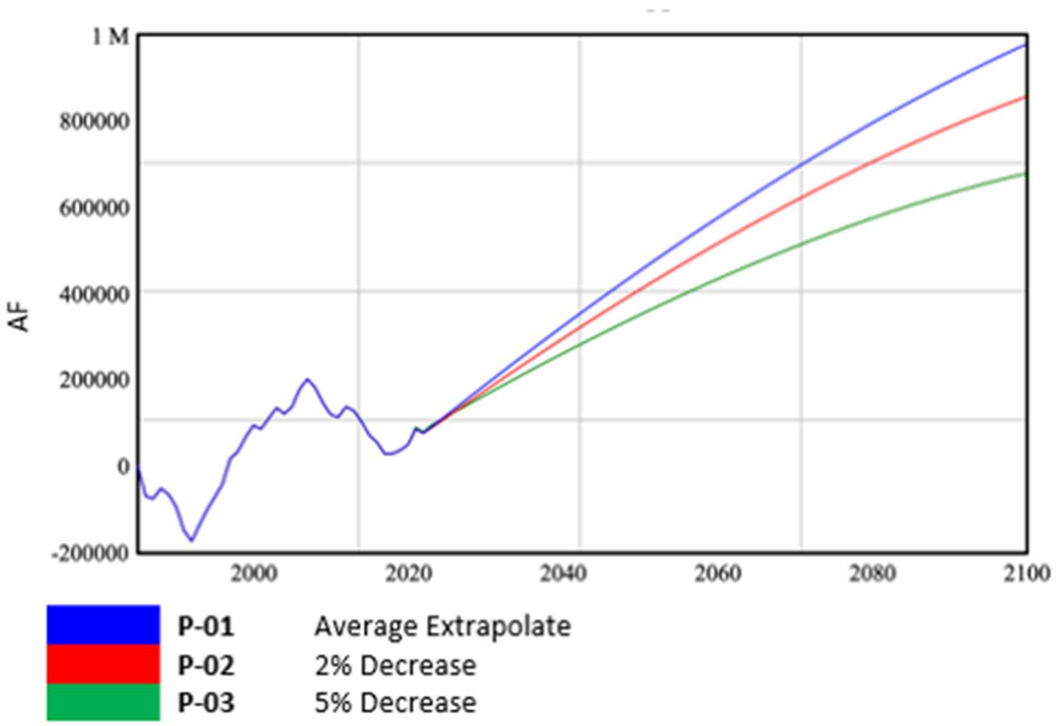


Figure 5-25. Oxnard Basin Cumulative Water Balance Under Average Extrapolated, 2% Decrease, and 5% Decrease Precipitation Scenarios

Drought Scenarios

The addition of drought to the average precipitation resulted in a lower cumulative water balance, as shown by Figure 5-26. The drought lasting five years (P-04) within the first drought period brought the cumulative water balance well below the 5% decrease in average precipitation scenario (P-03). With continued droughts the cumulative basin supplies was nearly half of the 5% decrease scenario (P-03). The drought lasting 10 years scenario(P-05) had even more dramatic impacts, resulting in negative supplies within the middle of the first 10 years of drought conditions. By 2075, the basin is consistently in negative or near negative supplies, with more leaving the basin than entering the basin. The drought lasting five years scenario which included a wetter than normal year following the drought period (P-06) had a significant benefit when compared to the drought lasting five years drought period (P-04). The excess precipitation recharged the basin following the drought period and provided an excess 133,474 AF by 2100.

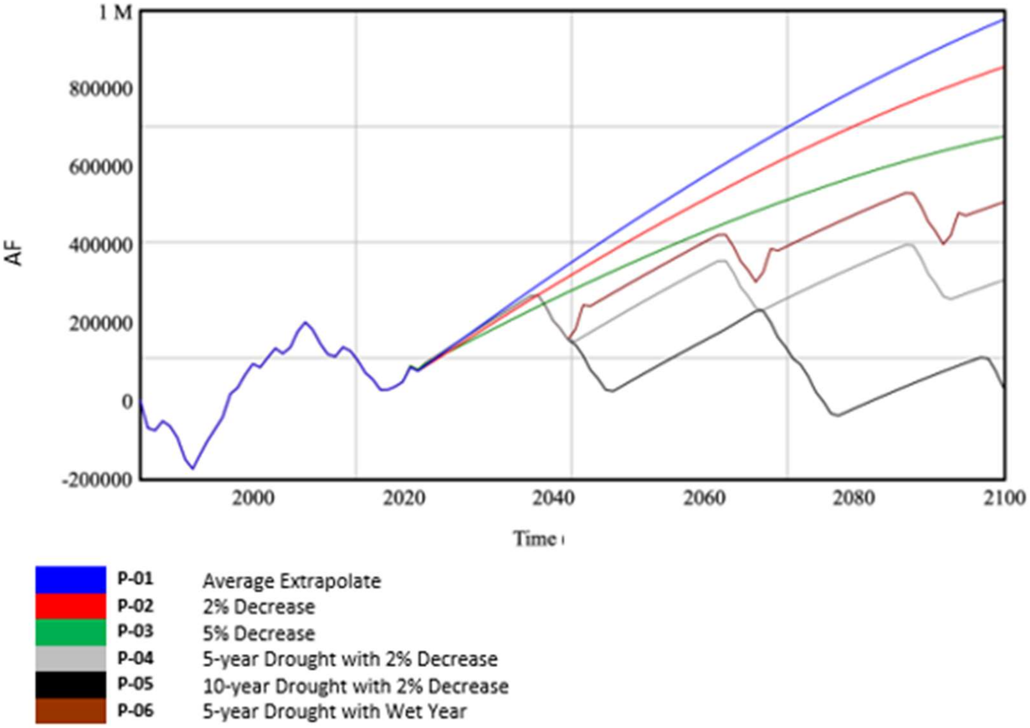


Figure 5-26. Oxnard Basin Cumulative Water Balance Under Average Extrapolated and Drought Precipitation Scenarios

Stochastic Random Generation of Future Precipitation

The precipitation scenarios developed with the stochastic method (P-07, P-08, P-09, P-10, and P-11) were compared over time to see the impact to the availability of water in the basin. As demonstrated by Figure 5-27, the existing average scenario (P-07) had the strongest positive benefit to the basin for the entire period, with year 2100 ending with a stock of more than 1 MAF. This also indicated that the stochastic average precipitation that was applied was less conservative than the average annual precipitation being extrapolated out as a constant value, as was done in P-01. The P-01 scenario had less than 1 MAF in the basin at 2100, which was less than the stochastic average method.

The stochastic scenarios with 2% and 5% increases in average precipitation (P-08, P-09) resulted in decreased overall accumulation, when compared to the stochastic existing average (P-07). However, in some years, the difference between the average (P-07) and 2% decrease (P-08) was minimal, as observed near 2080. However, cumulative differences over time resulted in a nearly 500,000 AF difference between the stochastic average extrapolated (P-07) and the stochastic 5%

decrease (P-09). These stochastic precipitation scenarios represent a limited set of traces. Further evaluation of stochastic scenario impact on the basin water supply would require Monti Carlo analysis.

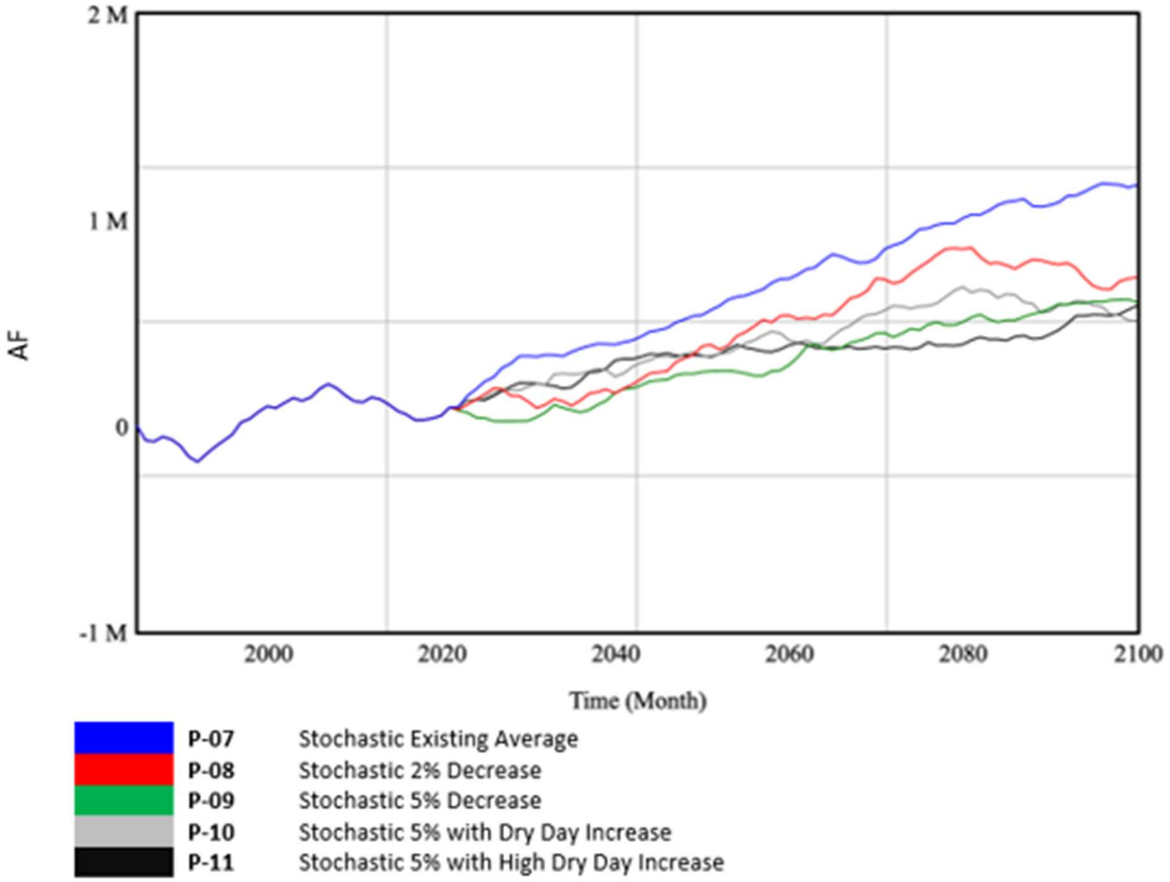


Figure 5-27. Oxnard Basin Cumulative Water Balance Under Stochastic Precipitation Scenarios

Since the stochastic precipitation patterns have variability over time, the ending 2100 cannot alone be used as an indicator of performance. An additional indicator that can be used is the percentage of years that had a net positive water balance. For the five stochastic precipitation patterns the number of years that the water balance was positive, meaning inflows were greater than outflows. As demonstrated by Figure 5-28, the stochastic existing average scenario (P-07) had the highest number of years with inflows greater than outflows, with 72% of the years having a net positive balance. The lowest net positive water balance was for the stochastic 5% with high dry day increase (P-11), where only 57% of years had a net positive water balance.

The stochastic 5% decrease scenario (P-09) had a higher number of years (63% of years) than the stochastic 2% decrease scenario (P-08). However, this is explained by the rainfall distribution. The average precipitation in the time-series for the 2% decrease scenario (P-08) was 11.87, with a minimum of 1.71 inches. The standard deviation was 5.36. The 5% decrease scenario (P-09) had a lower average rainfall of 11.65 inches, however, the minimum rainfall was higher at 4.11 inches. There was also a standard deviation of 4.45 that was lower than the 2% decrease scenario. This suggests that the stochastic precipitation generated for the 2% scenario (P-08) had much more variability than the 5% scenario (P-09).

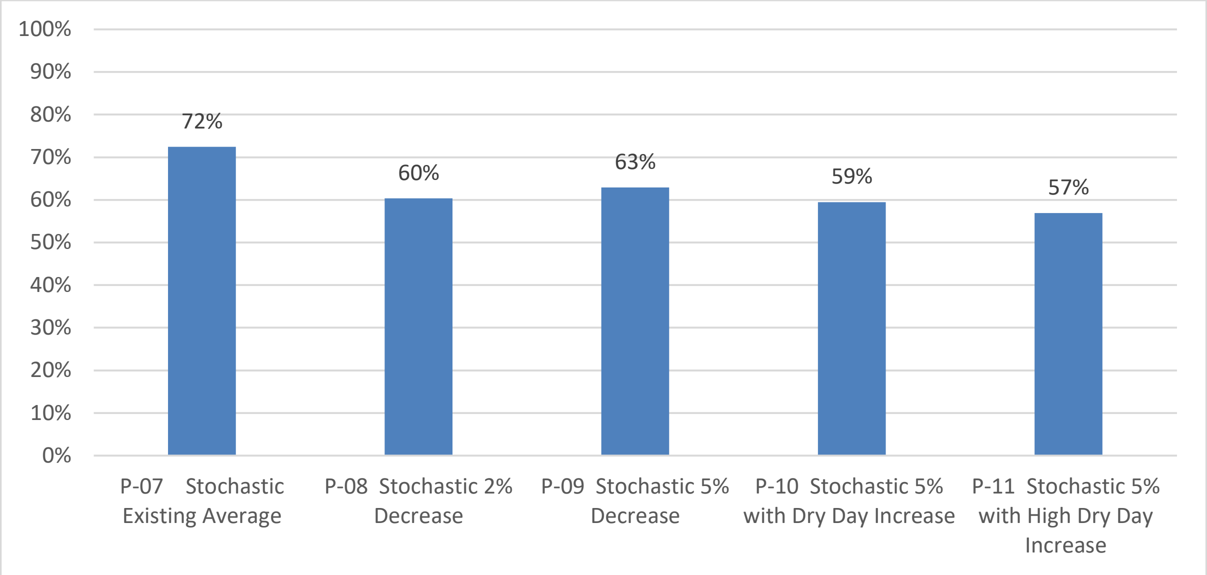


Figure 5-28. Percentage of Years with Net Positive Water Balance for Stochastic Precipitation Scenarios

Another method for comparing the stochastic rainfall scenarios is to compare the average and median water balance on a year-by-year basis. This reflects the average condition of the basin and will account for long-term trends in the data that may not be captured through evaluation of a single or final year. The average and median water balances are shown in Figure 5-29, with the numbers on top of the bars indicating the ranking of the highest to lowest water balance average and median values. This graph indicates that the existing average stochastic (P-07) has the highest average and median water balance, while both decreasing the stochastic average rainfall and the number of dry days decreases the average (P-10, P-11). The median, however, is not consistently lower with the increase in dry days, as observed by the comparison of P-09, P-10, and P-11.

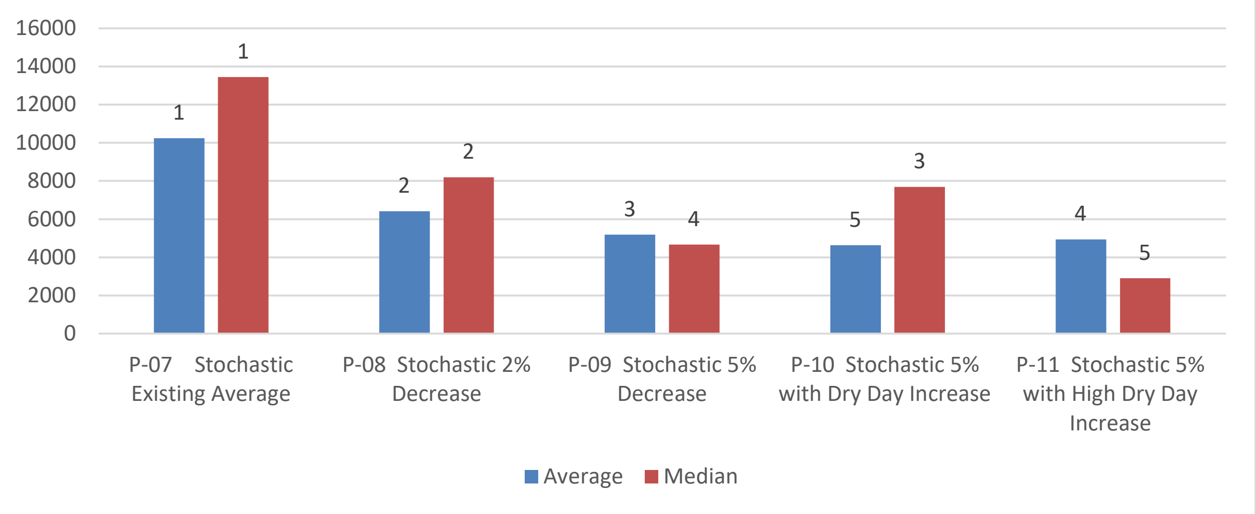


Figure 5-29. Average and Median Water Balance on Yearly Basis for Stochastic Precipitation Scenarios with Rankings from Highest to Lowest by Scenario

5.3.1.2 Imported Water –Table A Allocations

Table A allocations, the amount of the allocated volume of water from the State Water Project that the District can obtain and release through the Santa Felicia Dam varies each year based on a number of factors. Winter precipitation in northern California is the main driver of allocations, however, it is not the only factor. Four allocation scenarios were modeled to simulate potential future purchases of SWP water from Table A allocations.

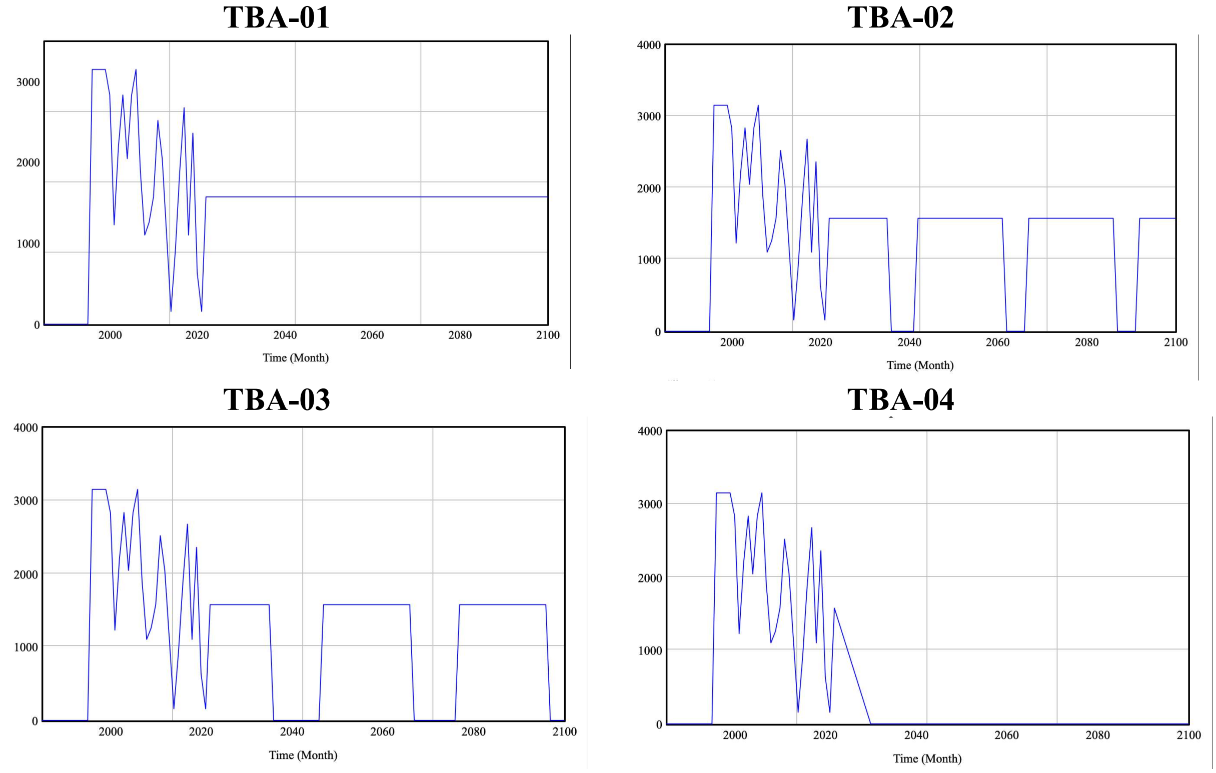
Historical allocations from the start of the SWP to 2020 were used as part of the calibration period (TBA-00). During the last 10 years, the average allocation has been 50%, resulting in a total allowable import of 3,150 AFY. The District has 5,000 AFY of allocations, however 1,850 are leased to PHWA and it was assumed that this agreement would stay in place indefinitely. The first scenario (TBA-01) assumes that the District will be able to regularly import 50% of their allocations through 2100. Allocations, however, have fluctuated with drought periods seen across California. The second and third scenarios (TBA-02, TBA-03) assume an average allocation of 50%, however during drought years, the allocation drops to 0. A drought lasting five and ten years are simulated through the precipitation scenarios (P-04, P-05, P-06) to evaluate the compounding effects.

A summary of the Table A allocation scenarios are described in Table 5-4 with the total imported volumes from Table A allotments shown in Figure 5-30.

Table 5-4. Table A Allocation Scenarios

ID	Name	Description
TBA-00	Existing Historical Allocations	Existing, only used for 1985-2020
TBA-01	Average Extrapolate	Average of last 10 years for future
TBA-02	0 During Drought (5 years of drought)	Average of last 10 years but 0 during drought
TBA-03	0 During Drought (10 years of drought)	Average of last 10 years but 0 during drought
TBA-04	Loss of SWP Imports	Average 2020-2030, 0 starting in 2030

Figure 5-30. Table A Allocation Scenario Inflow Graphs (Inflow, AFY)



Using the existing average precipitation condition extrapolated to the future, the impact of the 4 allocation scenarios were evaluated. There was minimal impact of the allocation scenarios on the cumulative water balance. The reduction to no allocations (TBA-04) had an adverse impact reducing the cumulative supplies from 1.14 MAF from the existing average extrapolated (TBA-01) to 1.11 MAF (TBA-04).

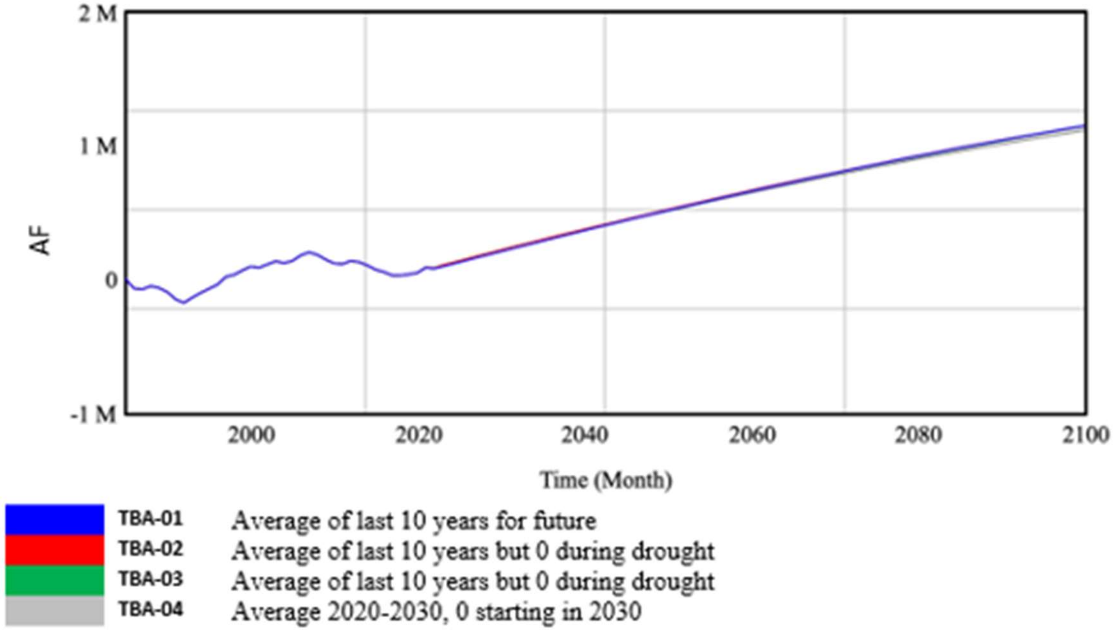


Figure 5-31. Oxnard Basin Cumulative Water Balance with Average Existing Precipitation Extrapolated Under Different SWP Allocations

A second simulation was conducted using the precipitation scenario that simulated a drought lasting five years every 20-years, with an average precipitation for other years 2% decreased from the current average (P-04). This precipitation was simulated with the SWP allocations average of the last 10 years, but 0 during a drought (TBA-02) as well as with the loss of SWP allocations starting in 2030 (TBA-04). The results show a significant impact when compared to the previous results that used the average precipitation extrapolated. The loss of SWP has a marginal negative impact on the cumulative water, as shown in Figure 5-32. The addition of SWP increases the Oxnard Basin supplies from 495,467 AF to 524,267 AF in 2100, resulting in a 28,800 AF difference with and without the allocations.

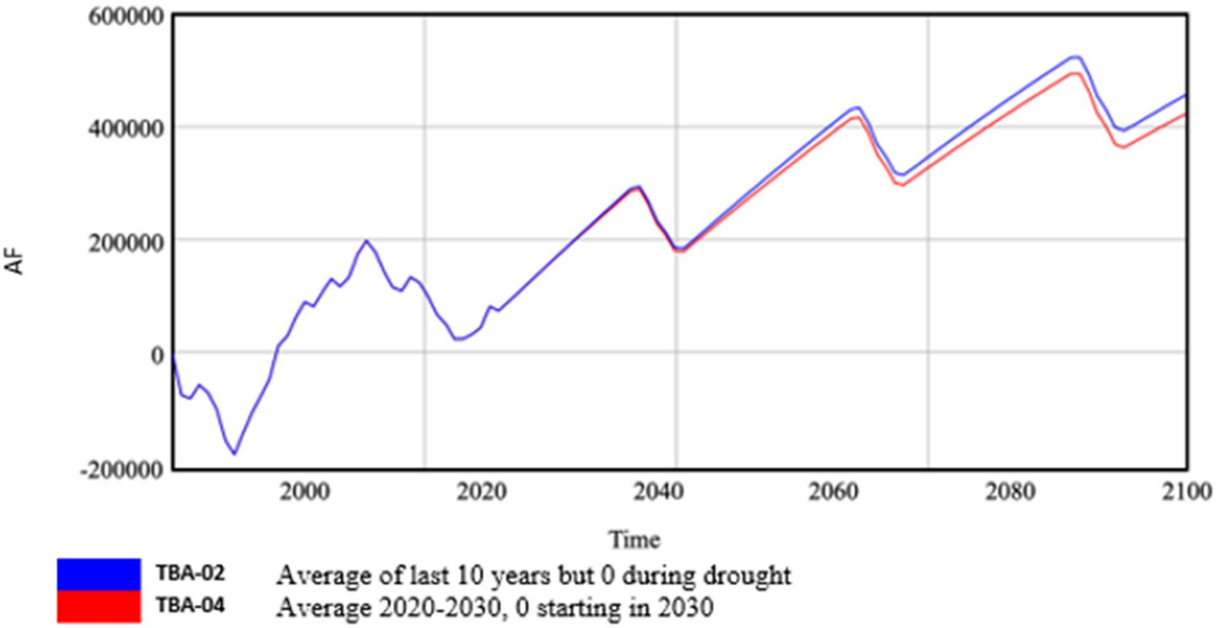


Figure 5-32. Oxnard Basin Cumulative Water Balance with 5 Years of Drought Every 20-Years Precipitation Under Different SWP Allocations

5.3.1.3 Imported Water –Article 21

Article 21 imparts, the amount of SWP beyond the annually allocated volume of water that the District can obtain and release through the Santa Felicia Dam varies each year based on several factors. Two Article 21 scenarios were modeled to simulate potential future purchases of Article 21 SWP water.

Historical purchases of Article 21 water was used for the existing years (ART-00). During the last 10 years, the average allocation of SWP has been decreasing as water scarcity increase across the state. The first scenario (ART-01) assumes that there will be no additional Article 21 purchases The second scenario (ART-02) assumes that some future Article 21 water can be purchased, that every 3 years, 10,000 AF is available. These scenarios were simulated with two of the stochastic precipitation scenarios; P-08 which assumed a 2% decrease in average precipitation and P-09 which assumed a 5% decrease in average precipitation. A summary of the Table A allocation scenarios are described in Table 5-5 with the total imported volumes from Table A.

Table 5-5. Article 21 Water Purchase Scenarios

ID	Name	Description
ART-00	Existing	Existing used 1985-2021
ART-01	No Article 21 Water	0 for entire period after 2020
ART-02	Periodic Article 21 Water	10,000 AF every 3 years

As shown in Figure 5-33, the 2% (top) and 5% (bottom) reduction in precipitation scenarios with and without the Article 21 purchased water have a slight decrease over time. Under the 2% decreased stochastic precipitation scenario, the cumulative water in the basin at year 2100 is 863,152 AF without Article 21 water. With Article 21 water this increases to 919,134 AF. The Article 21 water results in a 55,982 AF increase in cumulative water supplies in the basin by 2100. For the 5% decreased stochastic precipitation scenario, the cumulative water in the basin at year 2100 is 610,663 AF without Article 21 water. With Article 21 water this increases to 701,866 AF. The Article 21 water results in a 91,203 AF increase in cumulative water supplies in the basin by 2100. On a year-by-year basis the water availability is not significantly impacted by the Article 21 water. In the 5% decreased stochastic precipitation scenario, the difference between the purchase and non-purchase of Article 21 water results in net positive water balance is less than 1%. Without the purchase of Article 21 water, 62.9% of the years were net positive on a year-by-year basis, while with the purchase of Article 21 water, this increased to 63.7% of years being net positive on a year-by-year basis.

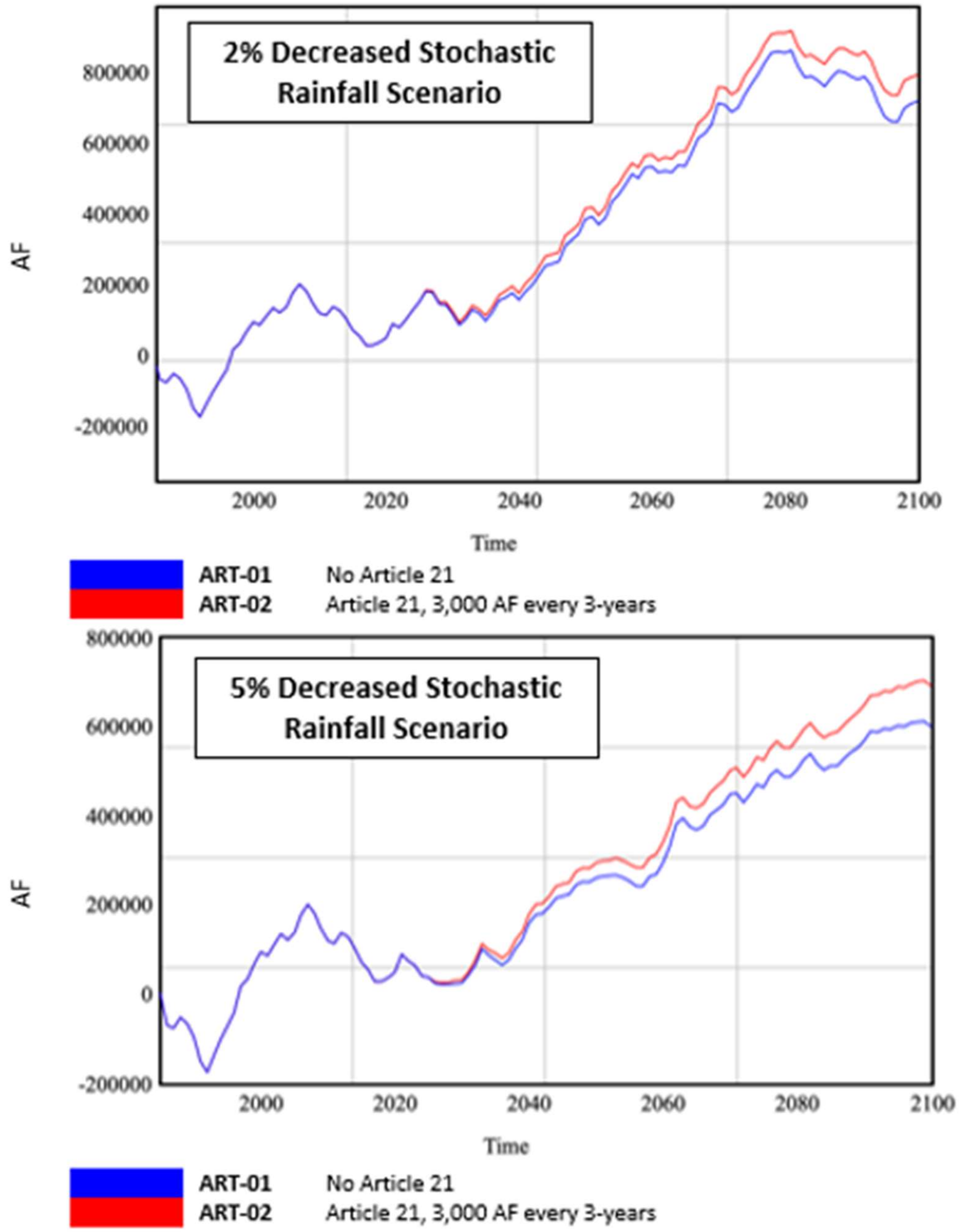


Figure 5-33. Oxnard Basin Cumulative Water Balance With and Without Article 21 Water Under 2% and 5% Decreased Stochastic Precipitaiton

5.4 Infrastructure Implementation Scenarios

Three infrastructure implementation scenarios were evaluated which assessed the impacts of implementing the EBB-Water Project, Freeman Diversion Expansion Project, and recycled water.

5.4.1.1 EBB-Water Project

The EBB-Water project was evaluated under the 2% decrease in average annual precipitation (P-02) and the stochastic 2% decrease in average annual precipitation (P0-8). The impact of implementing the project in 2025, 2027, 2030, and 2040 was evaluated with a 5,000 and 10,000 AFY treatment facility influent capacity. An increase in the recovery rate from 50% to 60% after 10-years of operation was also evaluated.

The addition of EBB-Water and an approximately 73,000 AF impact on the cumulative basin water balance when the project with a 5,000 AFY capacity was implemented. There was a minimal benefit observed when implementing the project in 2025 or delayed, as shown in Figure 5-34.

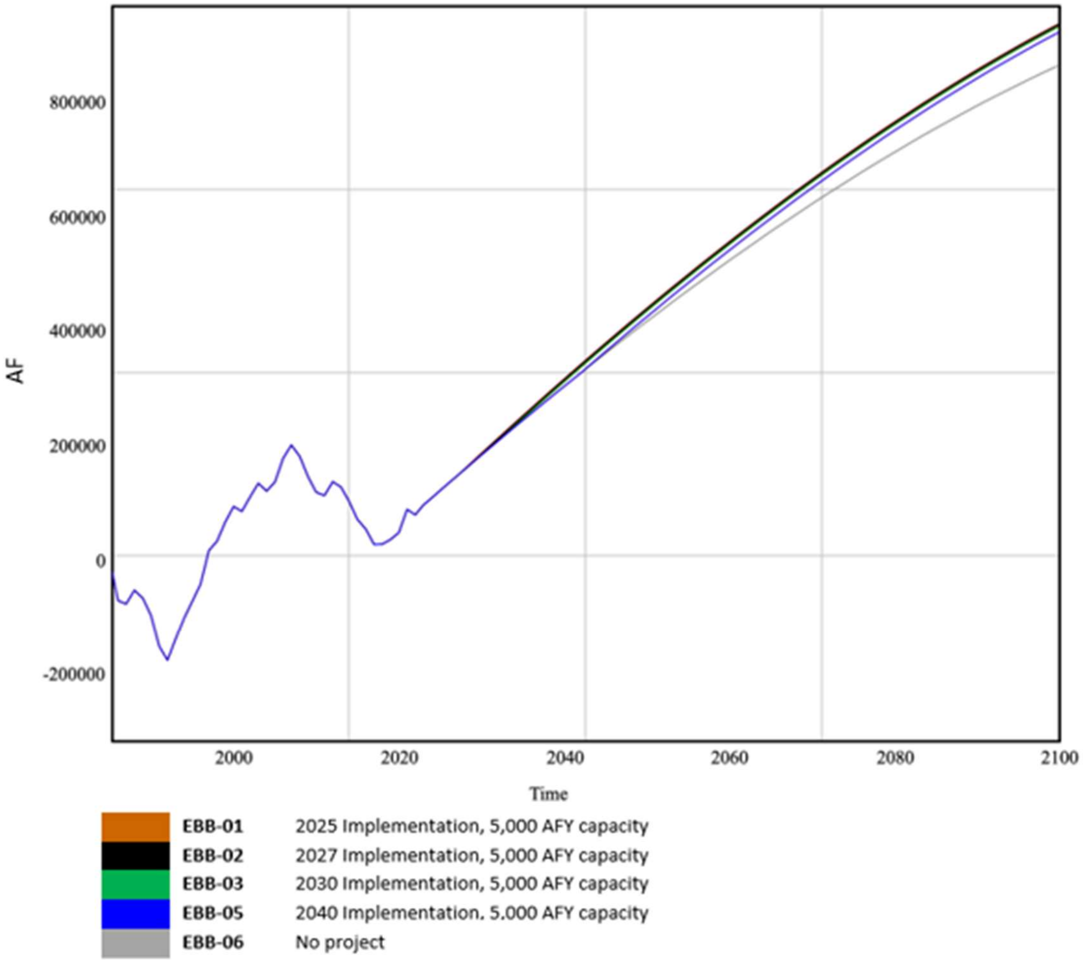


Figure 5-34. Oxnard Basin Cumulative Water Balance With 5,000 AFY EBB-Water

The EBB-Water accounts for less than 4% of the total water supplies in the system. Over time, after implementation of the project the percentage slightly decreases as demands in the system increase. By 2100, the EBB-Water accounts for approximately 3% of system supplies (Figure 5-35).

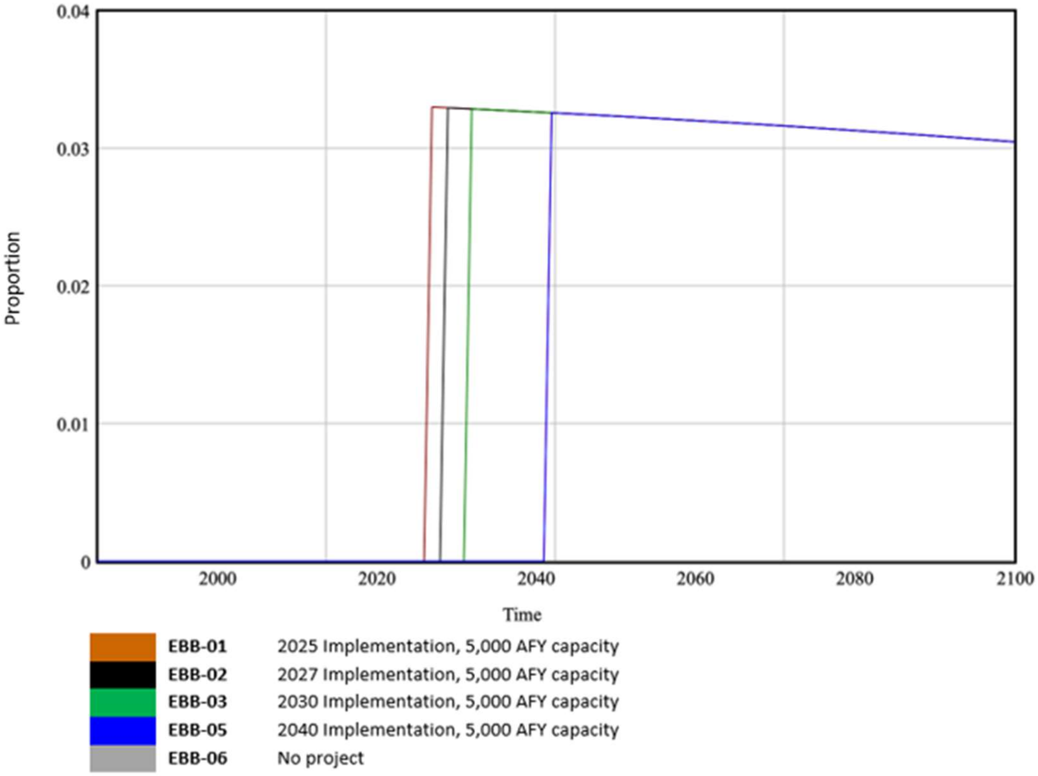


Figure 5-35. Proportion of EBB-Water Over Time with 5,000 AFY Capacity

The cost index is minimally impacted by the addition of the average amount of EBB-Water, with annual precipitation variation resulting in a much larger variation in the cost index (Figure 5-36).

However, for the small portion of water that the EBB-Water accounts for, it has a significant impact on average water quality. The TDS drops from an average of 1014 mg/L to 987 mg/L (Figure 5-37). While this TDS is not indicative of the daily water quality due to a number of factors such as deliver point, seasonal variability, and ability to mix with other sources, it demonstrates the significant impact the small portion of high-quality water can have on the water quality within the basin.

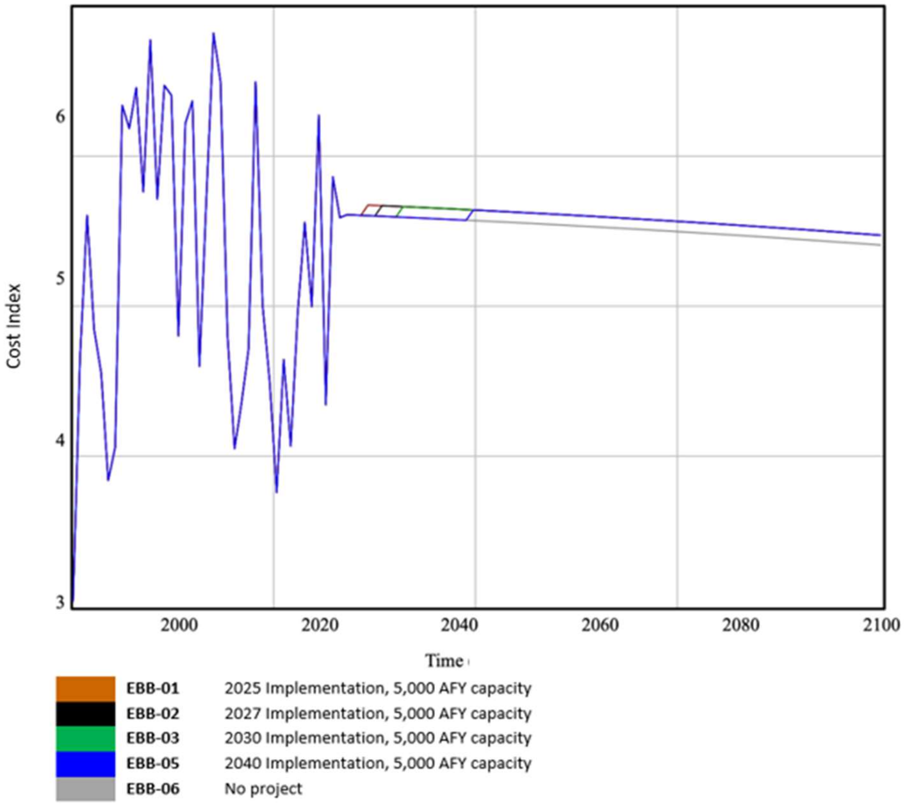


Figure 5-36. Cost Index for Basin with 5,000 AFY EBB-Water Implementation

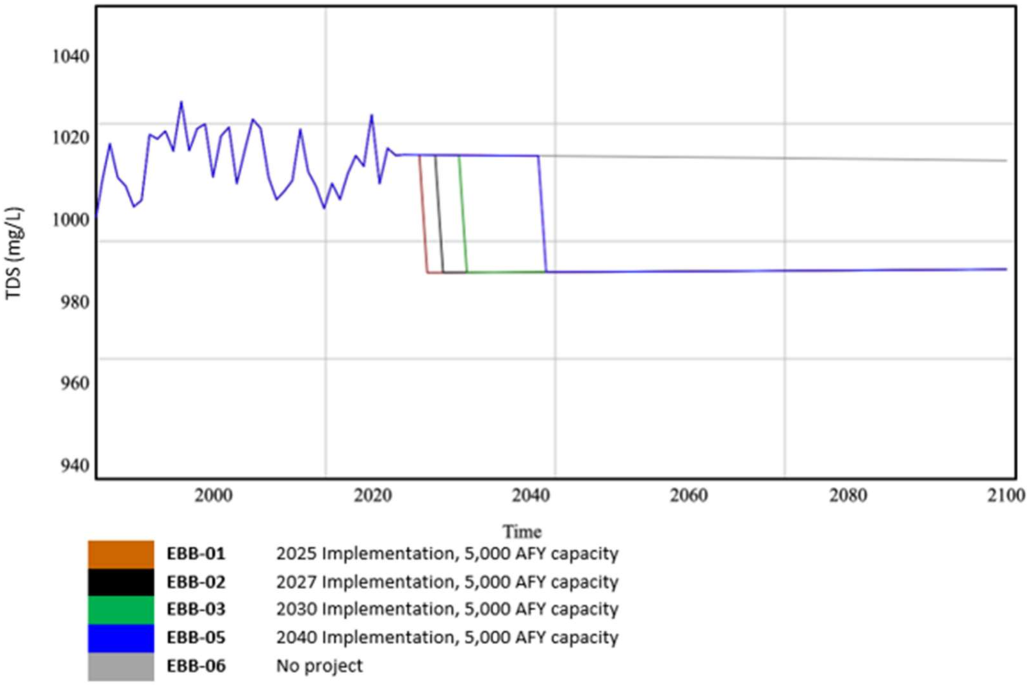


Figure 5-37. TDS Water Quality with 5,000 AFY EBB-Water Added to Supplies

This was similarly evaluated with the implementation of a system with a 10,000 AFY influent treatment capacity. A larger cumulative benefit was observed when compared from the 5,000 AFY system. The larger cumulative benefit also resulted in a larger benefit by 2100 if the system was implemented in 2025 versus 2050. When increasing the capacity of the facility to 10,000 AFY the percentage of water that is EBB-Water doubles from 3% to 6%. The cumulative benefit of implementing the larger project is 182,500 AF by 2100, when implemented in 2025 (Figure 5-39). Similarly, the added volume of highly pure water increases the water quality. The TDS decrease from an average of 1014 mg/L without the project to 961 mg/L with the 10,000 AFY project. Increasing the project from 5,000 AFY to 10,000 AFY results in a reduction of TDS by 26.5 mg/L, on average.

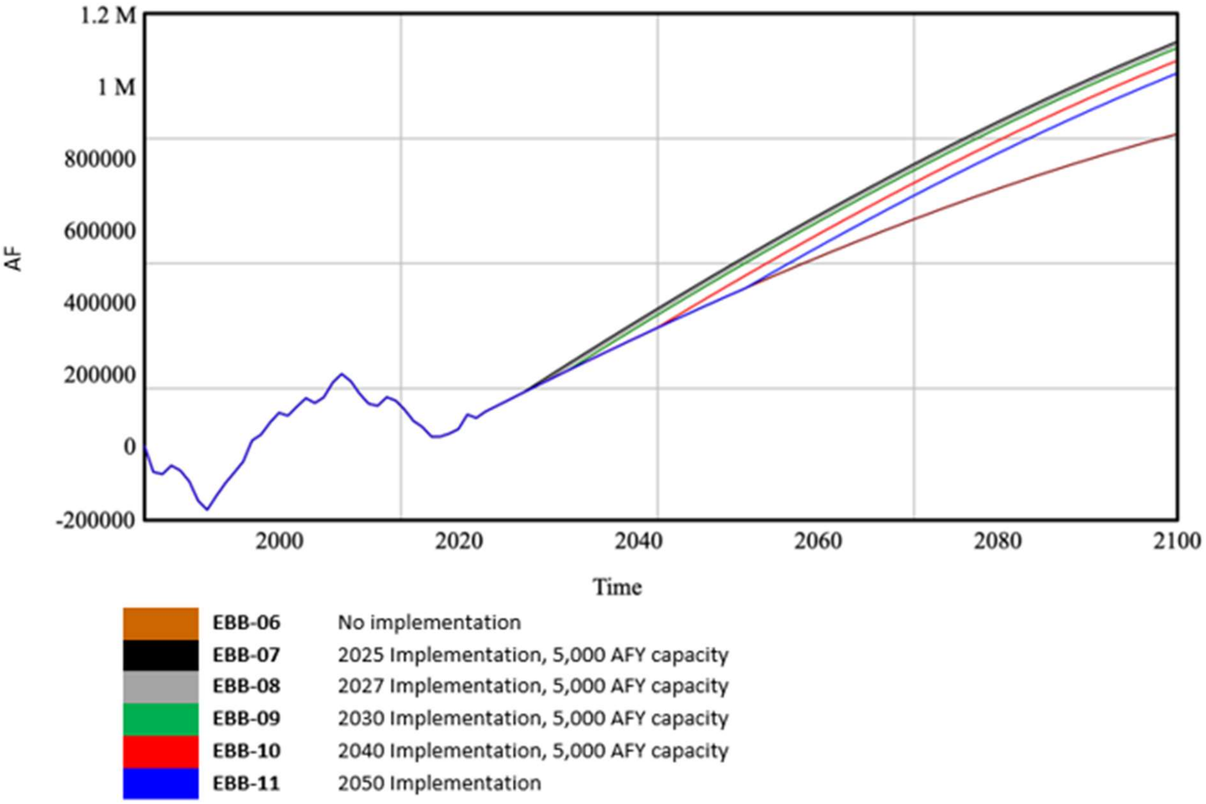


Figure 5-38. Oxnard Basin Cumulative Water Balance With 10,000 AFY EBB-Water

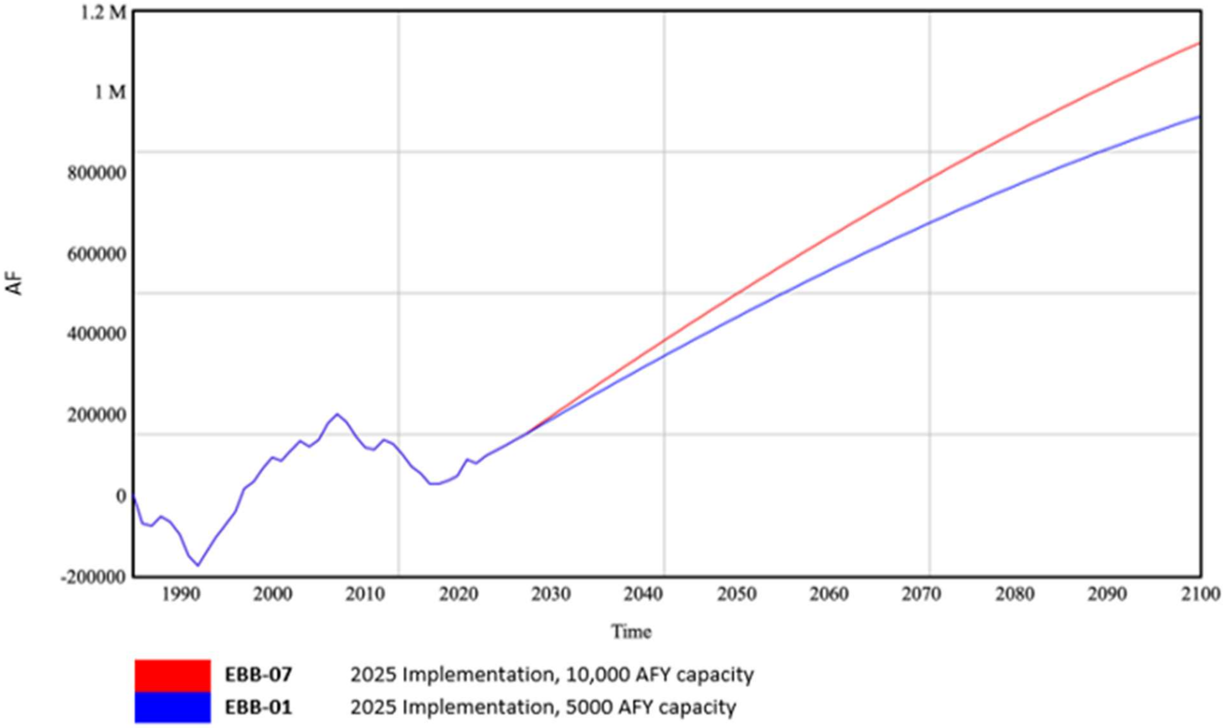


Figure 5-39. Oxnard Basin Cumulative Water Balance Comparison of 5,000 AFY and 10,000 AFY of EBB-Water

The ability to increase the recovery rate from 50 to 60% after 10-years of the project being online was evaluated. The results indicated that this resulted in a marginal benefit to the cumulative water balance (Figure 5-40). The 10% increase in recovery resulted in an additional 10.6 mg/L decrease in average TDS (Figure 5-41).

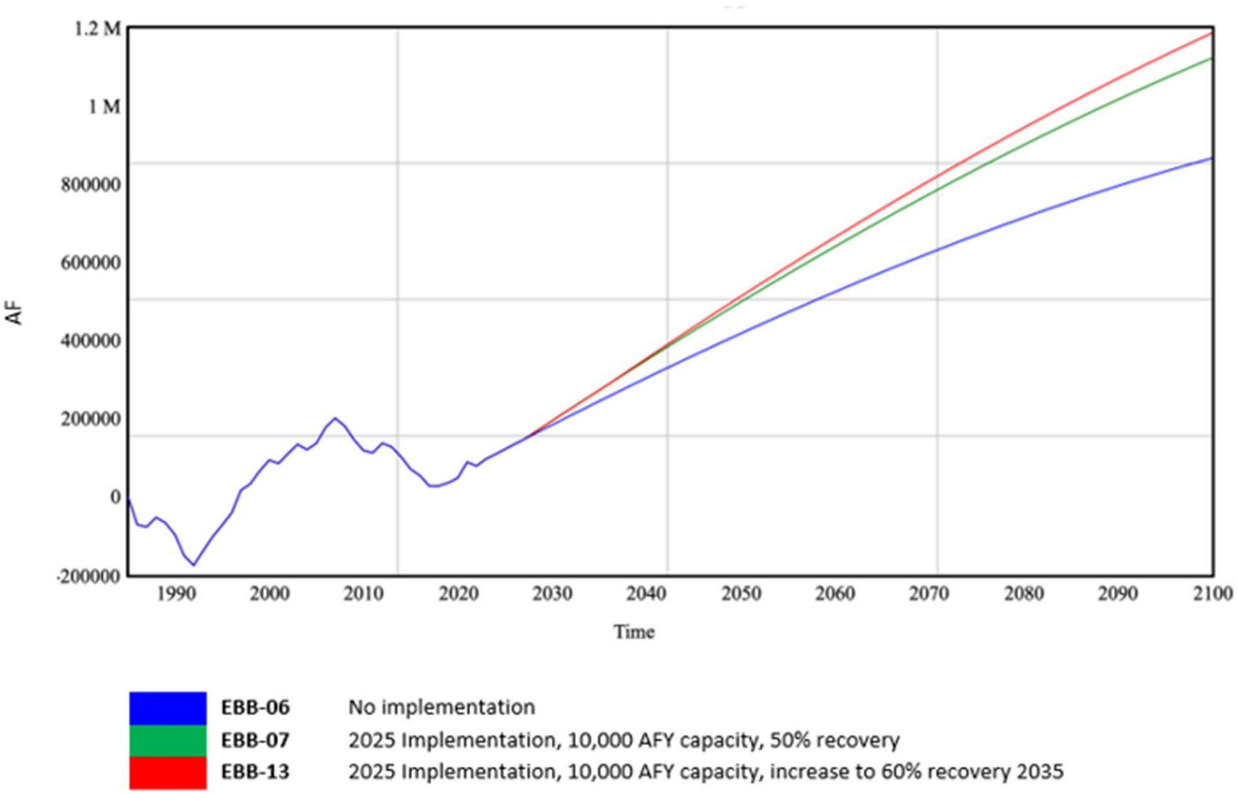


Figure 5-40. Oxnard Basin Cumulative Water Balance Comparison Increased System Recovery Rate Impact

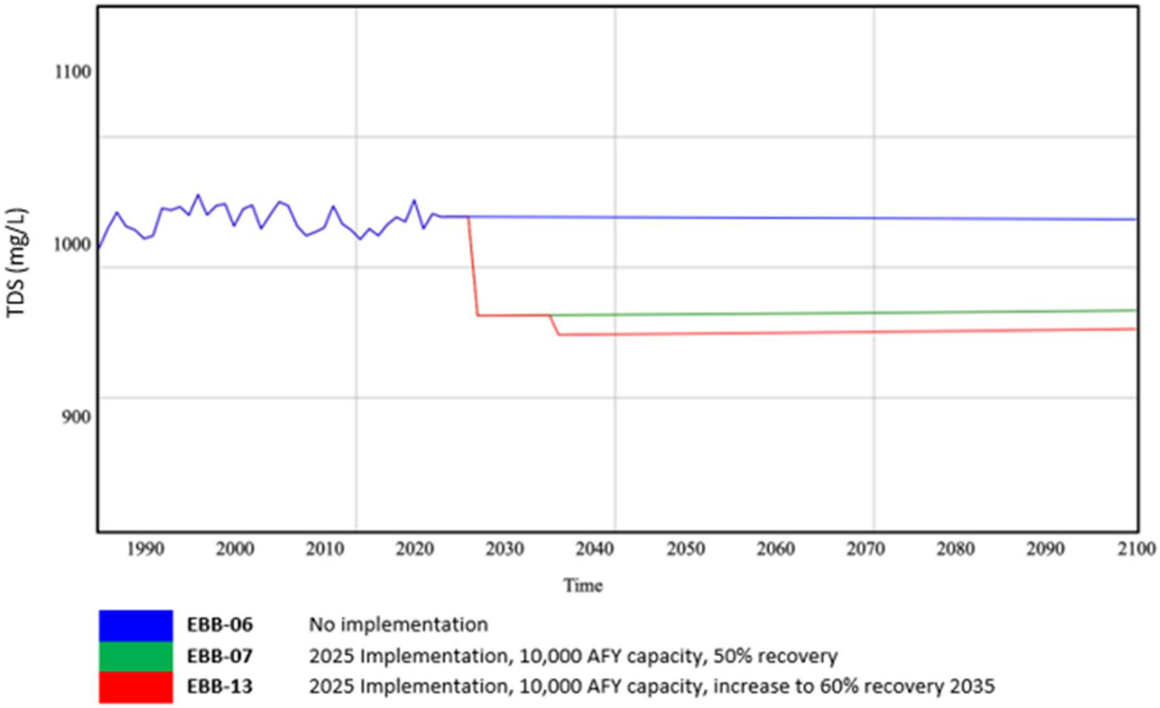


Figure 5-41. Recovery Rate Change Impact on Average TDS Under 10,000 AFY Scenario

The evaluation of the implementation of the EBB-Water project using the 2% stochastic precipitation (P-08) yielded similar results to the 2% average decrease in precipitation (P-02). Under the 5,000 AFY scenario with project implementation in 2025, the cumulative volume increased from 863,000 AF in 2100 without the project to 939,600 AF with the project. Similarly, under the 10,000 AFY scenario the cumulative volume increased to 1.1 MAF.

5.4.1.2 Freeman Diversion Expansion Project

The Freeman Diversion Expansion project was evaluated under the 2% decrease in average annual precipitation (P-02) and the stochastic 2% decrease in average annual precipitation (P0-8). The impact of implementing the project in 2025, 2030, 2040, and 2050 was evaluated with a 5% or 10% increase in capture of annual flows.

The 2% decrease in average precipitation (P-02) with a 5% increase in capture after implementation of the project was evaluated with implementation in 2025, 2030, 2040, and 2050. This implementation resulted in an average diversion of approximately 78,900 AFY, as shown in Figure 5-42. This is an increase in approximately 3,700 AFY, from 75,200 AFY without the project. The cumulative impact of the project on the basin water supplies indicates that with the project implemented in 2025, the total water supplies will increase by approximately 210,000 AF. Without the project the net basin supplies under this scenario are estimated to be 865,000 AF. However, with the project implemented in 2025, basin supplies will be approximately 1.08 MAF. Earlier implementation of the project will result in larger cumulative advantages, as shown in Figure 5-43.

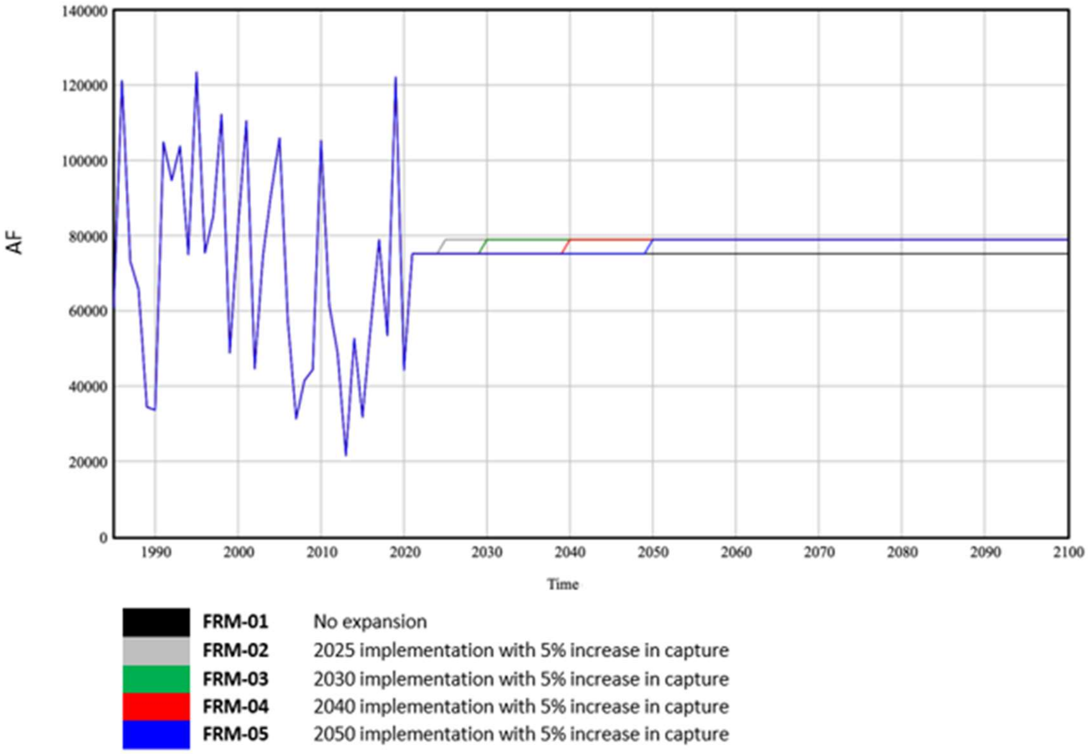


Figure 5-42. Freeman Diversion Expansions with 5% Increase in Capture

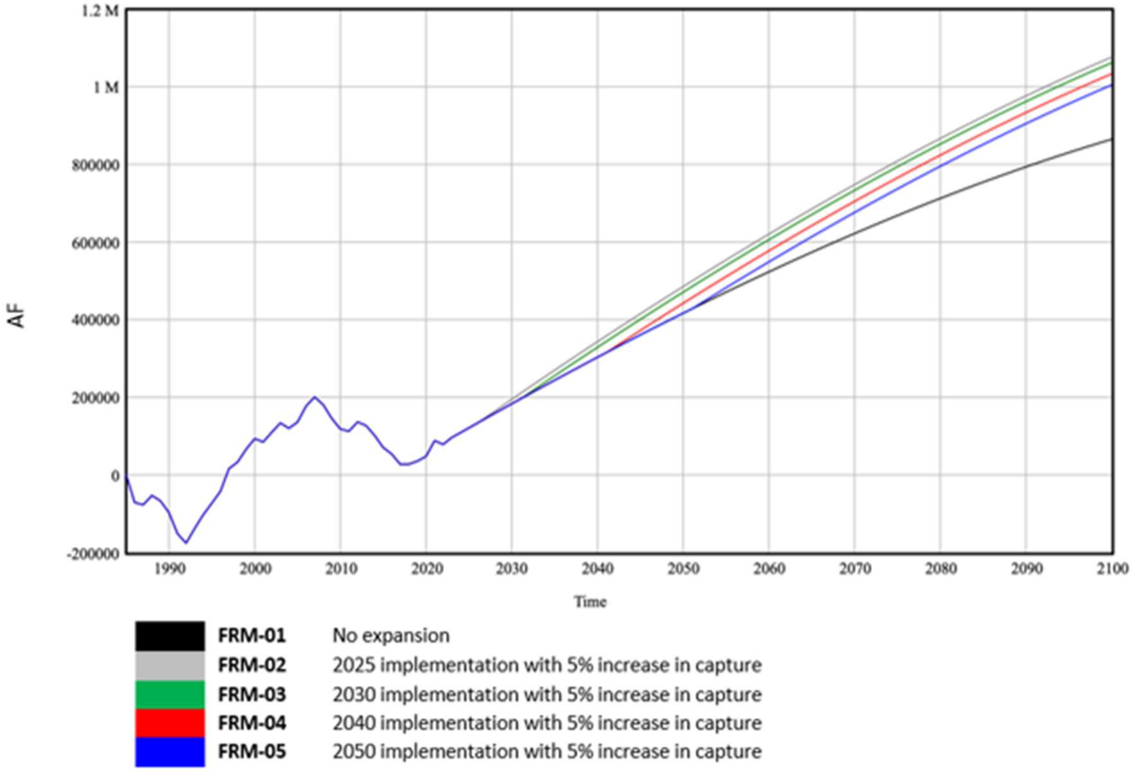


Figure 5-43. Oxnard Basin Cumulative Water Balance With Freeman Diversion Expansion at 5% Increase Capture under 2% Average Annual Decrease in Precipitation

The impact of increasing diversions by 10% had a larger positive benefit on the basin. The Freeman Diversion expansion increased average diversions from approximately 75,000 AFY to 82,600 AFY (Figure 5-44). The cumulative impact to the basin resulted in an increase in 414,000 AFY when implemented in 2025 (Figure 5-45).

The cumulative difference in increasing diversions by 5 or 10% was significant. With a 5% increase implemented in 2025 the cumulative benefit was 204,000 AF by 2100 when compared to the no-change scenario. With a 10% increase this increased to 414,000 AF, as shown in Figure 5-46.

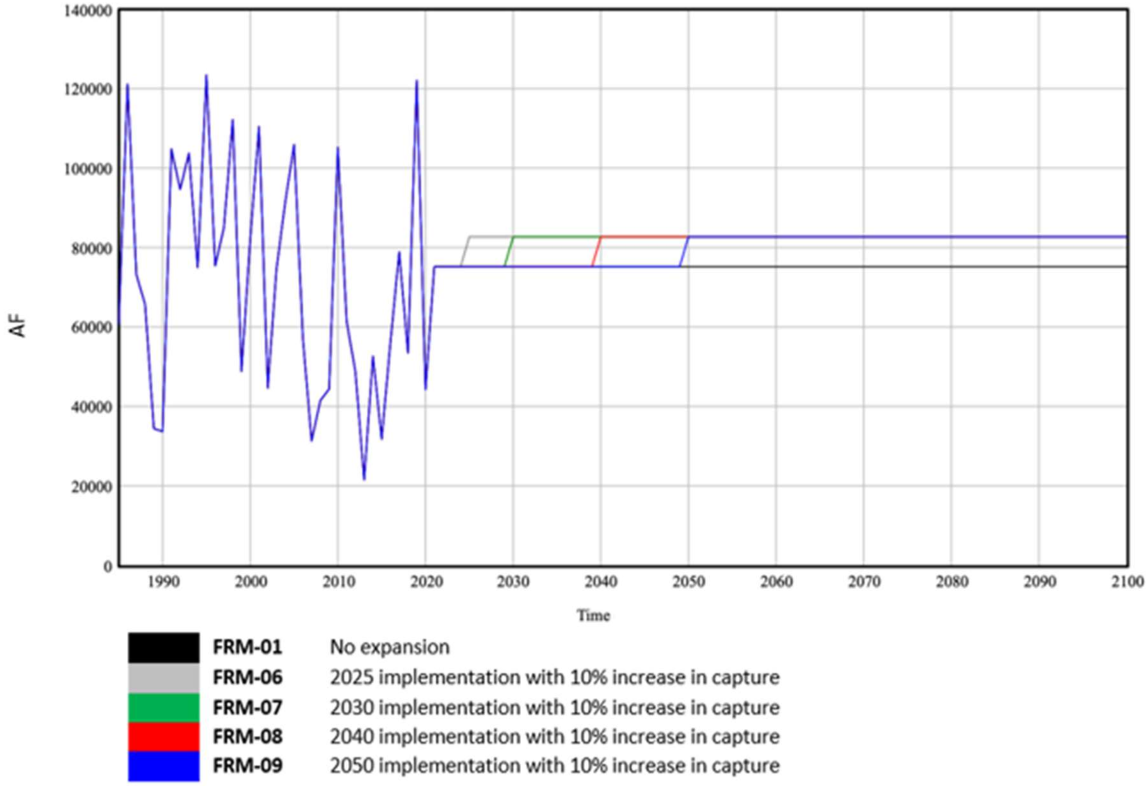


Figure 5-44. Freeman Diversion Expansions with 10% Increase in Capture

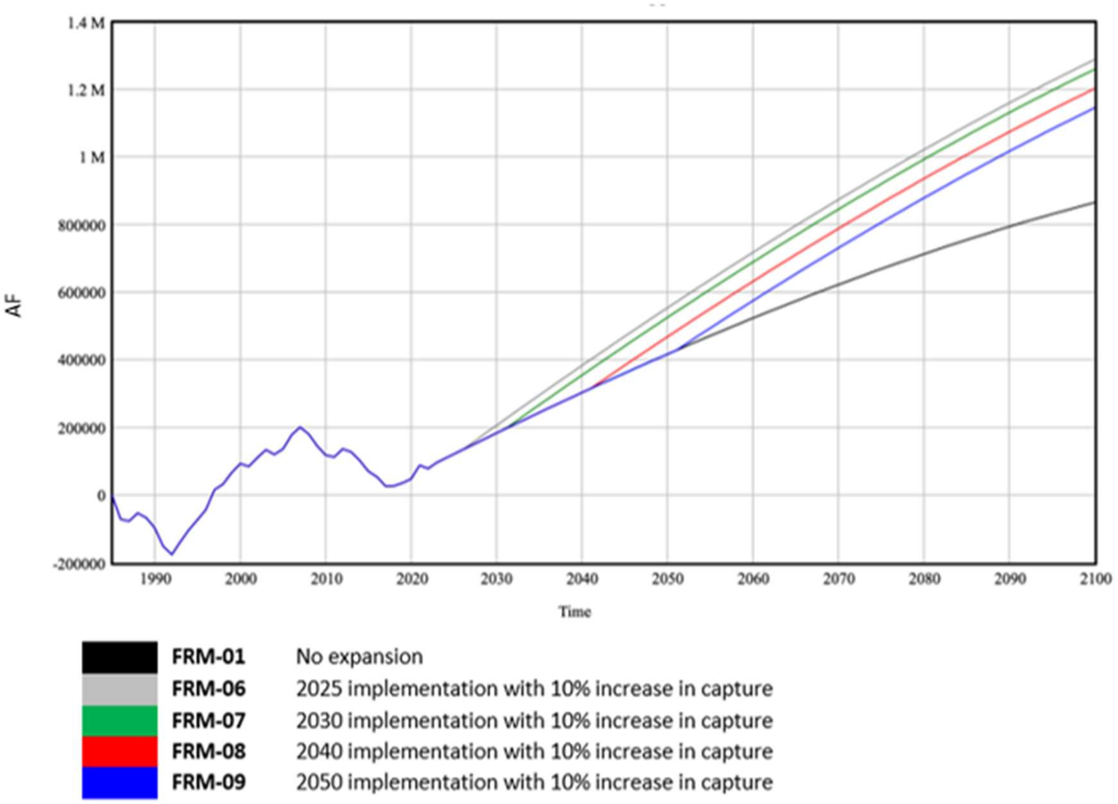


Figure 5-45. Oxnard Basin Cumulative Water Balance With Freeman Diversion Expansion at 10% Increase Capture under 2% Average Annual Decrease in Precipitation

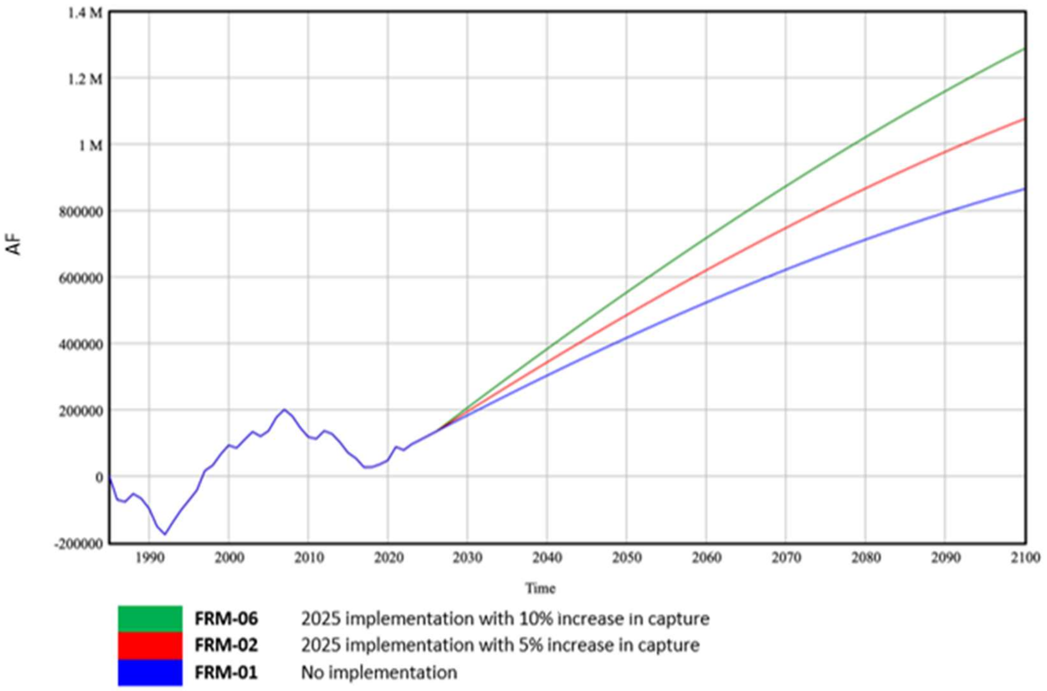


Figure 5-46. Oxnard Basin Cumulative Water Balance Comparison of 5% and 10% Increase in Diversion Capacity Under 2% Decreased Precipitaiton Scenario

The impact of climate change on storms anticipates higher intensity storm events which with existing infrastructure may reduce the percentage of Santa Clara River flows that can be captured. A 5 and 10% decrease in the capture of flows for a no action with climate change scenario was evaluated. The 2% decrease in precipitation with the stochastic precipitation was used for the evaluation. The impact on the total available water supplies by 2100 is demonstrated in Figure 5-47.

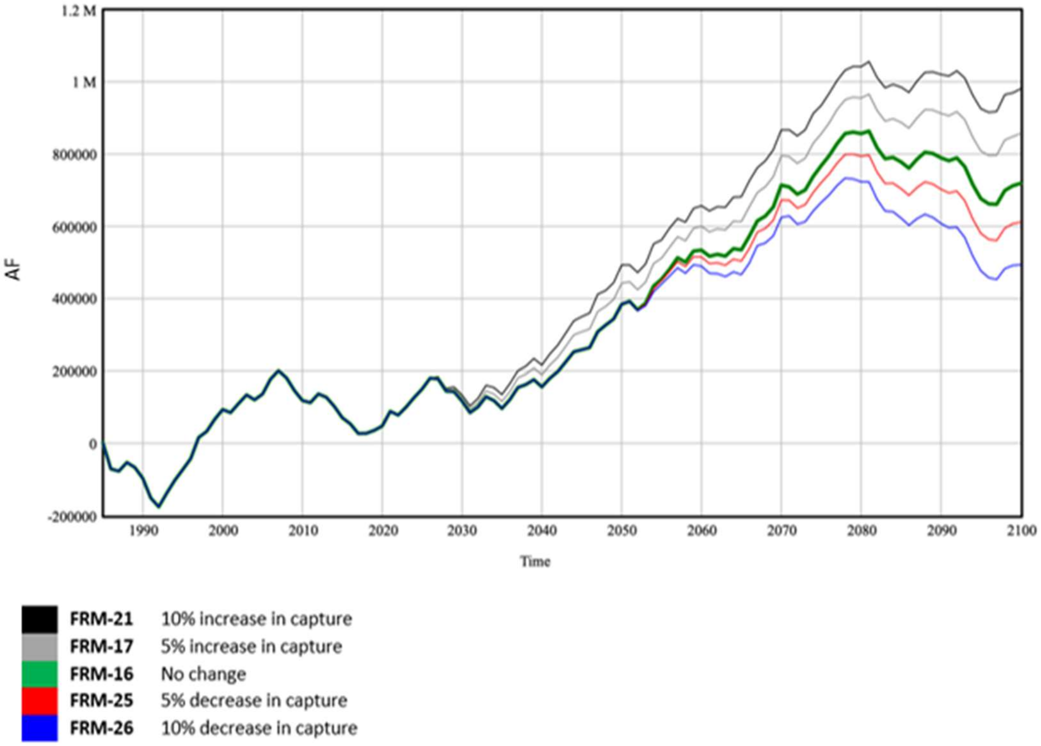


Figure 5-47. Oxnard Basin Cumulative Water Balance with 5% and 10% Increase/Decrease of Santa Clara River Capture

5.4.1.3 Recycled Water

The use of recycled water in the basin area was evaluated under the stochastic 2% decrease in average annual precipitation (P0-8). The impact of implementing the project in 2023 with different cumulative volumes. Gradually increasing implementation of the use of recycled water was also evaluated. The total available existing recycled water supplies from the four sources is 28,583 AFY. Implementation of 5, 25, 50, 75, and 100 percent of the available supplies was evaluated. The cumulative benefit of the implementation of just 5% of the available recycled water in 2023 results in a cumulative benefit in the basin of 165,700 AF by 2100. While implementation of 100% of regional recycled water for use in the basin is unlikely due to financial, contractual, and infrastructure constraints, it highlights the significant benefits it can have to the basin.

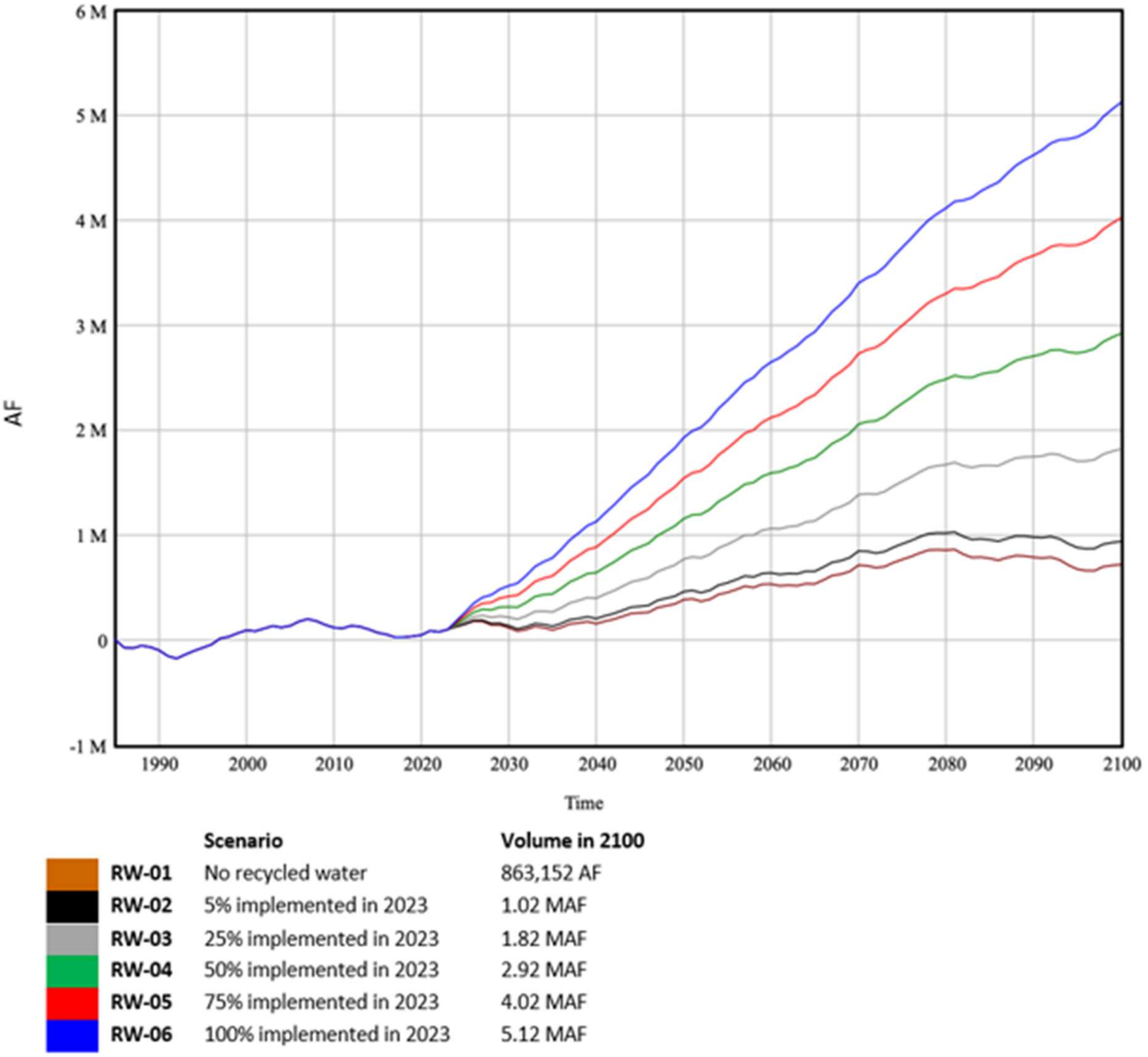


Figure 5-48. Oxnard Basin Cumulative Water Balance with Addition of Recycled Water in 2023

A phased approach to the implementation of recycled water was evaluated. This simulates the gradual expansion of recycled water in the basin. This would reflect a phased construction approach to allow for the use of more recycled water within the basin. Two adoption scenarios were simulated. The first (RW-07) was a conservative adoption of recycled water into the basin, with 5% of available recycled water in 2023, 10% in 2025, and 15% in 2030. A second scenario that was less conservative (RW-08) assumed 5% in 2023, 25% in 2025, and 35% in 2030. The results of these adoption scenarios are demonstrated in Figure 5-49.

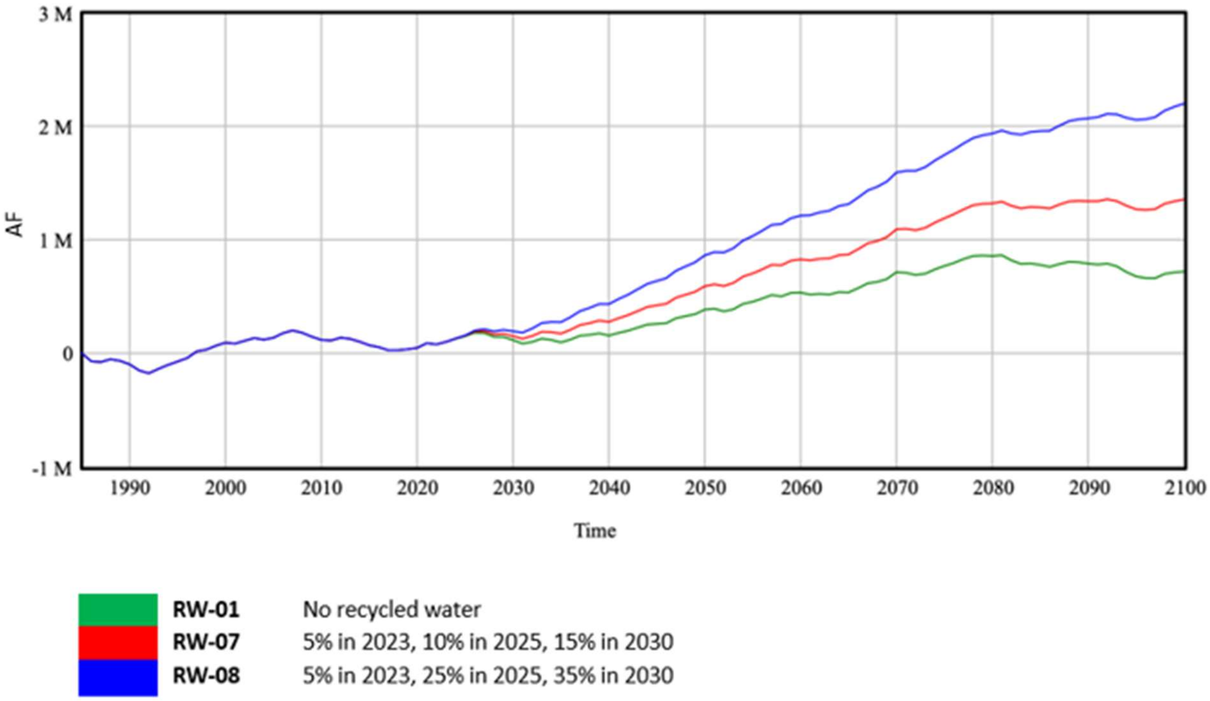


Figure 5-49. Oxnard Basin Cumulative Water Balance Under Phased Approchaed to Recycled Water Implementation

5.4.1.4 Combination of Projects

A combination of the three projects were evaluated. The implementation of all three projects provides the largest benefit to the basin, doubling the available water supplies by 2100 under the 2% decrease stochastic (P-08) precipitation scenario, when compared to the baseline scenario with a 5% decrease in the ability to capture Santa Clara River flows due to anticipated climate change. The results suggest that the second-best combination of projects in the context of increased water supplies is the implementation of recycled water and the Freeman Diversion Expansion project.

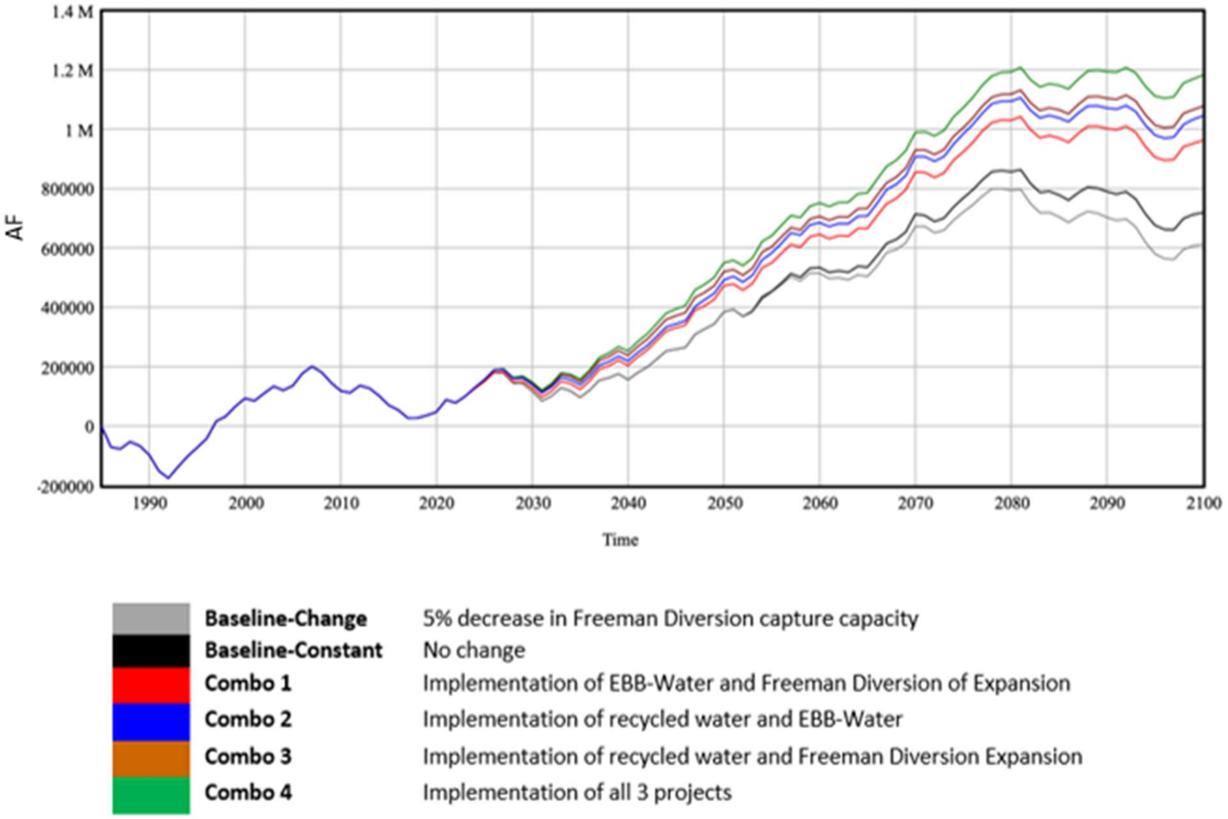


Figure 5-50. Oxnard Basin Cumulative Water Balance with Combination of Project

5.5 Coastal Flux Impact on Water Security

A portion of the water balance is the coastal flux, which is included in the Oxnard Basin cumulative water balance. However, coastal influx is higher salinity water than desired for the basin. While it does provide water into the basin it has a negative impact on the basin's water quality. The existing model maintains an average water quality with variability based on the implementation of projects. This assumption is since water quality varies throughout the basin based on proximity to the coast and depth of the aquifer. A simulation was conducted without accounting for coastal flux (inflow and outflow of water to the ocean). The results are shown in Figure 5-51. This indicated that the coastal flux had a significant impact on the availability of water supplies in the basin. This suggests a strong relationship with regional water quality that is currently not accounted for in the model.

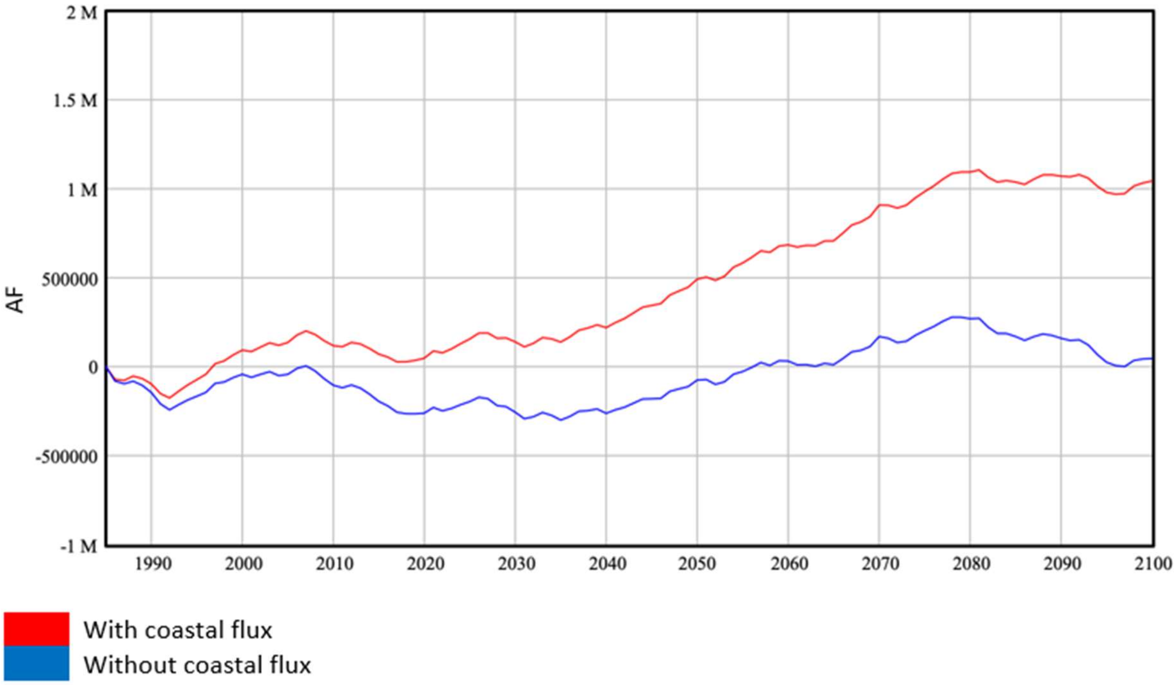


Figure 5-51. Oxnard Basin Cumulative Water Balance with and without Coastal Flux

6. DISCUSSION

This chapter provides a summary of findings from the model development and analysis, a discussion of the methodological contribution to the application of system dynamics for water resource management, as well as future opportunities to expand upon this research.

6.1 Summary of Findings

The research intended to answer three main research questions. The findings relating to these three questions is summarized below.

<u>Question 1:</u> Can a systems dynamic approach be used to understand complex water resource management decisions for the Oxnard Basin?

It was possible to apply a system dynamics approach to evaluating the Oxnard Basin. This was demonstrated through the modeling, calibration, and scenario simulation efforts presented in this thesis. Using a system approach required evaluating the understood relationship between variables, studying the existing data to identify additional relationships, and modeling those variables over time. The model was able to replicate historical data for the basin and then be used to extrapolate future scenarios that may occur to evaluate the impact on the overall basin. Significant benefits of this modeling approach include:

- Ability to forecast future scenarios such as hydrology changes, infrastructure development, policy changes, and climate changes to evaluate how they may impact other parts of the system.
- Ability to simulate hundreds of simultaneous simulations and optimize decision making based on a desired outcome.
- Ability to conduct sensitivity analyses to understand the sensitivity of the model to proposed changes or variables within the model.

Limitations of the system dynamics approach include:

- Limited ability to model complex groundwater and surface water hydraulic interactions. The existing model is limited in scope and capabilities when compared to some of the existing hydraulic and hydrologic models that have already developed for this region.

- Required stakeholder agreement and consensus on variable interaction and relationships. This model was developed based on available data and understanding of how variables interact with each other. However, new information, collaboration with stakeholders, further evaluation of the feedback in the system may give rise to new or different relationships between variables, requiring model adjustments. Modeling is an iterative process.
- System dynamic models require continued revision and calibration of the model over time as new policies and decisions within the system are made, as well as new information that contradicts the model.
- Some variables are not easily quantifiable, and as such may be considered to be ‘fuzzy’ variables. Identifying these variables and their potential impact on the model results is important in understanding the model results and model limitations.

While there are limitations, the continued development of this system dynamic model could prove to be a useful tool in future decision making. This modeling effort has demonstrated the ability to transform a complex system into a model that allows for the testing of different scenarios and conditions. Further refinement of the model would allow for informed decision making. This is further discussed in ***Section 6.3 Future Opportunities***.

<u>Question 2:</u> What are the drivers of water security in the Oxnard Basin?

The factors driving water security were identified through the modeling effort. These included the following:

1. **FCGMA Regulation:** It was observed during the calibration of the model that the implementation of FCGMA regulation. FCGMA limitations on irrigation and M&I pumping showed a noticeable impact on the water use based on historical data and the timing of the restrictions.

2. **Population Growth:** The sensitivity analysis indicated that water security may be highly sensitive to population growth. There is not anticipated to be significant growth in the area; however, an increase in growth well above the projected growth rate could have significant adverse impacts on the water security for the basin.
3. **Precipitation:** Precipitation is a driving force of water security due to the strong relationship between irrigation demand and precipitation. A decrease in average precipitation by 5% with extended dry periods could have a significant adverse impact on the basin. Extreme drought conditions, such as the precipitation scenario that was simulated using a 10-year drought period with an annual average decrease in precipitation by 2%, was found to have negative water balance by 2070 despite the existing policy and infrastructure efforts that have historically been made to improve water security in the basin.
4. **Proposed Infrastructure Projects:** Recycled water provides a potential significant opportunity to supplement water supplies. A combination of approaches including recycled water, the EBB-Water project, and the Freeman Diversion Expansion project have the largest benefit to the basin.
5. **Coastal Flux:** A portion of the net positive water balance in some simulations is a result of coastal influx. This accounts for water that is higher in salinity and may have negative impacts on water quality near the coast.

In conclusion, it was found that FCGMA regulation, population growth, precipitation, coastal flux, and proposed infrastructure such as the ability to supplement water supplies with recycled water are significant drivers of water security in the basin.

<u>Question 3:</u> How can water management and implementation decisions be optimized to maximize water security in the Oxnard Basin?

It was identified that projects that can be done more immediately with a significant net-positive benefit to the basin can have a cumulative positive benefit on the basin. For example, the addition of recycled water in a phased approach allowed for significant cumulative benefits over time. With further refinement and calibration of this model, this model can be used to evaluate future infrastructure and policy decisions. This model was used for testing scenarios, however, there is an optimization tool within the Vensim software that can also be used to further optimize decision making based on the desired outcome for the basin.

6.2 Knowledge Gaps

The knowledge gaps that have been identified as part of this modeling effort include the following:

- **Daily & Seasonal Variability:** The model looks at an annual timestep which may not be able to accurately account for the storage constraints, especially as they relate to surface water.

- **Water Quality Changes:** the model does not account for any actions or policy changes that may impact water quality. It is anticipated that the lack of the EBB-Water project would adversely affect the TDS water quality. This is currently not reflected in the model.

- **Policy & Economic Implications:** The model includes some FCGMA regulations and their impact on consumption patterns. However, additional investigation into water-policy and cost implications would have a significant benefit on model refinement.

- **Defining Water Security Thresholds:** Water security was defined as cost, water quality, and quantity. This assumption should be further defined and refined with stakeholders. Doing this would allow for further analysis of infrastructure planning in the future accounting for water security as part of the feedback loop for infrastructure development.

6.3 Future Opportunities

The existing model is a ‘first-step’ in applying a system dynamics approach to the Oxnard Basin. Results of this model should be taken in the context of preliminary approach. Model results used for infrastructure decision making and policy decisions should undergo a peer-review process. System dynamics modeling in particular should be developed in conjunction with all engaged stakeholders of a project. Further advancement of the model would require further collaboration with the District, FCGMA, the SWP, California climate studies, and water users, especially irrigation users.

Based on the findings from the development of this model it would be recommended that the following next steps be taken to further improve the model before being used as a tool for decision making:

1) Solicitation of feedback from stakeholders.
2) Evaluation of the ability to integrate existing surface water and groundwater models into the system dynamic model for improved accuracy of ‘fuzzy values’.
3) Policy and economic evaluation to improve variable interaction under changes in economic or policy conditions.
4) Continued evaluation of potential infrastructure and policy implementation scenarios with a refined model.

Following these proposed next steps this model could provide a valuable tool for evaluation and analysis of water quality, costs, and system optimization. Water systems are complex, involving water balances, economics, water quality, water policy, as part of complex human and natural interactions. System dynamics may provide a useful tool in the future for decision makers to use when approaching water-decision making.

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APPENDIX A: MODEL FORMULAS

Water Inflow Formulas

Variable	Formula	Units
Allocation	LOOKUP (Time, Series))	AFY
Article 21	LOOKUP (Time, Series))	AFY
Coastal Flux In	942.28*EXP(3e-05*Irrigation)	AFY
Unincorporated Inflow	353	AFY
Upper Basin Recharge	0.5*SWP at Piru Lake	AFY
Table A	3150	AFY
Surface Water at Freeman Diversion	INTEG (Santa Clara River to Diversion + Imported SWP to Oxnard Basin-Incoming Surface Water -Pleasant Valley, 1)	AFY
Surface Water Basin Capacity	93750+Add Surface Water Storage	AFY
SWP at Piru Lake	INTEG (Imported SWP-Upper Basin Recharge-Imported SWP to Oxnard Basin,0)	AFY
Stream Leakage Recharge	729.12*Precipitation	AFY
Return Ag Flows	Irrigation*0.14	AFY
Return M&I	M&I*0.05	
Subbasin Inflow	(-0.1471*Incoming Surface Water)+14156	AFY
Precipitation Recharge	(785.29*Precipitation)-697.74	AFY
Santa Clara River Flows	(5747.7*Precipitation)+6826.1	AFY
Santa Clara River to Diversion	IF THEN ELSE(Increase Santa Clara River Capture<Remaining Freeman Capacity , Increase Santa Clara River Capture, Remaining Freeman Capacity)	AFY
Stream Leakage	IF THEN ELSE(Santa Clara River to Diversion>100000 :AND:(precipdelay+Precipitation)>28, 500 , 0)	AFY
Imported	Incoming Surface Water-(Imported SWP to Oxnard Basin-(Imported SWP to Oxnard Basin *0.1222))	AFY
Imported SWP	Article 21+Imported Table A	AFY
Imported SWP to Oxnard Basin	0.5*SWP at Piru Lake	AFY
Imported Table A	Allocations/100)*Table A	AFY
Potable Demands	Domestic+"M&I"	AFY
Natural Recharge	Coastal Flux In+Precipitation Recharge+Return Ag Flows+"Return M&I"+Stream Leakage Recharge +Subbasin Inflow+Unincorporated Inflow	AFY
Freeman Diversion Capacity	INTEG (0, Initial Freeman Capacity)	AFY
Remaining Freeman Capacity	Freeman Diversion Capacity-Surface Water at Freeman Diversion	AFY
Pleasant Valley	Incoming Surface Water*0.1222	AFY
Incoming Surface Water	Surface Water at Freeman Diversion*0.8778	AFY

Water Outflow Formulas

Variable	Formula	Units
Oxnard Basin Demands	Irrigation Adjusted+Potable Demands	AFY
Natural Losses	Subsurface Outflow+Evapotranspiration+Tile Drains+Coastal Flux Out+Stream Leakage +Unincorporated Outflow	AFY
M&I	31500+(0.1825*Populations*"Per Capita M&I")-(278.818*Precipitation)	AFY
Evapotranspiration	33898.6-(394.36*Temperature)+(136.66*Precipitation)	AFY
Unincorporated Outflow	105	AFY
Tile Drains	33.9212-(0.11273 *Irrigation) + (1.99359 * Evapotranspiration)	AFY
FCGMA Regulation	0+STEP(0.5 ,1991)+STEP(0.5 , 1997) IF THEN ELSE(Time>1991, 0.5,IF THEN ELSE(Time>1997 , 1 , 0)	N/A
Domestic	IF THEN ELSE(FCGMA Regulation=0 , 3400, IF THEN ELSE (FCGMA Regulation=0.5 , 566, (-0.001418 * Populations) +(Precipitation*3.25514)+677.17))	AFY
Coastal Flux Out	IF THEN ELSE(Coastal Flux In>10000,(0.0652*Coastal Flux In)-2729, (0.7624* Coastal Flux In)-7844.9)	AFY
Irrigation	IF THEN ELSE(FCGMA Regulation<0.5, (-854.19*Precipitation)+77785, IF THEN ELSE (FCGMA Regulation<0.55,xTime,(-1011*Precipitation)+52472)	AFY
Irrigation Adjusted	Pumping Adjustment*Irrigation	AFY
Per Capita M&I	0.0915775	AFY

Water Balance

Variable	Formula	Units
Water Balance	EBB to Oxnard Basin+Incoming Surface Water+Natural Recharge-Natural Losses -Oxnard Basin Demands	AF
Water Availability	IF THEN ELSE(Incoming Surface Water+Natural Recharge-Natural Losses-Oxnard Basin Demands >0, 1 , 0)	1 = positive balance 0= negative balance
Oxnard Basin Supplies	INTEG (Recycled Water+EBB to Oxnard Basin+Incoming Surface Water+Natural Recharge+Recycled Water-Natural Losses-Oxnard Basin Demands, 1000)	AF

Alternative Projects

Variable	Formula	Units
EBB to Mugu Navy	IF THEN ELSE(EBB Water For Delivery>1500, 1500, EBB Water For Delivery)	AFY
Brine	EBB Treated Brackish Groundwater*brine waste Rate	AFY
Brine Rate	0.5 [0.1,0.9,0.05]	%
Brine Waste Rate	brine rate-STEP(0.1, improved recovery)	%
Ebb Capacity	5000 [0,12000,1000]	AFY
EBB Permeate	EBB Treated Brackish Groundwater-Brine	AFY
EBB to Oxnard Basin	EBB Water For Delivery-EBB to Mugu Navy	AFY
EBB Treated Brackish Groundwater	INTEG (Influent to EBB-Brine-EBB Permeate,0)	AFY
EBB Water For Delivery	INTEG (EBB Permeate-EBB to Mugu Navy-EBB to Oxnard Basin, 0)	AFY
EBB-Timed	STEP(ebb capacity, EBB Implementation Year)	Year
Capture Percentage	STEP(Freeman Capacity Change Percentage Yr1 , Capacity Expansion Year 1)+STEP (Yr2,Capacity Expansion Year 2)+STEP(Yr3, Capacity Expansion Year 3)	%
Proportion EBB-Water	(EBB to Oxnard Basin+EBB to Mugu Navy)/Oxnard Basin Demands)	AFY
Recycled Water	Recycled Water Capacity	AFY
Recycled Water Capacity	STEP(1429, 2023) Freeman Capacity Change Percentage Yr1=0.05	AFY
Improved Recovery	EBB Implementation Year+10	Year
Increase Santa Clara River Capture	Santa Clara River Flows+(Capture Percentage*Santa Clara River Flows)	AFY
Initial Freeman Capacity	200000	AFY
Initial Treatment Capacity	0	AFY
Local Groundwater Water Treatment Capacity	INTEG (0, Initial Treatment Capacity)	AFY
Influent to EBB	EBB-Timed	AFY

Water Quality Formulas

Variable	Formula	Units
Water Quality Compliance	(WQ Indicator TDS*TDS Weight)+(WQ Indicator Sulfate*Sulfate Weight)+(WQ Indicator Chloride *Chloride Weight)+(Boron Weight*WQ Indicator Boron)	1 = meet WQ standard, 0= does not meet
WQ Trend	TREND(Water Quality Compliance, 3 , 0)	N/A

Boron Water Quality

Boron for Groundwater= 0.5
Boron For Surface Water=0.7
Boron for Treated EBB-Water= 0.3
Boron Treatment Goal=0.5

Boron Weight= 0.1
WQ Indicator Boron=IF THEN ELSE(Finished WQ Boron<Boron Treatment Goal,1, 0)
Finished WQ Boron= (Boron for Groundwater*Proportion Groundwater)+(Boron For Surface Water*Proportion Surface Water)+("Boron for Treated EBB-Water"*"Proportion EBB-Water")

Chloride Water Quality

Chloride for Groundwater=50.667
Chloride for Surface Water= 61
Chloride for Treated EBB Water=47.5
Chloride Treatment Goal= 80
Chloride Weight= 0.4
WQ Indicator Chloride=IF THEN ELSE(Finished WQ Chloride<Chloride Treatment Goal,1, 0)
Finished WQ Chloride= (Chloride for Groundwater*Proportion Groundwater)+(Chloride for Surface Water *Proportion Surface Water)+(Chloride for Treated EBB Water*"Proportion EBB-Water")

Sulfate Water Quality

Sulfate for Groundwater=414.33
Sulfate for Surface Water= 493
Sulfate for Treated EBB Water= 1.25
Sulfate Treatment Goal= 250
Sulfate Weight=0.1
Finished WQ Sulfate= ("Proportion EBB-Water"*Sulfate for Treated EBB Water)+(Proportion Groundwater*Sulfate for Groundwater)+(Proportion Surface Water*Sulfate for Surface Water)
WQ Indicator Sulfate=IF THEN ELSE(Finished WQ Sulfate<Sulfate Treatment Goal,1, 0)

Total Dissolved Solids (TDS) Water Quality

TDS for Groundwater=997.33
TDS for Surface Water=1134
TDS for Treated EBB-Water"= 126.5
TDS Treatment Goal= 450
TDS Weight= 0.4
Finished WQ TDS= ("Proportion EBB-Water"*"TDS for Treated EBB-Water")+(Proportion Groundwater*TDS for Groundwater)+(Proportion Surface Water*TDS for Surface Water)
WQ Indicator TDS= IF THEN ELSE(Finished WQ TDS<TDS Treatment Goal,1, 0)

Water Security

Variable	Formula	Units
Water Security	((Water Balance Trend*Water Availability Weight)+(WQ Trend*Water Quality Weight)+(Cost Index Trend*Water Cost Weight))*100	N/A
Cost Index	(Proportion Non Imported Water*1)+(Proportion Groundwater*2)+("Proportion EBB-Water" *4)+(Proportion Imported Surface Water*3)	N/A
Cost Index Trend	TREND(Cost Index, 3 , 0)	N/A

Other

Variable	**Formula**	**Units**
Precipitation	WITH LOOKUP (Time,Series)	inch
Precip delay	DELAY INFORMATION(Precipitation , 1, 0)	Inch
Initial Population	287000	People
Growth Rate	0.0093	People
Population Added	Populations*Growth Rate	People
Population Decline	0	People
Population Removed	Populations*Population Decline	People
Population	INTEG (Population Added-Population Removed, Initial Population)	People
Temperature	WITH LOOKUP (Time,Series)	Fahrenheit