Marin Municipal Water District

Draft Report – WORKING DRAFT

Strategic Water Supply Assessment

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This Document Prepared by:

Management Review

Ben Horenstein
Marin Municipal Water District
General Manager

Paul Sellier, P.E.
Marin Municipal Water District
Water Resources Director

Lucy Croy, P.E.
Marin Municipal Water District
Water Quality Manager

Carrie Pollard
Marin Municipal Water District
Water Efficiency Manager

Preparation Team

Armin Munévar, P.E.
Jacobs
Global Technologist, Climate Resilience and Water Resources

Marcelo Reginato, P.E.
Jacobs
Senior Technologist, Climate Resilience and Water Resources

Laura Harnish
Jacobs
Principal Planner, Climate Resilience and Water Resources

Jim Lozier, P.E.
Jacobs
Principal Technologist, Water Resources

Ryujiro Tsuchihashi, P.E.
Jacobs
Senior Wastewater Engineer

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Acronyms and Abbreviations

Acronym	Definition
AR	Atmospheric Rivers
AR4	Intergovernmental Panel on Climate Change Assessment Report 4
AR5	Intergovernmental Panel on Climate Change Assessment Report 5
AR6	Intergovernmental Panel on Climate Change Assessment Report 6
BACWA	Bay Area Clean Water Agencies
BCM	Bedload Assessment in Gravel-bedded Streams
BCSD	Bias-correction and spatial downscaling
BMP	Best management practices
CCTAG	Climate Change Technical Advisory Group
CDFW	California Department of Fish and Wildlife
CMIP3	Coupled Model Intercomparison Project 3
cfs	cubic foot (feet) per second
CMIP5	Coupled Model Intercomparison Project 5
CNAP	California-Nevada Applications Program
CNRM-CM3	Centre National de Recherches Météorologiques Coupled Global Climate Model Version 3
CoSMoS	Coastal Storm Modeling System
CWD	Climatic water deficit
CW3E	Center for Western Weather and Water Extremes

Acronym	Definition
DWR	Department of Water Resources
ESD	Equivalent Single-Family Dwelling Unit
FEMA	Federal Emergency Management Agency
FIRO	Forecast-Informed Reservoir Operations
Flood-MAR	flood-managed aquifer recharge
FVA	final viability assessment
GCM	General circulation models
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse gas
HEC-ResSim	Hydrologic Engineering Center – Reservoir System Simulation
IPCC	Intergovernmental Panel on Climate Change
I/I	Infiltration/Inflow
IWRSS	Integrated Water Resources Science and Services
LBNL	Lawrence Berkely National Laboratory
LOCA	localized constructed analogs
Marin Water	Marin Municipal Water District
MOA	memorandum of agreement
NBCAI	North Bay Climate Adaptation Initiative
NCAR CCSM3	National Center for Atmospheric Research Community Climate System Model version 3
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OAR	Oceanic and Atmospheric Research
OCSD	Occidental County Sanitation District

Acronym	Definition
OneRain	Sonoma Water's Real-time Rainfall, River-Stream and Reservoir Data
OPC	Ocean Protection Council
PCM1	NCAR Parallel Climate Model 1
PVA	preliminary viability assessment
PVP	Potter Valley Project
QPI	quantitative precipitation information
RCM	regional climate model
RCPA	Regional Climate Protection Authority
SARP	Sectoral Applications Research Program
SCADA	supervisory control and data acquisition
SCWA (or Sonoma Water)	Sonoma County Water Agency
SIO	Scripps Institution of Oceanography
Sonoma Water (or SCWA)	Sonoma County Water Agency
SOP	standard operating procedure
SSO	sanitary sewer overflow
SWRCB	State Water Resources Control Board
UCCE	U.C. Cooperative Extension
USACE	U.S. States Army Corps of Engineers
USGS	U.S. Geological Survey
WWTP	wastewater treatment plant

Executive Summary (5 pgs)

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SECTION 1

Introduction

The Marin Municipal Water District (MMWD or District) serves the populous eastern corridor of Marin County from the Golden Gate Bridge northward up to, but not including Novato. The district covers approximately 147 square miles and serves a population of approximately 190,000 customers with surface water supplies from seven local reservoirs, augmented with Russian River supplies imported from the Sonoma County Water Agency (Sonoma Water). Historically, MMWD has successfully met demands during periods of extreme drought with a combination of rationing, conservation, and increased Sonoma Water supplies. However, recent drought conditions that severely threatened water supply reliability have prompted MMWD to explore various water supply options to enhance resiliency for its customers.

MMWD’s local watersheds are some of the most productive in the state. Water supply is generally sufficient in most years and of high quality. These watersheds are expected to continue to be productive in the future, but the variability from one year to another is likely to increase. The challenge for water resource planning, however, is how to best manage the extremes, whether flood or drought. Jacobs was selected to lead a Strategic Water Supply Assessment (SWSA) to help develop a water supply roadmap for MMWD. The SWSA includes an assessment of current and future hydrological conditions, performance of the MMWD system under these conditions, and a robust consideration of alternatives and strategies, and eventual roadmap to a more resilience water supply future.

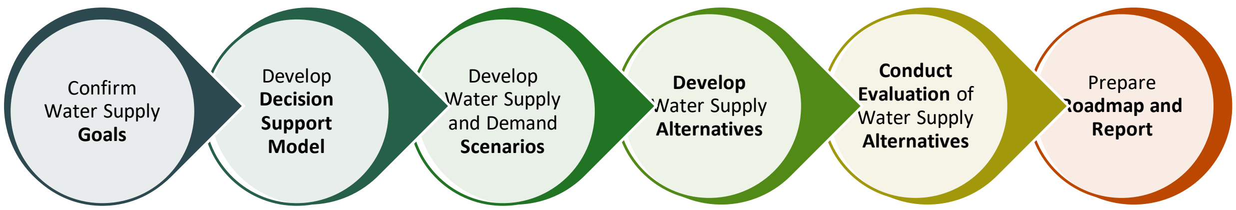
The SWSA was conducted using a proven water planning framework as show in Figure 1. In general, the framework ensures a comprehensive understanding of the problem and project goals, includes a robust consideration and evaluation of water management opportunities to meet the goals, and leads toward a strategic roadmap to guide future MMWD water management decisions.

The main elements of the framework are listed below:

1. Establish goals and document performance measures (section 4)
2. Develop decision support model to represent system and system performance (section 5)
3. Identify and quantify scenarios to represent the future uncertainty (section 6)
4. Consider and develop a robust set of water management alternatives and portfolios (section 7)
5. Conduct evaluation of the alternatives and portfolios based on performance measures and additional evaluation criteria (section 7 and 8)

6. Utilize results and findings from all previous steps to develop a strategic water supply resiliency roadmap (section 9)

Figure 1. SWSA Planning Framework and Project Scope Elements



The approach and methods for each of these elements is described in the subsequent sections.

SECTION 2

MMWD Water Supply System

2.1 Introduction

Established in 1912, the Marin Municipal Water District (MMWD or District) is the oldest municipal water district in the state of California (MMWD, 2020). The District encompasses the eastern corridor of Marin County, extending from the Golden Gate Bridge up to, but not including, the City of Novato. The District is bounded by the San Francisco Bay on the east and extends through the San Geronimo Valley on the west.

The incorporated cities and towns of the District's service area include San Rafael, Mill Valley, Fairfax, San Anselmo, Ross, Larkspur, Corte Madera, Tiburon, Belvedere and Sausalito (MMWD, 2021). Historically, MMWD has successfully met demands during periods of extreme drought with a combination of rationing, conservation, and increased Sonoma Water supplies. However, recent drought conditions that severely threatened water supply reliability have prompted MMWD to explore various water supply options to enhance resiliency for its customers. The purpose of this section is to discuss the current MMWD Water System as it pertains to different water supply alternatives discussed later in this report.

2.2 Water System

The District covers approximately 147 square miles and serves approximately 191,000 customers through about 61,700 active service connections (MMWD, 2022, MMWD, 2021). The District's potable and raw water distribution system includes approximately 886 miles of water mains, 94 pump stations, and 121 treated water storage tanks with a total storage capacity of 74.96 million gallons (MG) (MMWD, 2021). The District's water supplies come from a mixture of local surface water, imported water from Sonoma County Water Agency (SCWA or Sonoma Water), and recycled water. The District's service area boundaries, location of water treatment plants, and water pipelines are shown in Figure 2 below.

Figure 2. MMWD Service Area, Pipelines, and Treatment Plants

2.2.1 Water Treatment Plants

The District treats water at its three treatment plants, the Bon Tempe Treatment Plant (BTTP) near Ross, the San Geronimo Treatment Plant (SGTP) in Woodacre, and the Ignacio treatment facility in Novato (MMWD, 2021). In combination, the District's treatment plants have a design capacity of 71 million gallons per day (MGD) (MMWD, 2021). In 2019, the total production of the District's plants averaged 22.8 MGD (25,557 AFY) (MMWD, 2021). The daily average maximum flow is approximately 22.5 MGD (25,220 AFY) (MMWD, 2021). Summer time flows are more than double winter flows and can peak around 35 MGD in August.

2.2.2 Potable and Recycled Water

The District's potable water system includes pipelines ranging in size from 3/4-inch pipes connecting customers' water meters to the District's mains, to 42-inch transmission mains that carry source water to the treatment plants (MMWD, 2021). In addition to the District's potable water system, the District also partners with the Las Gallinas Valley Sanitary District (LGVSD) to produce and distribute recycled water from the Recycled Water Treatment Facility (RWTF). In In 2019, LGVSD in partnership with Marin Water expanded the capacity of the RWTF. With the current upgrades, the RWTF has a total capacity of 5.4 MGD and MMWD is entitled to a firm 1.8 MGD (MMWD, 2021).

The majority of the recycled water is distributed by the District in the Terra Linda area of San Rafael. The District's recycled water system is supplemented with the District's potable water system to meet demands when necessary (MMWD, 2021).

2.2.3 Reservoirs

The District's primary water supply is local surface water. The current surface storage for the total system is estimated to be 78,384 AF according to the latest bathymetric survey from 2017. The District's reservoirs include the Alpine, Bon Tempe, Kent, Lagunitas, Phoenix Lake, Nicasio, and Soulajule. Five of the seven District reservoirs (Alpine, Bon Tempe, Kent, Lagunitas, and Phoenix Lake) are located on the north slope of Mt. Tamalpais while the two remaining reservoirs are located outside the District's service areas in West Marin. Until 2045, the District expects to supply between 25,000- 29,000 AFY to its customers and approximately 10,500 AFY of environmental releases from Kent and Soulajule lakes (MMWD, 2021).

On average, the District's annual runoff is approximately 83,000 AF. Annual runoff into the District's reservoirs can range as low as 4,000 AF (occurring in 1977) to over 211,000 AF (occurring in 2017). From the District's local reservoirs, water is conveyed to either the Bon Tempe Treatment Plant or the San Geronimo Treatment Plant. Table 1 below shows the capacity of each of the District's Treatment Plants.

Table 1. MMWD Treatment Plants Capacity and Supply Source

Reservoir Name	Year Constructed	Capacity AF initial/more recent 2017 survey
Lake Lagunitas	1987	350/331
Phoenix Lake	1905	411/306
Bon Tempe Reservoir	1948	4,017/4,504 (2017 survey)
Alpine Lake	1918 1924 1941	3,069 4,600 8,891/ 8,953 (2017 survey)

Reservoir Name	Year Constructed	Capacity AF initial/more recent 2017 survey
Kent Lake	1953 1982	16,050 32,895
Nicasio Reservoir	1960	22,430/ 20,723 (2017 survey)
Soulajule Reservoir	1980	10,572/ 10,723 (2017 survey)

2.2.4 Sonoma Water

The District purchases supplemental water supply from the Sonoma Water transmission system which conveys treated groundwater from the Sonoma Water's Russian River Project. The water is extracted from a stretch of the Russian River located upstream of the Wohler Bridge and percolates through sand and gravel where it is treated with chlorine to meet drinking water quality standards (MMWD, 2021). Sonoma Water also pumps a portion of its water supply from the Santa Rosa Plain Subbasin of the Santa Rosa Valley Basin (MMWD, 2021). Groundwater supplies from the Santa Rosa Plain are primarily used during drought periods or when the Russian River supplies are constrained.

SECTION 3

Background and Previous Reports

3.1 Introduction

The Strategic Water Supply Assessment (SWSA) is intended to be additive to past planning efforts and is designed to fill in the gaps on new water supply alternatives. Many reports and studies have been produced by MMWD describing the feasibility and capacity of a variety of different water supplies.

An extensive list of documents was provided by MMWD for review. The list below indicates the primary documents provided by MMWD for review that were included in the project proposal. More information regarding each document can be found in Appendix A.

- Water Supply Master Plan (1989)
- SASM-MMWD Recycled Water Feasibility Study (2014)
- CMSA Technical Memorandum Direct Potable Reuse Feasibility Study (2022)
- CMSA-MMWD Recycled Water Feasibility Study (2016)
- Water Resources Plan 2040 (2017)
- North Bay Water Reuse Plan Phase 2 (2018)
- Marin Municipal Water District Desalination Plan EIR (2008) and Unpublished Updates (2021)
- Water Shortage Contingency Plan (2021)
- Urban Water Management Plan (2021)
- CMSA-MMWD Briefing Document Evaluating Direct Potable Reuse in Marin
- Kastania Pump Station Operations (2022)
- EBMUD-MMWD Intertie EIR (2022, in progress)
- MMWD's In-System "Bottleneck" Study (2022, as available).

Additional documents were collected by Jacobs or provided by MMWD during the course of the SWSA. These documents were also reviewed but considered secondary documents with respect to relevance. More information on these documents can be found in Appendix A.

3.2 Summary of Reports

This section summarizes the most relevant water resources and water supply reports. More details on each of the studies can be found in Appendix A.

Water Supply Master Plan (Bookman-Edmonston Engineering, 1989)

The purpose of the report is to identify sources of water supply to meet water demands. The report defines existing water use demands, future development and water use demands, assesses the quality and treatment of current water supplies, determines the adequacy of available supply sources, and identifies alternative methods to provide future water supply treatment and conveyance.

SASM-MMWD Recycled Water Feasibility Study (Carollo, 2014)

The SASM-MMWD Recycled Water Feasibility study evaluates the feasibility of constructing a new recycled water (RW) system to replace or increase existing irrigation supplies. The development of RW service within the Sewerage Agency of Southern Marin (SASM) service area would offset potable water use to promote the beneficial use of RW for irrigation, cooling tower use, and/or wetlands enhancement.

Draft CMSA Technical Memorandum Direct Potable Reuse Feasibility Study (Carollo, 2022)

The CMSA Direct Potable Reuse Feasibility study is an update of CMSA-MMWD Recycled Water Feasibility Study (2016) with a focus on studying the DPR project at CMSA for the treated water augmentation (TWA) DPR system. Two DPR production capacities were analyzed: 2 and 4 MGD. This study evaluated the treatment process based on the draft DPR regulations in California and evaluated two potential connection points to the MMWD's existing potable water distribution system.

CMSA-MMWD Recycled Water Feasibility Study (Carollo, 2016)

The purpose of the CMSA-MMWD Recycled Water Feasibility study is to determine the feasibility of developing a recycled water system to augment water supplies for MMWD. The report evaluated recycled water uses such as irrigation, commercial reuse, dual-plumbing at San Quentin Prison, and direct potable reuse. The recommended project for the CMSA-MMWD Recycled Water Feasibility Study is Alternative 1B – San Quentin Prison with microfiltration treatment.

Water Resources Plan 2040 (RMC and W&C, 2017)

In the Water Resources Plan, a total of 40 resiliency options were developed to evaluate and improve the District's resiliency and ability to meet demands in times of potential supply shortages. The resiliency options ranged from alternatives such as water use efficiency, reuse, expanding SCWA facilities, expanding storage, greater water and groundwater purchases, and desalination.

North Bay Water Reuse Plan Phase 2 (Brown and Caldwell, 2018)

The North Bay Water Reuse Authority (NBWRA) establishes Phase 1 and Phase 2 programs to develop, capture, and use 25,000 AFY of recycled water that is discharged into the San Pablo Bay. Phase 1, which includes, upgraded wastewater treatment plants, distribution pipelines, and small storage reservoirs plan to deliver recycled water for urban uses. Phase 1 provides 3,800 AFY for urban/agricultural water use, and 1,400 for environmental enhancement. The report discusses in greater detail Phase 2, which further develops recycled water as part of the region's water supply portfolio.

Marin Municipal Water District Desalination Plan EIR (URS, 2008) and Unpublished Updates (URS, 2021)

The 2008 report describes an Environmental Impact Statement of the proposed desalinization plant in San Rafael. The 2021 updates present the overall design parameters and concepts for the two approaches to a supplemental desalination supply. The report summarizes the availability, capacity, conceptual construction costs and potential schedule for a short-term (12-month) leased seawater desalination facility with a capacity of approximately 3.6 MGD.

MMWD's In-System "Bottleneck" Study (W&C, 2022)

The 2022 report describes potential improvements to the District's water conveyance system which would allow excess winter water to be moved from the SCWA (Sonoma County Water Agency) system through Marin Water's system to meet demand and fill existing storage. The report focuses on five different conveyance improvement projects (North Redwood Highway, Santa Margarita, Forbes Hill, San Quentin, and Federal Works) and describes the associated costs for each project.

Water Shortage Contingency Plan (EKI, 2021)

The 2020 Urban Water Management Plan Appendix H: Water Shortage Contingency Plan provides actions that can be implemented in the event of a water shortage event, such as a drought or supply interruption. The Plan presents the annual water supply assessment procedures which categorized water shortage levels and associated water conservation actions.

Urban Water Management Plan (EKI and W&C, 2021)

The UWMP suggests that the available supplies would be sufficient to meet projected demands in all hydrologic conditions, including a five-year drought period, and under climate change impacts. The report, consistent with prescriptive state guidelines, analyzed system water demands, projected water demands, and climate change impacts to current and future water demand. The report provides information regarding water supply reliability, water shortage and contingency planning, and demand management measures.

CMSA-MMWD Briefing Document Evaluating Direct Potable Reuse in Marin (Carollo, 2021)

The report presents an analysis of the potential advanced water purification facility (AWPF) under three different production capacities: 2, 4, and 8 MGD of feed water. The purpose of the report is to update the 2016 Study and feasibility of recommending the most viable approach to achieve treated water augmentation (TWA.) From the study, the most efficient direct potable reuse DPR project is to construct an AWPF at Central Marin Sanitation Agency wastewater treatment plant.

Kastania Pump Station Operations (Kennedy-Jenks, 2022)

The report summarizes the maximum available flow that Kastania Pump Station (KPS) can deliver to Ignacio Pump Station (IPS) through the Petaluma/North Marin Aqueduct (NMA) system while meeting the North Marin Water District's (District) minimum pressure and maximum velocity requirements.

EBMUD-MMWD Intertie EIR (MMWD, 2022 in progress)

The report, prepared by MMMD, discusses three alternatives (Winter Water from SCWA, desalinization, and intertie) to mitigate drought effects to the region. The intertie option is discussed in greater detail, with extra emphasis given to alternatives for location, tie in, and routes for both the eastern and western pipeline. Specific project elements such as, the Richmond Pump Station, Pelican Way Site Improvements, Eastern Pipeline, RSR bridge work, Western Pipelines, and Richmond Distribution System Improvements are discussed.

SECTION 4

Goals and Performance Measures

4.1 Introduction

Goals are necessary to provide clarity on “what” is intended to be achieved in addition to “how” it is to be achieved. Goals, to be useful, must also be measurable. In this strategic water supply assessment, the goals established through this process provide guidance on how Marin Water defines a reliable and resilient water supply in the face of the effects of climate variability and change, namely future droughts of varying severity and duration. The goals also provide guidance as to the values of Marin Water with respect to water use, cost, the environment and overall equity. The goals are also used to establish more specific performance metrics and evaluation criteria that will be applied to the range of water supply alternatives.

In addition to the draft goals provided below, are “actions” that together can be implemented to achieve the goals, along with metrics, that will be used to determine whether and how the various alternatives achieve the goal. Beyond being used to compare and select alternatives, the goals and metrics can be used to assess progress and success of the implemented alternative(s) and adapt implementation as needed to assure goals are met.

The District’s Board Policies and Handbook from June 3, 2021 (MMWD 2021) outlines the key values and goals of the District. Building from these values and goals, and in discussion with District staff, the following goals have been articulated to guide the SWSA. Goals have been developed for the following categories:

- Water Supply
- Water Quality
- Sustainability and Environmental
- Economic and Financial
- Equity

For each goal category, an overarching goal statement has been prepared, combined with specific actions and metrics to allow for clarity and measurement of performance.

4.2 Water Supply

Goal: Provide a reliable and resilient water supply now and for the future

Actions:

1. Develop supplemental water supply to improve resilience during drought periods
2. Reduce water demand through enhanced water conservation and water recycling programs
3. Increase flexibility and coordination of operations across connected regional resources
4. Plan for a range of climate and climate change outcomes

Metrics (KPIs)

- Meet demand during a four-year drought with no more than 25 percent mandatory conservation (Water Shortage Contingency Plan Stage 3)
- Total Marin Water storage does not fall below 30,000 acre-feet during most severe droughts
- Meet or exceed statewide indoor residential per capita water use targets of 47 GPCD by 2025 and 42 GPCD by 2030
- Meet or exceed the statewide outdoor landscape water use standard based on landscape area and climate consistent with compliance methodology determine by SWRCB.

4.3 Water Quality

Goal: Assure that water produced is of high quality and protects public health from source to customer's residence

Actions:

1. Recognize and enhance the water quality benefits provided by source watersheds
2. Invest in appropriate treatment levels for water supplies
3. Ensure new supplies are integrated into the system with little change in the customer's actual or perception of water quality

Metrics

- Water quality meets or exceeds all US drinking water quality regulations
- Source watersheds are protected, and natural functional processes are maintained

4.4 Sustainability and Environmental

Goal: Protect the environment for future generations by ensuring protection and stewardship of source watersheds, and promoting sustainable practices in district operations

Actions:

1. Provide responsible stewardship of land under district management, balancing existing mandates to safeguard ecological integrity, protect against wildfire, and maintain water quality.
2. Ensure the use of renewable energy in and optimize the use of energy in District operations including treatment and distribution of water supplies.
3. Ensure the overall sustainability of District operations through a sustainability program that focuses on waste reduction, energy conservation, etc.

Metrics

- Use of established environmental, social, and economic sustainability indicators in program and project evaluation and implementation.
- Source watersheds are protected, and natural functional processes and ecosystem benefits are maintained.

4.5 Economic and Financial

Goal: Maintain and improve District's infrastructure and operations in a cost-effective manner

Actions

1. Actively leverage state and federal sources of funding to offset capital costs of improving water supply to rate-payers
2. Weigh trade-offs between investments in reliability and environmental, social and economic values
3. Ensure integrity, accountability and transparency in financial management
4. Provide a water rate structure that is fair and reasonable, and that adequately funds the long-term maintenance and capital needs of the District's supply and delivery systems

Metrics

- State and federal grants form a significant portion of the Marin Water's capital funding.
- Integrity, Accountability and Transparency: 100 % of planned audits should be completed, 100% of audit findings should be resolved.
- Ensure water rates are consistent with COSA regulations and sufficient to maintain the water system.

4.6 Equity

Goal: Ensure the costs, benefits, and impacts of providing a resilient and reliable water supply are borne equitably across the service area population

Actions:

1. Develop and implement a District Equity Action Plan to understand and address any outstanding water equity issues within the District including, access, participation in decision-making, and disproportionate impacts or reduced benefits.

Metrics:

- Are actions identified in the Equity Action Plan invested in and implemented?
- Water is available for all users and water quality meets all state and federal regulations.

The goals, actions, and metrics indicated in this section are used to support performance and evaluation criteria in developing the roadmap. Specifically, the Water Supply Goal and metrics are used to assess performance of the system and in establishing potential future water supply needs. Other goals are incorporated in the evaluation criteria discussed in subsequent sections.

SECTION 5

System Model Description

A decision support model representing the District's existing water supply system and system performance was developed for the Strategic Water Supply Assessment to explore various water supply options. The MMWD Decision Support Model Tool (MarinDSM) builds on an existing model developed for Sonoma Water agency that initially (prior to 2021) included a simplified representation of the MMWD system. The original Sonoma Water model was expanded to include significantly more details related to the MMWD system.

Using a combined model of both the MMWD and SCWA water supply systems assisted the project team in evaluating risks for droughts and potential projects from a more comprehensive system perspective, compared to previous developed models that were focused only within the MMWD system. For example, the MarinDSM tool can predict drought conditions in the Russian River and storage levels at Lake Sonoma and Lake Mendocino. Storage levels at the Russian River eventually will determine the availability of imported water supplies to MMWD, currently the second most important water supply to MMWD after its own local surface storage reservoirs.

Prior MMWD mathematical models of the water supply system have been developed and used by the District to assist in decisions related to key infrastructure projects and long-term resiliency planning. These water supply models have been limited in scope to the District's local system as the primary objective has focused on minimizing the impact of drought on MMWD's ability to supply its customers. Previous models are described in reports by MBK Engineers (2002) and RMC (2017).

The following subsections describe key model features, a more complete MarinDSM model documentation is presented under Appendix B.

5.1 System Representation

The MarinDSM model includes the water system components described in section 2 (MMWD Water Supply System) as well as the potential projects that are being considered in the study. Figure 3 illustrates the MarinDSM domain downstream of Ely booster (the next potential system bottleneck for MMWD imported water after recent improvements in Kastania pump station) with potential projects that could increase water supplies to the system.

An important section of the transmission system between Sonoma and Marin is the transmission line between Ely booster and Ignacio pump station, as capacities in that section can be cause bottlenecks of imported water to the MMWD system. The North Marin district is also included in Figure 3 due to some interactions with MMWD system, mainly in the sharing of existing and future conveyance and pump stations that convey imported water to both systems.

Figure 3. MarinDSM system representation of the MMWD water system including current infrastructure and potential future projects

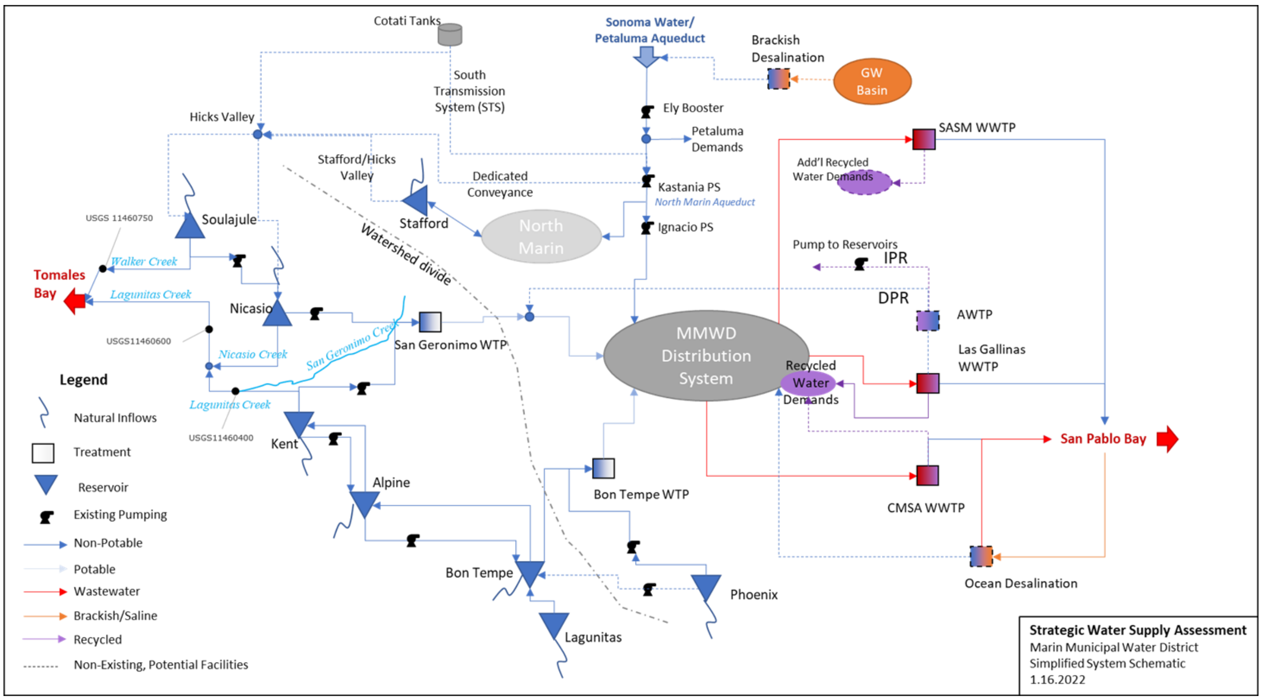


Figure 3 shows the system's reservoirs, water/wastewater treatment plants, potential facilities, and type of water supplied to MMWD's distribution system. Natural inflows into the reservoirs are from precipitation. Imported water comes from the Russian River delivered by the Sonoma Water via the Petaluma Aqueduct. Potential future inflows into the system can include new connections to the Sonoma aqueduct or ocean (brackish desalination). In this study, it is assumed that once the water is treated in one of the three treatment plants, it can reach all the District's system via MMWD distribution system. This assumption is consistent with the goals of this study, which is concerned about the availability of water supplies to meet system demands during drought events.

5.2 Model Inputs

The current MMWD system relies on surface and imported water to supply its customers. The main model input to MarinDSM are local reservoir and Russian River inflows. MMWD reservoir inflows and reservoir capacity determine how much local supply is available and can dictate how much imported water is needed. The Russian River inflows determine the amount of imported water that is available to MMWD as imported water.

Russian River inflows are available from October 1910 to September 2017 in a daily time step based on USGS's Basin Characterization Model (BCM) (USGS 2022) and extended to 2022 by correlation (past years between 1910 and 2017 were repeated after 2017 based on similar years).

MMWD reservoir inflows are available from October 1927 to December of 2021 in a monthly time step. The DSM accounts for all the latest inflow data to reservoirs that is available and was provided by MMWD, from October 1927 to December 2021.

For consistent time window analysis and to fill up the gap between 1910 to 1927 in the MMWD reservoir inflows, the MMWD reservoir inflows were correlated to Russian River Inflows between 1910 and 1927, when Russian River flows are available but MMWD's inflows are not. Appendix B shows details on the correlation of flows between two Russian River stations and total MMWD reservoir inflows. The established correlation allows MMWD reservoir inflows to be extended (now from 1910 to 2022) and allows the use of range of climate inflow scenarios available for the Russian River to be applied to the MMWD reservoirs.

The model used a fixed monthly evaporation rate (mm/month) lookup table for the MMWD reservoirs. The evaporation rates were obtained from the same logic implemented in the WaterSim model simulation (RMC 2017). Each reservoir has its own monthly average evaporation rate (mm/month), the final daily evaporation is obtained by the product of the monthly evaporation rate and the current storage area of the reservoirs. Annual total evaporation from reservoirs in the MMWD area can vary from less than 1,500 AFY to a little over 4,000 AFY due to reservoir water surface area variations.

Another main model input is the system demand. The system demand will drive the use of multiple water supplies in the system, indicating the usage of different sources and potential shortages under different hydrological and demand scenarios. System demands are the actual system deliveries for past years and mainly demands estimated by the multiple agencies Urban Water Management Plans (UWMP). Demands can be adjusted in the model depending on the scenario that the user wants to run.

The gap between supplies and demands plus MMWD reservoir levels are captured in model metrics. Potential shortages or drop in reservoir levels below certain thresholds will trigger the need for water supply projects. Water supply projects will also be tested in the model and their ability to reduce potential shortages or drops in storage levels will be evaluated.

5.3 System Operation

The logic in the system operation to meet water demands is described in more detail under Appendix B – System Model Description. The main steps to meet system demands are described under this section, these are:

- Determine system demands
- Activate and choose the order of priority that different supplies will be used to meet demands
- Adjust system assumptions related to infrastructure capacity and availability of projects

The general system operates by providing supplies to the system demands at every daily time step. The MarinDSM demand inputs are based on annual demand projections but can vary depending on the scenario run by the model. Besides the initial annual projection input for demands based on growth, the model adjusts demands based on potential conservation schedules and Shortage Allocation Levels policy (WSAL). The WSAL assumes conservation levels as a function of April first storage levels in the system and is described under Appendix B. This logic tries to capture the fact that the community reduces water usage during years that the region or even the State faces serious water shortages. The WSAL is a user input, meaning that can be turned on or off and values for conservation can be adjusted according to storage levels.

Different supplies are available for each one of the Sonoma Contractors plus MMWD (e.g Imported water, groundwater, recycled water, desalination if available). Water supplies available to MMWD include local surface storage from seven reservoirs, imported water, and reuse water .

Each supply has a priority to be used in fulfilling demands. The priority is a user specified input and cannot be changed in the middle of a simulation except if programed to do so in some specific cases. For example, MMWD in a calibration model run gives priority to receive local supply from its reservoirs over imported water, however that priority flips if MMWD reservoirs drop below a certain threshold storage value.

Imported supplies are limited by pipes and pump stations that convey imported water from Russian River to Ignacio Pumping plant. In general, there is enough capacity in the Sonoma Water transmission lines to supply Petaluma, North Marin, and MMWD Districts' contractual amounts from the Sonoma Water collectors all the way to Ely booster. From Ely booster to Ignacio Pump station the system can be limited by conveyance capacity and share of conveyance capacity with Petaluma and North Marin demands. The conveyance capacities can be adjusted in the MarinDSM to account for different scenario assumptions.

Local supplies are limited by the volume available in storage, ability to pump from storage to the two existing water treatment facilities (Bon Tempe and San Geronimo), and the treatment capacity of the treatment plants.

The recycled water supplies are assumed to be delivered all years and therefore the total demands are subtracted by the recycled water supplies (that equals to the demands). There is an exception to potential Direct Potable or Indirect Potable water projects, which can be connected to MMWD reservoirs or directly to the distribution system.

Desalination supplies are utilized up to the maximum capacity. Due to potential conflict with other supplies, depending on the user preference of when desalination is used, the maximum capacity might not match the amount that is needed in the system, if that's the case, model outputs should be checked for "unused" desalination flows. To avoid this operation, it is preferable to give desalination higher priority than any other source if desalination supplies are included in a simulation.

5.4 Model Validation

The goal of this study was to evaluate the overall system supply conditions assuming that water treatment capacities and ability to use storage were being reasonably used to avoid system shortages and minimize imported water usage. Therefore, an overall storage comparison (model versus historical) and annual imported water comparison (model versus historical) were important to achieve trust in model results. Other model comparisons presented under Appendix B were also important for overall model verification of results and assurance that reservoir inflows were not being over or underestimated.

The model validation consists in comparing model results (flows and storage volumes) to available time series of measured historical flows and system storages. This comparison indicates how well the system is being represented by model equations. This section presents the most important validation comparisons and Appendix B presents more details of the model validation.

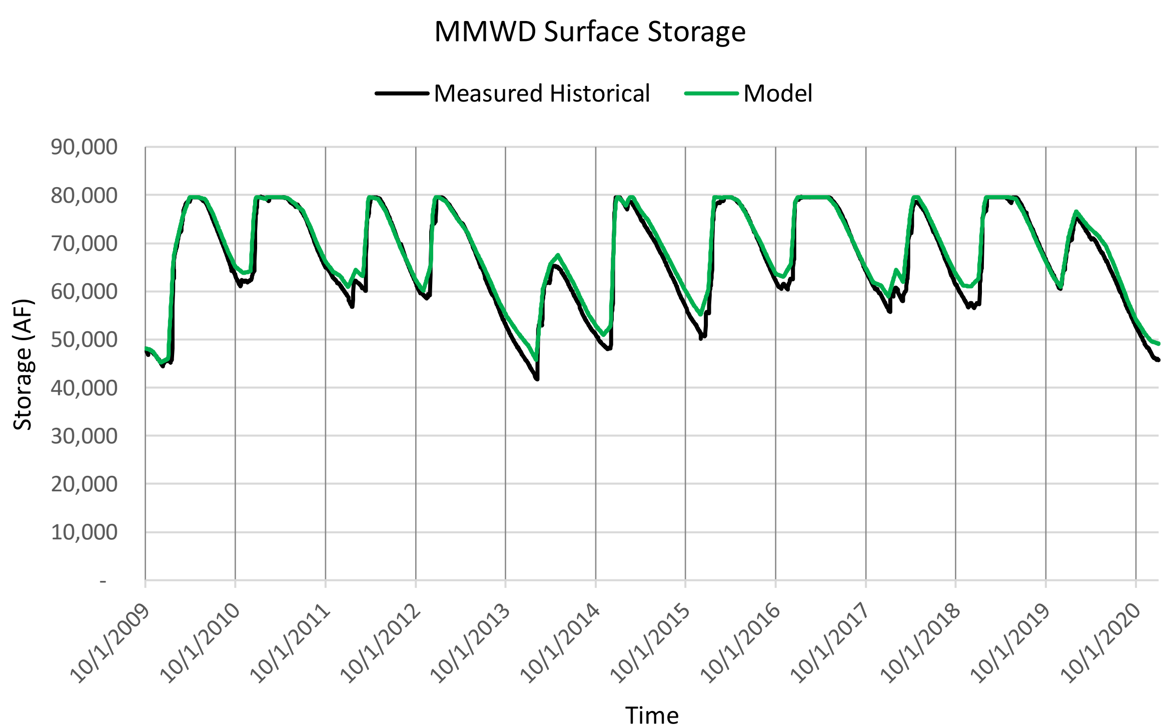
The model validation period chosen was from October 2009 to December 2020. This time window was chosen because actual MMWD system demands and historical reservoir inflows were available as time series and could be used as inputs to the model . Fixing reservoir releases to historical values would account for or reduce potential errors in the operation of the system. The reservoir releases followed model logic to meet system demands.

A previous version of the MarinDSM, (version developed for Sonoma Water with minimal MMWD representation), had its validation done with the comparison of Lake Sonoma and Lake Mendocino storages, Russian River diversion at the collectors, and deliveries to Sonoma water contractors and MMWD. An exact match with historical operations was challenging given that the operation of storage for supply releases and environmental purposes is not always consistent and not easily translated in a set of rules that reflect all nuances of operation. Despite the challenges, the MarinDSM model offered good matching between model results and measured data validating the Russian River operations with adequate accuracy and general operation needed for the model goals.

The main measured historical datasets available for the MarinDSM model validation were individual reservoir storage for MMWD's seven reservoirs, and historical imported water volumes. MMWD historical storage and historical imported water volumes are presented in this section, other measured historical timeseries comparisons for model validation like water treatment and Lagunitas creek flow comparisons are presented under Appendix B.

Figure 4 shows the comparison of total MMWD system storage between MarinDSM and measured values. It is noteworthy mention that MarinDSM can use the latest bathymetric information available from 2017, which states that the maximum system storage is 78,384 AF, but can also use the historical maximum storage pre 2017 survey, which estimated maximum storage at 79,566 AF. The model validation was executed with pre-2017 survey capacity so that model storage could be compared against historical storage data. Model presented excellent correlation between historical and modeled MMWD storage (R-squared coefficient of 0.97) with good representation of storage filling (as a function of time series inputs) and storage releases (as a function of model rules to provide flows to demands, environmental requirements, and spills). The strong comparison between total model versus historical storage, including the good replication of the most recent 2020 drought period, indicates that the rules programmed in the MarinDSM capture the main system operation of the reservoirs, and that these rules could be tested under different reservoir inflow conditions. The model simulations extending beyond 2022 use the most current 2017 storage capacity values.

Figure 4. MMWD total storage comparison between model results and measured storage for model validation period

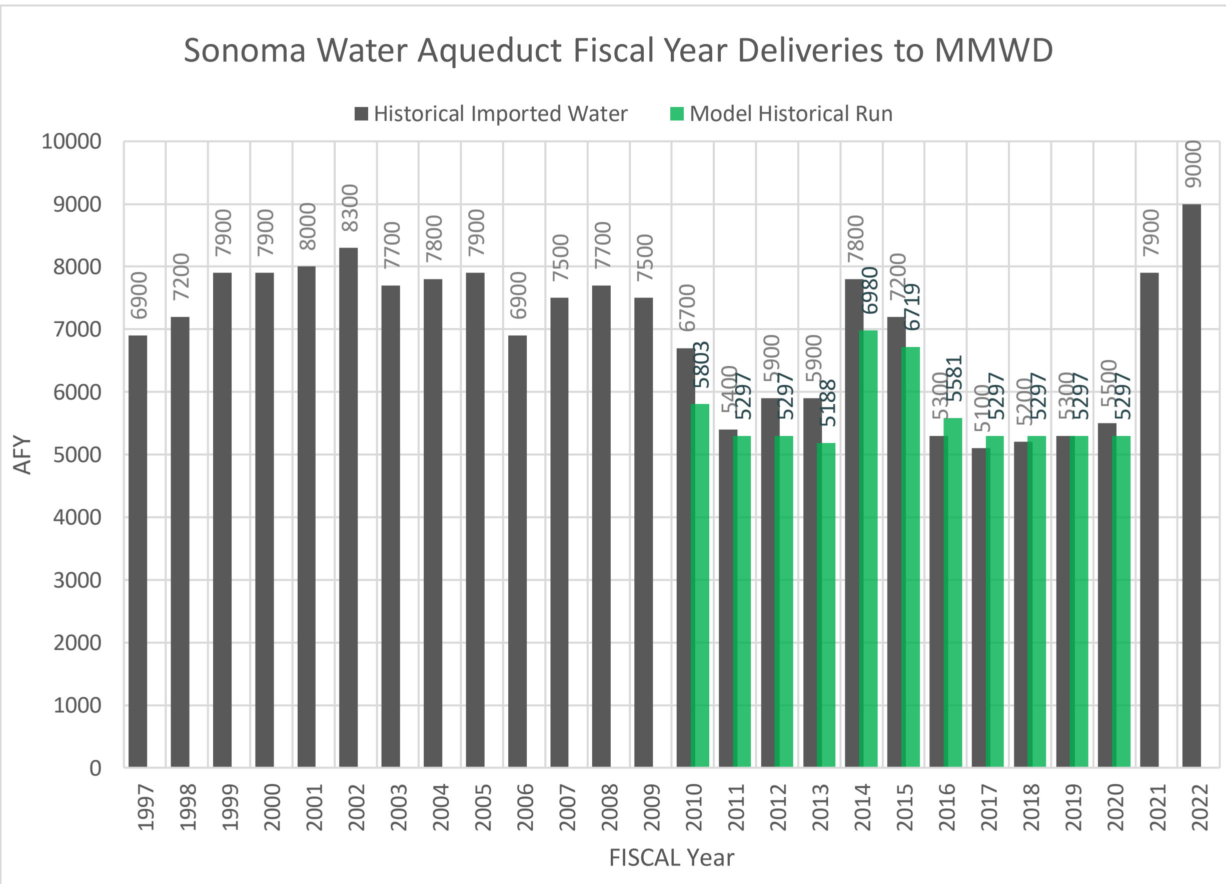


Historical MMWD imported water amounts were also available for fiscal years 1997 to 2022, however, MMWD actual demands were available only until December 2020 (incomplete fiscal year 2021 from July 2020 to June 2021). Figure 5 shows the comparison between the model estimates of imported water to MMWD versus actual imported water for the fiscal years that a comparison could be done. Although there wasn't a strict fixed historical rule followed by

MMWD to import water from Sonoma Water, the rules established by the Fourth Amended Offpeak Water Supply Agreement, 2015 included in the model, plus the general rule that MMWD will request additional imported water if MMWD's total surface storage drops below 55,000 AF, offer a good correlation with the historical imported water volumes. The 55,000 AF is an empirical rule based on past imported water patterns, MMWD requested more than the minimum take and pay mostly on years that MMWD's storage reach volumes below 55,000 AF. Currently the district does not have a written rule that specifies how much should be imported every year.

MMWD can currently import a maximum of 14,300 AFY and minimal 5,300 AFY (take or pay) from Sonoma Water based on current agreement (Fourth Amended Offpeak Water Supply Agreement, 2015).

Figure 5. Comparison of total historical MMWD's imported water versus MarinDSM estimates (Model Historical Run)



The same validation model runs were done substituting monthly measured inflows to MMWD reservoir with daily flows estimated from correlations with Russian River (inflows to MMWD reservoirs were determined as a function of Russian River flows) as a validation test. Similar results were obtained for storage and flows at Lagunitas creek with a slightly underestimation of inflows in some years. This comparison, presented in Appendix B validates the use of correlated flows for MMWD's reservoirs when measured flows are not available, and for model runs that use flows estimated from climate models.

SECTION 6

Drought Scenarios

Drought scenarios were developed as part of the study to test the MMWD system response under different potential future reservoir inflow conditions, demand variations, and operational challenges. A total of four scenarios were developed to help understand plausible future conditions under a range of hydrological conditions. A summary of the drought scenarios and the hydroclimate, demand, and operational assumptions are presented in Table 2.

Table 2. Summary of Model Scenarios

Scenario	Hydroclimate Assumptions	Demand Assumptions	Operational Assumptions
Scenario 1 – Current Trends	Historical observed	Passive-level savings; drought conservation per WSCP	Current operations; local supply preference; supplemental water with Kastania Pump Station rehabilitation
Scenario 2 – Short and Severe Drought	Severe 4-Yr drought (2020, 2021, 1976, 1977)	Passive-level savings; drought conservation per WSCP	Current operations; local supply preference; supplemental water with Kastania Pump Station rehabilitation
Scenario 3 – Beyond Drought of Record	Long-range, extended 6- or 7-Yr drought (based on climate change projections)	Passive-level savings; drought conservation per WSCP	Current operations; local supply preference; supplemental water with Kastania Pump Station rehabilitation
Scenario 4 – Abrupt Disruptions	Severe 2-Yr (2020, 2021) or 4-Yr drought (2020, 2021, 1976, 1977); high wildfire likelihood	Passive-level savings; drought conservation per WSCP	Operational disruptions due to post-wildfire sediment loads; Treatments plants at reduced capacity (Bon Tempe offline & San Geronimo @ 50% operating capacity for 6 months)

6.1 Water Demands

All scenarios assume MMWD future water demands consistent with those presented the 2020 Urban Water Management Plan (UWMP) with updates to reflect the Regional Housing Needs Assessment (RHNA) growth projections. These water demand projections include passive level water savings consistent with UWMP assumptions. The demands used in the SWSA are shown in Table 3. The annual demand is estimated to be 25,707 AF in 2022 and increases to 29,140 AF in 2045. Historical environmental demands averaged 10,543 AFY between 2016 and 2020.

In addition, all scenarios include implementation of the Water Shortage Contingency Plan conservation actions up to Stage 3 restrictions. Stage 1 (10% drought conservation) is triggered when April storage falls below 70,000 AF, Stage 2 (20% drought conservation) is triggered when storage falls below 65,000 AF, and Stage 3 (30% drought conservation) is triggered when storage falls below 55,000 AF. The analysis included in this assessment assumes that a maximum of 25% conservation could be achieved at the Stage 3 level based on recent experience in 2021.

Table 3. MMWD potable demands based on passive-level savings (AFY)

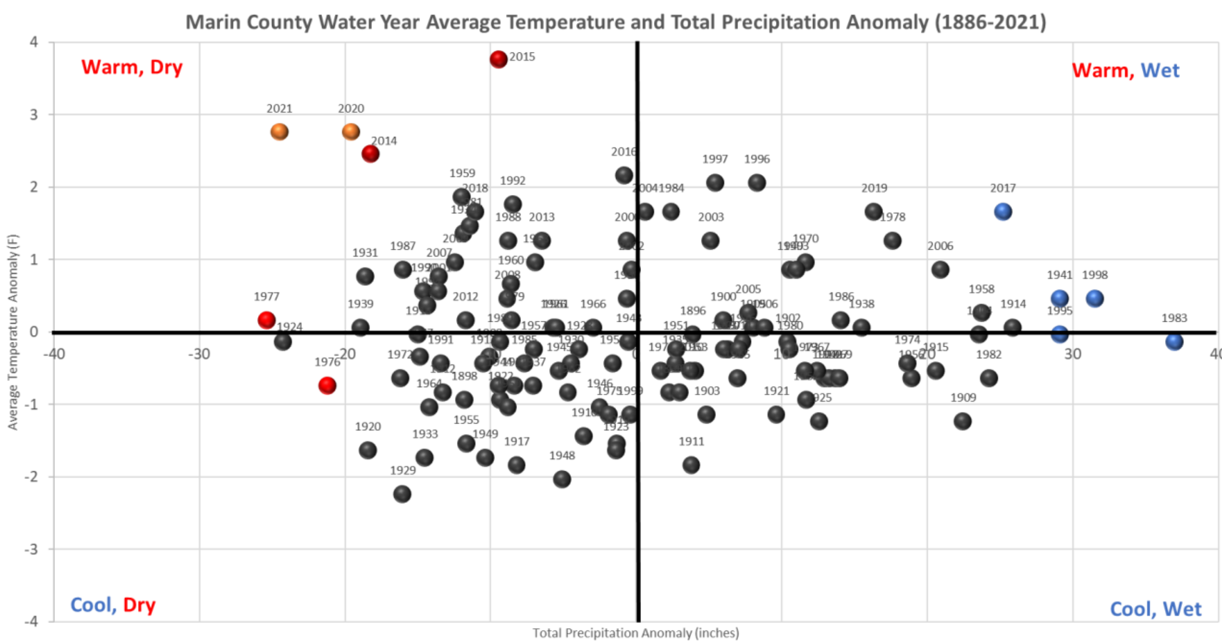
Calendar Year	MMWD Demands	Calendar Year	MMWD Demands
2022	25,707	2034	28,870
2023	26,194	2035	28,902
2024	26,681	2036	28,915
2025	27,168	2037	28,928
2026	27,483	2038	28,941
2027	27,798	2039	28,954
2028	28,113	2040	28,967
2029	28,428	2041	29,002
2030	28,743	2042	29,036
2031	28,775	2043	29,071
2032	28,807	2044	29,105
2033	28,838	2045	29,140

6.2 Hydroclimate

As part of the development of scenarios, an assessment of historical and future drought conditions was conducted. Historical climate and flow data for the Marin and Russian River watersheds were collected and evaluated. Data sources include historical observed temperature, precipitation, and streamflow.

Figure 6 shows the temperature and precipitation anomaly (difference from long-term mean) for Marin County for 1886-2021 using data from National Climate Data Center (NCDC). The figures shows the data in four quadrants to reflect warm-dry, warm-wet, cool-dry, and cool-wet conditions. Each point on the graph represents one year. Highlighted in red, yellow, and blue on Figure 6 are representative dry and wet years from the historical record. The driest years in the historical record are 1976-1977 and 2020-2021. The wettest years in the record are 1983 and 1998.

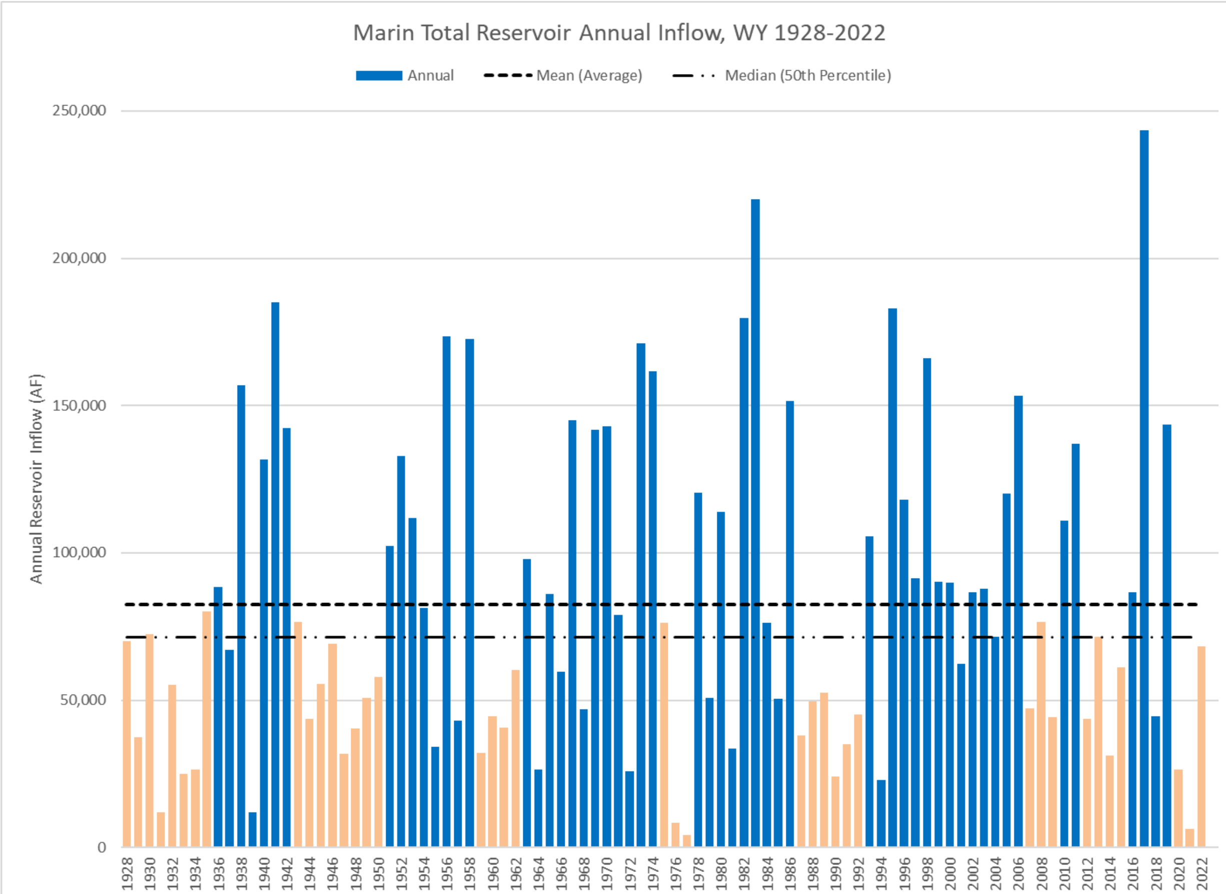
Figure 6. Marin County historical annual temperature and precipitation anomalies



In reviewing streamflow and drought trends, long-term records of the Marin reservoir inflow and Russian River natural flow were used to assess droughts of significance. Annual flow data for Marin total reservoir inflow for water years 1928 – 2022, and Russian River naturalized flow for water years 1911-2022 were evaluated.

Figure 7 shows the total MMWD historical reservoir inflows from water years 1928 through 2022. The inflows are represented by high inter-annual variability with annual flows as low as 4,133 AF in 1977 and as high as 243,371 in 2017. The recent drought period included years with inflows of 26,555 in water year 2020, 6,309 in 2021, and 68,353 AF in 2022. The water year of 2020 was the fifteenth driest water year on record with 26,558 AF of reservoir inflows.

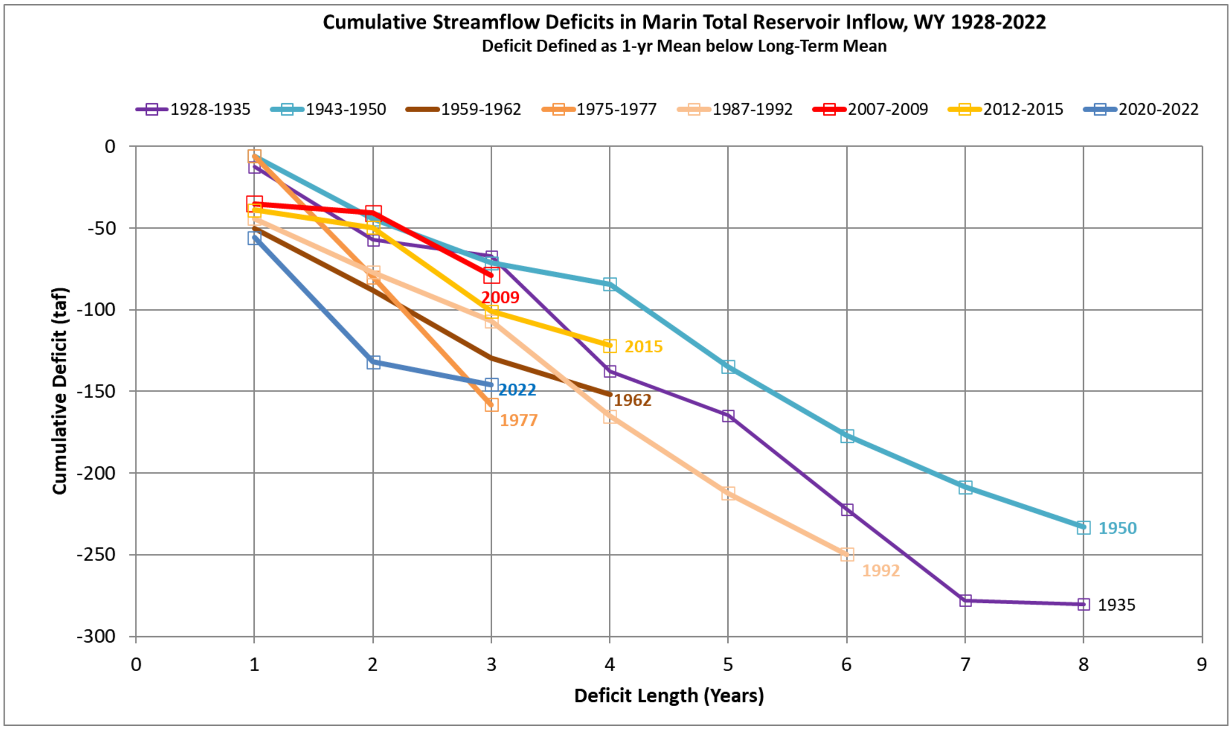
Figure 7. Marin Reservoir total annual inflows, WY 1928-2022

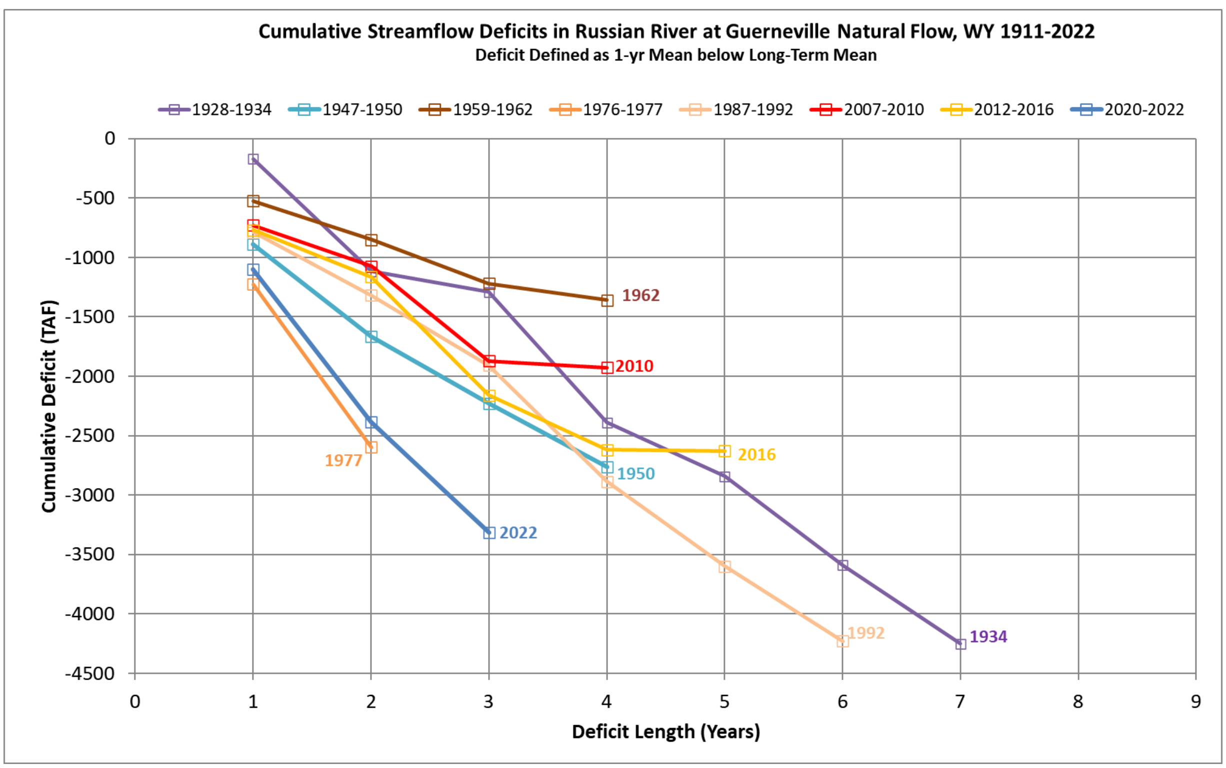


For a more illustrative analysis of extended dry periods, droughts were assessed as any sequence in which annual flows were lower than the period mean. Drought length and deficits were computed as the number of years in which low flow persisted and the amount of cumulative flow deficit. The results of this assessment are shown in Figure 8 and indicate the most significant droughts over the historical period. Short, severe 2-year droughts are observed for 1976-1977 and 2020-2021. Less severe, but longer persistent droughts are observed for 1928-1935, 1943-1950, 1987-1992, and 2012-2016.

In order to provide for consistent hydrological time periods between Marin and the Russian River systems, the Marin reservoir inflow data set was extended to include 1911-1927 based on a correlation to Russian River at Guerneville flow information. The correlation coefficient, R-squared, between the annual flows in these two systems is greater 0.9 suggesting a very high correlation.

Figure 8. Cumulative streamflow deficits in observed natural flow records (Marin watersheds and Russian River)





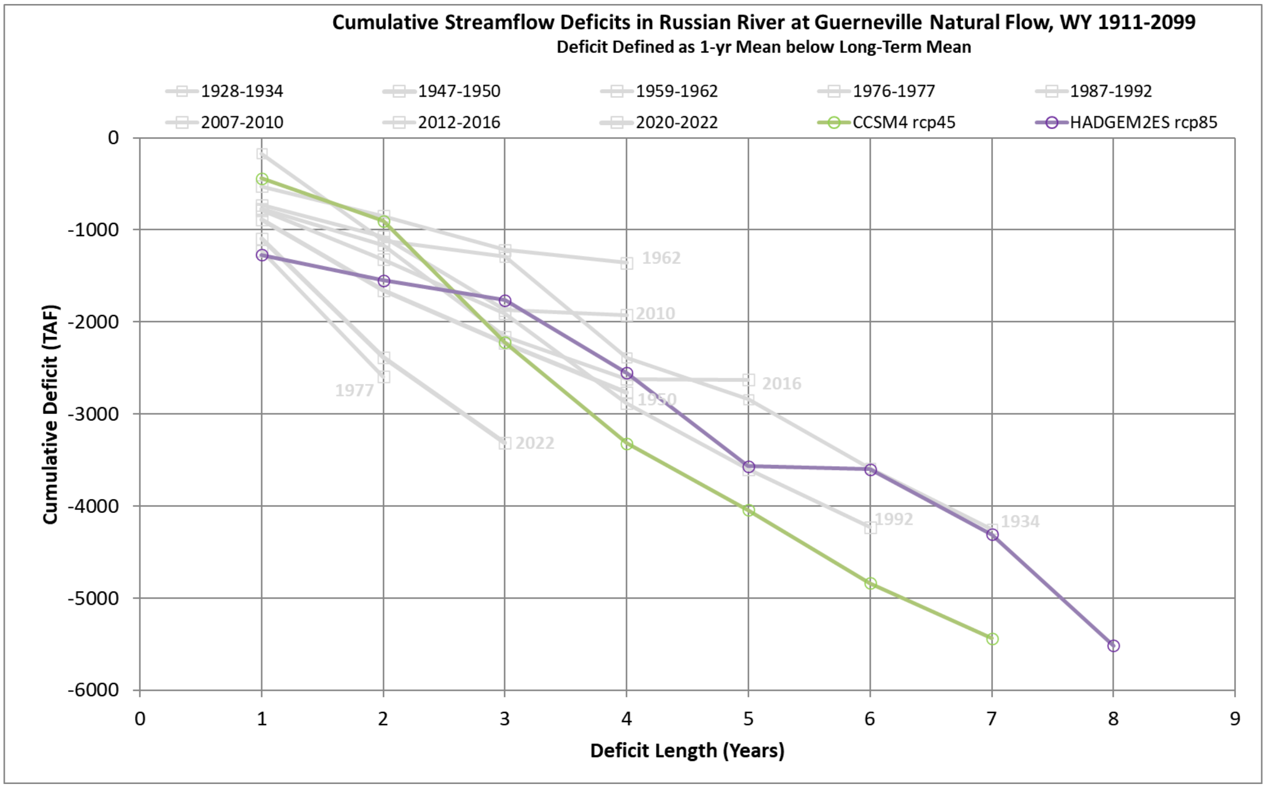
Projections of future climate conditions are generally performed through global climate models (GCMs) forced with specific global greenhouse gas (GHG) emission scenarios (IPCC 2013). The projections included in this analysis rely upon available climate projections using the models and emissions scenarios included in the Coupled Model Intercomparison Project 5 (CMIP5). Twenty individual downscaled GCM projections were selected from ten different GCMs and two different Representative Concentration Pathways (RCPs), RCP4.5 and RCP8.5. The ten GCMs were chosen by the DWR Climate Change Technical Advisory Group (CCTAG) based on a regional evaluation of climate model ability to reproduce a range of historical climate conditions (DWR CCTAG, 2015). The 20 climate projections were downscaled to approximately 6 km (3.75 miles) spatial resolution by Scripps Institution of Oceanography (Pierce et al., 2014) and subsequently further downscaled to a 270-meter resolution by the USGS as part of the Basin Characterization Model (BCM) data set. These projections are consistent with those used in climate applications for the Russian River watershed conducted by Sonoma Water, and were used to develop a consistent hydrological data set for the both the Russian River and Marin watersheds. The individual GCMs and RCPs are shown in Table 4.

Table *4.* MMWD demands based on passive-level savings (AFY)

GCM	**RCP 4.5**	**RCP 8.5**
ACCESS1-0	X	X
CCSM4	X	X
CESM1-BGC	X	X
HadGEM2-CC	X	X
CMCC-CMS	X	X
CNRM-CM5	X	X
CanESM2	X	X
GFDL-CM3	X	X
HadGEM2-ES	X	X
MIROC5	X	X

The 20 climate projections were evaluated to determine whether climate models suggest more extreme droughts in the future. Using the 20 individual CMIP5 climate projections, two projections were assessed to have important droughts for consideration as shown in Figure 8. The HadGemES (RCP 8.5) and CCM4 (RCP 4.5) model projections indicate droughts of 7- to 8-year durations similar to the 1987-1992 historical drought are possible and may challenge water management. However, the climate model projections did not indicate greater severity of shorter duration droughts as compared to the most severe historical droughts of 1976-1977 and 2020-2022. While not found in this set of climate projections, it should be noted that climate models are not robust in capturing inter-annual variability changes, and more severe droughts in this region cannot be ruled out.

Figure 9. Cumulative streamflow deficits in observed and projected future natural flows



Based on this assessment, a review of statewide and regional hydroclimatic information, and through discussions with MMWD staff, four scenarios were developed to test the MMWD system response to extreme drought conditions. These scenarios are described in the following sections.

6.3 Water Supply Deficit

One key factor in determining the performance of MMWD's system under a range of future water supply and demand conditions is the water supply "deficit". For the purposes of this assessment, the deficit is made up of two components: (1) MMWD reservoir storage below 30,000 AF and (2) shortages in delivering water to MMWD demands. Either of these two conditions suggest poor system performance related to the water supply goal. The deficit is calculated during a drought as the volume of water in storage below 30,000 AF plus the cumulative delivery shortage that may have occurred during the same drought. In order to characterize the deficit as an annual amount, the total cumulative deficit is divided by the drought length.

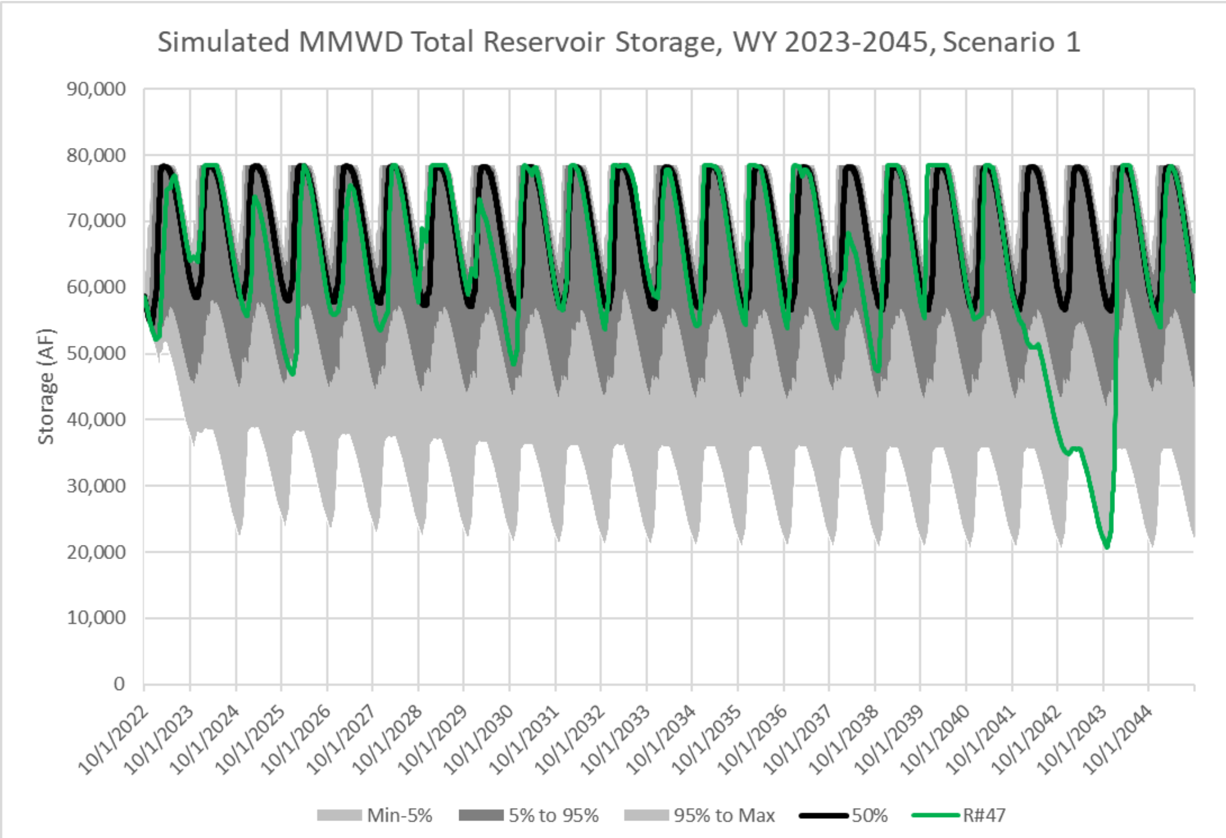
For example, a 4-year drought that results in low point reservoir storage of 20,000 AF and a cumulative shortage of 2,000 AF would be expressed as 3,000 AFY of annual deficit (10,000 storage deficit plus 2,000 shortage deficit, divided by 4 years). In this sense, the annual deficit can be thought of as the amount of additional supply that, if provided each year during the drought period, would have allowed the system performance (storage and delivery) to be satisfied. While the annual deficit is useful in characterizing the magnitude of the challenge, it is important that water management alternatives that seek to address the deficit are adequately evaluated in the integrated MMWD water system and operations.

6.4 Scenario 1 – Current Trends

Scenario 1 is based on current trends in that it assumes historical hydrology and current operations. The future simulation spans the period of October 1, 2022 to September 30, 2045 (water years 2023-2045) with future water demands and WSCP stage 3 conservation actions as presented in the preceding section. Model simulations use September 30, 2022 actual storage conditions for initial MMWD reservoir storage (58,672 AF). Under scenario 1, the system utilizes the historical hydrological sequences to simulate the future period of 2023 to 2045. For example, the first realization will utilize the hydrological sequence and inflows from 1911 to 1933 to represent the future period, the second realization 1912 to 1934, and so on. A total of 112 realizations are simulated to ensure that all historical sequences are sampled. Sequences that utilize the last year of the historical inflow data (e.g. 2021) are followed by a wrap-around to the water year 1911 conditions. This index-sequential technique is commonly applied a water resource simulations for drought analysis.

Results for total MMWD reservoir storage from the stochastic simulations are shown in Figure 10. The figure shows the minimum, maximum, median, and 5th to 95th percentile range of storage results. As indicated in the figure, over 95 percent of the years result in minimum storage conditions above 45,000 AF. Less than 2% of the realizations (drought sequences such as realization #47 in the figure) resulted in storage lower 30,000 AF. At the same time, the simulation suggests that WSCP stage 3 restrictions would be triggered approximately 4% of the years. The lowest simulated storage for scenario 1 is 20,521 AF in November 2045. The greatest water supply deficit over the 2-year drought period is 10,200 AF, or 5,100 AFY when averaged over the period of the drought.

Figure 10. Scenario 1 stochastic results for MMWD total reservoir storage



These most severe outcomes occur when the drought sequence occurs toward the end of the simulation period with greatest water demands (green line in Figure 10). This realization results in the lowest storage outcome and highest water supply deficits. In order to focus on this particular realization more closely, water budget and storage results from this sequence are presented in Table 5. The table shows the simulation year, selected historical reference hydrology year, reservoir inflows, evaporation, spills, environmental releases, reservoir releases, Sonoma Water imports, and end of water year storage. As can be seen in the table, this realization is challenging in that the 1976-1977 drought occurs when demands are high. While reservoir storage falls below the 30,000 AF criteria, relatively small shortages occur. However, in some years and at specific reservoirs, the storage conditions are such that the environmental releases are not possible to fully meet the downstream requirements. These are shown in the table as unmet environmental demands.

Table *5.* Water Budget Summary for one realization (#47) for Scenario 1

Simulation Year	Hydrology Year	Lagunitas Rainfall	Reservoir Inflow	Reservoir Evaporation	Reservoir Spills	Env. Demand	Env. Releases	Waterer Demand	Adjusted Water Demand	Reservoir Deliveries	Sonoma Water Imports	Recycled Water	Total Deliveries	EOY Reservoir Storage	Shortage	Unmet Env. Demands
WY	WY	IN	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF
2023	1957	44.1	43,168	3,956	4,922	10,771	10,771	26,085	26,085	18,139	7,196	750	26,085	64,052	0	-
2024	1958	82.0	175,300	4,043	144,282	7,956	7,956	26,572	26,572	20,824	4,997	750	26,572	62,247	0	-
2025	1959	33.6	32,152	3,739	5,871	11,257	11,257	27,059	27,059	20,965	5,344	750	27,059	52,567	0	-
2026	1960	39.9	43,718	3,845	4,239	10,461	10,461	27,412	27,412	18,726	7,936	750	27,412	59,014	0	-
2027	1961	35.2	40,755	3,860	7,891	8,857	8,857	27,727	27,727	21,678	5,299	750	27,727	57,483	0	-
2028	1962	46.6	61,633	3,865	26,788	9,919	9,919	28,042	28,042	20,782	6,510	750	28,042	57,761	0	-
2029	1963	64.3	98,036	4,045	59,871	7,755	7,755	28,357	28,357	22,308	5,299	750	28,357	61,818	0	-
2030	1964	33.6	26,434	3,679	2,116	10,962	10,962	28,672	26,956	20,907	5,299	750	26,956	50,588	0	-
2031	1965	58.6	86,059	3,941	42,723	9,250	9,250	28,768	27,609	20,728	6,131	750	27,609	60,005	0	-
2032	1966	43.9	60,246	3,855	26,789	10,477	10,477	28,799	28,799	22,750	5,299	750	28,799	56,380	0	-
2033	1967	78.0	144,912	4,028	103,003	8,608	8,608	28,831	28,831	22,358	5,724	750	28,831	63,295	0	-
2034	1968	37.7	46,237	3,846	17,784	9,070	9,070	28,863	28,863	22,814	5,299	750	28,863	56,018	0	-
2035	1969	76.5	141,843	3,922	104,994	8,639	8,639	28,895	28,895	21,807	6,338	750	28,895	58,499	0	-
2036	1970	65.5	143,354	3,872	109,727	9,567	9,567	28,912	28,912	22,541	5,621	750	28,912	56,145	0	-
2037	1971	49.6	79,013	3,931	40,536	10,156	10,156	28,925	28,925	22,459	5,716	750	28,925	58,074	0	-
2038	1972	30.2	25,631	3,548	988	10,667	10,667	28,938	27,210	20,600	5,860	750	27,210	47,902	0	-
2039	1973	72.5	171,077	3,887	127,263	8,891	8,891	28,951	27,784	21,191	5,844	750	27,784	57,747	0	-
2040	1974	76.6	161,876	4,002	125,029	7,569	7,569	28,964	28,964	22,915	5,299	750	28,964	60,108	0	-
2041	1975	47.7	76,378	3,901	40,879	9,699	9,699	28,994	28,994	22,945	5,299	750	28,994	59,063	0	-
2042	1976	24.7	8,388	2,941	227	10,984	10,860	29,028	24,695	15,069	8,876	750	24,695	38,353	0	124
2043	1977	25.3	4,132	1,984	111	6,627	5,369	29,063	21,797	12,899	7,989	750	21,637	22,123	160	1,258
2044	1978	65.8	121,455	3,723	54,308	7,275	7,161	29,098	26,167	18,170	6,721	750	25,642	60,214	525	114
2045	1979	43.7	50,669	3,902	15,717	9,529	9,529	29,132	29,132	22,417	5,966	750	29,132	59,318	0	-

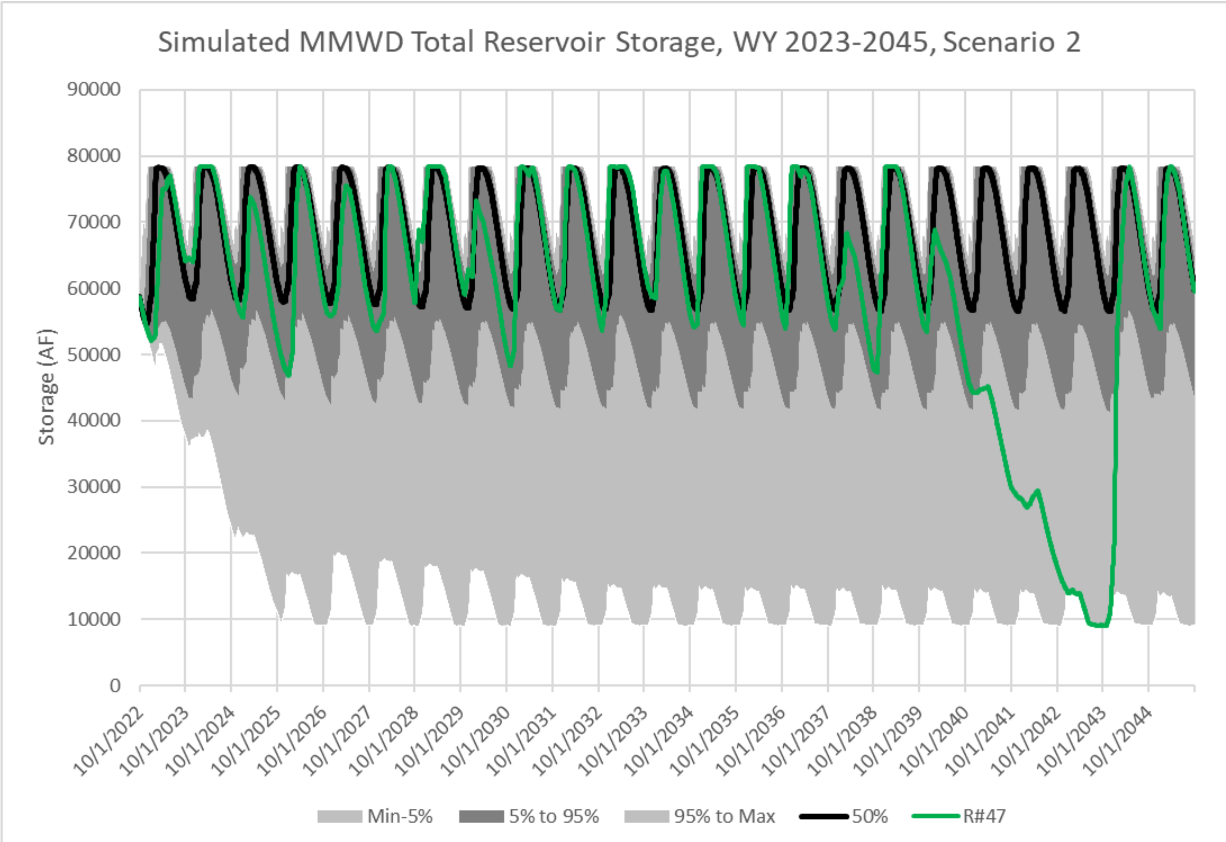
6.5 Scenario 2 – Short and Severe Drought

Scenario 2 was developed to test the MMWD system with a synthetic drought that is more severe than that observed in the historical records or indicated in the future climate projections. A synthetic four-year drought was developed by grouping the two most severe historical dry historical periods: the most recent 2020-2021 drought and the 1976-1977 drought. The total inflows for the four years equal to 45,425 AF or an average of 11,356 AFY.

Stochastic simulations were conducted to evaluate the effects of this 4-year drought sequence occurring at differing times within the future 2023-2045 period and with differing preceding and subsequent hydrologic conditions. A total of 112 different realizations were simulated to capture this uncertainty.

Results for total MMWD reservoir storage from the stochastic simulations are shown in Figure 11. The figure shows the minimum, maximum, median, and 5th to 95th percentile range of storage results. As indicated in the figure, over 95 percent of the years result in minimum storage conditions above 40,000 AF. Less than 3% of the realizations (drought sequences such as realization #47 in the figure) resulted in storage lower 30,000 AF. At the same time, the simulation suggests that WSCP stage 3 restrictions would be triggered approximately 5% of the years. The lowest simulated storage for scenario 2 is 8,990 AF in November 2045. The greatest water supply deficit over the 4-year drought period is 34,016 AF, or 8,504 AFY when averaged over the period of the drought.

Figure 11. Stochastic results for MMWD total reservoir storage for Scenario 2



These most severe outcomes occur when the drought sequence occurs toward the end of the simulation period with greatest water demands (green line in Figure 11). This realization results in the lowest storage outcome and highest water supply deficits. In order to focus on this particular realization more closely, water budget and storage results from this sequence are presented in Table 5. The table shows the simulation year, selected historical reference hydrology year, reservoir inflows, evaporation, spills, environmental releases, reservoir releases, Sonoma Water imports, and end of water year storage. As can be seen in the table, this realization is challenging in that the 2020-2021-1976-1977 drought sequence occurs when demands are high at the end of the period. Unlike scenario 1, this scenario results in large deficits due to both storage criteria and shortages. As in scenario 1, in some years and at specific reservoirs, the storage conditions are such that the environmental releases are not possible to fully meet the downstream requirements. These are shown in the table as unmet environmental demands.

Table 5. Water Budget Summary for one realization (#47) for Scenario 2

Simulation Year	Hydrology Year	Lagunitas Rainfall	Reservoir Inflow	Reservoir Evaporation	Reservoir Spills	Env. Demand	Env. Releases	Waterer Demand	Adjusted Water Demand	Reservoir Deliveries	Sonoma Water Imports	Recycled Water Production	Total Deliveries	EOY Reservoir Storage	Shortage	Unmet Env. Demands
2023	1957	44.12	43,168	3,956	4,922	10,771	10,771	26,085	26,085	18,139	7,196	750	26,085	64,052	0	-
2024	1958	81.98	175,300	4,043	144,282	7,956	7,956	26,572	26,572	20,824	4,997	750	26,572	62,247	0	-
2025	1959	33.64	32,152	3,739	5,871	11,257	11,257	27,059	27,059	20,965	5,344	750	27,059	52,567	0	-
2026	1960	39.91	43,718	3,845	4,239	10,461	10,461	27,412	27,412	18,726	7,936	750	27,412	59,014	0	-
2027	1961	35.2	40,755	3,860	7,891	8,857	8,857	27,727	27,727	21,678	5,299	750	27,727	57,483	0	-
2028	1962	46.55	61,633	3,865	26,788	9,919	9,919	28,042	28,042	20,782	6,510	750	28,042	57,761	0	-
2029	1963	64.25	98,036	4,045	59,871	7,755	7,755	28,357	28,357	22,308	5,299	750	28,357	61,818	0	-
2030	1964	33.55	26,434	3,679	2,116	10,962	10,962	28,672	26,956	20,907	5,299	750	26,956	50,588	0	-
2031	1965	58.56	86,059	3,941	42,723	9,250	9,250	28,768	27,609	20,728	6,131	750	27,609	60,005	0	-
2032	1966	43.87	60,246	3,855	26,789	10,477	10,477	28,799	28,799	22,750	5,299	750	28,799	56,380	0	-
2033	1967	77.99	144,912	4,028	103,003	8,608	8,608	28,831	28,831	22,358	5,724	750	28,831	63,295	0	-
2034	1968	37.69	46,237	3,846	17,784	9,070	9,070	28,863	28,863	22,814	5,299	750	28,863	56,018	0	-
2035	1969	76.54	141,843	3,922	104,994	8,639	8,639	28,895	28,895	21,807	6,338	750	28,895	58,499	0	-
2036	1970	65.52	143,354	3,872	109,727	9,567	9,567	28,912	28,912	22,541	5,621	750	28,912	56,145	0	-
2037	1971	49.59	79,013	3,931	40,536	10,156	10,156	28,925	28,925	22,459	5,716	750	28,925	58,074	0	-
2038	1972	30.2	25,631	3,548	988	10,667	10,667	28,938	27,210	20,600	5,860	750	27,210	47,902	0	-
2039	1973	72.5	171,077	3,887	127,263	8,891	8,891	28,951	27,784	21,191	5,844	750	27,784	57,747	0	-
2040	2020	35.77	26,558	3,563	1,418	10,418	10,418	28,964	27,235	20,522	5,963	750	27,235	48,384	0	-
2041	2021	20.35	6,310	2,554	139	8,290	7,949	28,994	23,497	14,104	8,643	750	23,497	29,947	0	341
2042	1976	24.7	8,388	1,706	216	7,832	6,894	29,028	21,771	11,448	8,313	750	20,510	18,071	1261	938
2043	1977	25.28	4,132	1,008	111	6,627	4,057	29,063	21,797	7,929	3,291	750	12,065	9,098	9732	2,570
2044	1978	65.82	121,455	3,647	42,713	7,275	6,781	29,098	26,167	17,250	6,253	750	24,159	60,162	2008	494
2045	1979	43.66	50,669	3,902	15,686	9,527	9,527	29,132	29,132	22,396	5,986	750	29,132	59,319	0	-

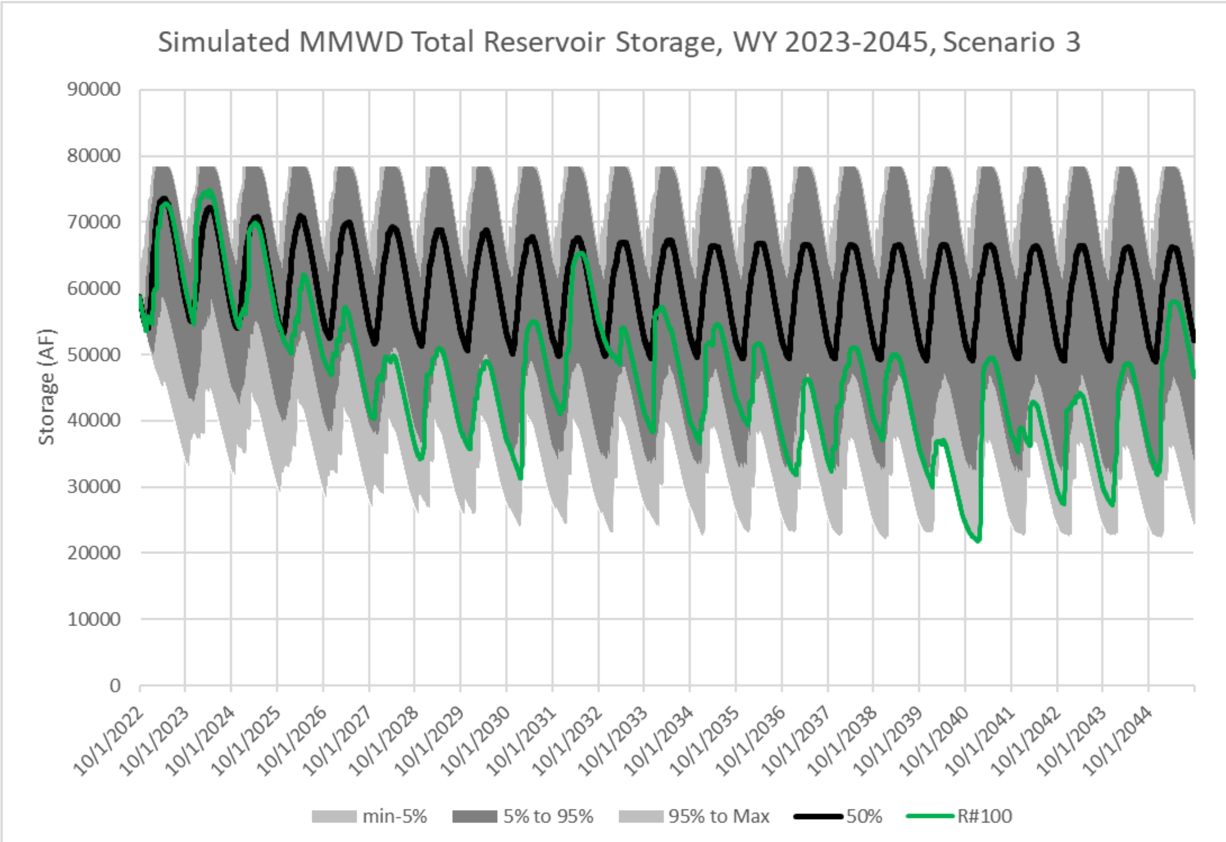
6.6 Scenario 3 – Beyond Drought of Record

Scenario 3 represents a future hydroclimatic condition based on the two most significant droughts indicated in the future climate projections: CCSM4 4.5 and HADGEM 2ES 8.5 climate projections. These two projections represent plausible, sustained droughts of 7 to 8 years as depicted by climate modeling.

Stochastic simulations were conducted to sample varying 23-year sequences from the HADGEM 2ES 8.5 climate projection and apply these hydrologic conditions for the future 2023-2045 simulation period. A total of 150 different sequences were sampled from the climate projection.

Results for total MMWD reservoir storage from the stochastic simulations are shown in Figure 12. The figure shows the minimum, maximum, median, and 5th to 95th percentile range of storage results. As indicated in the figure, no realizations resulted in storage below 30,000 AF before 2026. Less than 6% of the realizations (drought sequences such as realization #100 in the figure) resulted in storage lower 30,000 AF. However, this scenario presents a challenge of persistent moderate flow conditions that does not allow storage to fully fill for a period of years to a decade. This persistent moderate flow and non-recovery condition drives storage in the range of 30,000 to 50,000 AF and could lead to persistent WSCP restrictions. The simulation suggests that WSCP stage 3 restrictions would be triggered approximately 20% of the years. The lowest simulated storage for Scenario 3 is 21,971 AF AF. This scenario includes a 2-year drought within a decade of moderate-low flow conditions. The greatest water supply deficit is found in this 2-year period and results in 8,326 AF, or 4,163 AFY deficit when averaged over the period of the drought.

Figure 12. Stochastic results for MMWD total reservoir storage for Scenario 3



These most severe outcomes occur when the drought sequence occurs toward the end of the simulation period with greatest water demands (green line in Figure 12). This realization results in the lowest storage outcome and highest water supply deficits. In order to focus on this particular realization more closely, water budget and storage results from this sequence are presented in Table 6. The table shows the simulation year, selected historical reference hydrology year, reservoir inflows, evaporation, spills, environmental releases, reservoir releases, Sonoma Water imports, and end of water year storage. As can be seen in the table, this realization is challenging in that below average inflow occurs for the period of 2033 through 2040 and creates a gradual decline in storage and begins to produce some modest shortages. As in both Scenario 1 and 2, in some years and at specific reservoirs, the storage conditions are such that the environmental releases are not possible to fully meet the downstream requirements. These are shown in the table as unmet environmental demands.

Table 6. Water Budget Summary for one realization (#100) for Scenario 3

Simulation Year	Hydrology Year	Reservoir Inflow	Reservoir Evaporation	Reservoir Spills	Env. Demand	Env. Releases	Waterer Demand	Adjusted Water Demand	Reservoir Deliveries	Sonoma Water Imports	Recycled Water Production	Total Deliveries	EOY Reservoir Storage	Shortage	Unmet Env. Demands
2023	2050	78,713	3,955	40,669	13,271	13,271	26,085	26,085	19,505	5,830	750	26,085	59,984	0	-
2024	2051	84,244	3,945	48,307	12,943	12,943	26,572	26,572	20,480	5,342	750	26,572	58,553	0	-
2025	2052	60,073	3,845	27,625	13,224	13,224	27,059	25,437	18,766	5,920	750	25,437	55,166	0	-
2026	2053	25,802	3,613	910	13,638	13,638	27,412	23,030	13,344	8,936	750	23,030	49,463	0	-
2027	2054	24,590	3,383	2,722	14,339	14,339	27,727	22,182	11,990	9,442	750	22,182	41,618	0	-
2028	2055	26,197	3,193	3,134	14,485	14,485	28,042	21,595	10,703	10,141	750	21,595	36,300	0	-
2029	2056	48,428	3,266	19,558	13,117	13,117	28,357	21,268	10,333	10,115	750	21,198	38,454	70	-
2030	2057	38,383	3,238	13,450	13,239	13,239	28,672	21,504	9,839	10,916	750	21,504	37,070	0	-
2031	2058	108,674	3,391	73,900	12,662	12,662	28,768	21,576	11,591	9,235	750	21,576	44,200	0	-
2032	2059	148,792	3,728	108,527	11,987	11,987	28,799	22,459	13,569	8,141	750	22,459	55,181	0	-
2033	2060	14,782	3,287	453	13,126	13,126	28,831	22,204	11,744	9,710	750	22,204	41,353	0	-
2034	2061	54,146	3,287	24,155	13,746	13,746	28,863	22,509	14,393	7,366	750	22,509	39,919	0	-
2035	2062	59,887	3,378	29,570	12,978	12,978	28,895	22,253	10,455	10,623	750	21,828	43,424	426	-
2036	2063	34,274	3,248	11,654	13,906	13,906	28,912	21,684	11,469	9,465	750	21,684	37,420	0	-
2037	2064	28,382	3,078	3,946	13,112	13,112	28,925	21,694	11,716	8,998	750	21,463	33,950	231	-
2038	2065	72,834	3,313	40,064	13,226	13,226	28,938	21,704	10,055	10,854	750	21,659	40,127	45	-
2039	2066	40,339	3,219	17,384	13,399	13,399	28,951	21,713	10,708	10,256	750	21,713	35,757	0	-
2040	2067	17,070	2,668	532	12,972	12,763	28,964	21,723	12,338	8,286	750	21,375	24,525	349	209
2041	2068	79,567	3,140	41,284	12,872	10,159	28,994	21,745	11,470	8,580	750	20,800	38,039	946	2,713
2042	2069	21,459	2,972	1,680	13,424	13,424	29,028	21,771	11,771	9,250	750	21,771	29,652	0	-
2043	2070	48,709	3,001	20,948	13,715	13,201	29,063	21,797	11,159	9,591	750	21,500	30,053	297	514
2044	2071	68,993	3,167	37,180	12,673	10,834	29,098	21,823	11,746	9,327	750	21,823	36,118	0	1,839
2045	2072	116,048	3,466	75,882	12,127	12,127	29,132	22,719	14,219	7,750	750	22,719	46,473	0	-

6.7 Scenario 4 – Abrupt Disruptions

Scenario 4 includes similar assumptions to Scenario 2, but also explores the potential disruptions with the water supply system under a wildfire in the watershed. In this scenario, it is assumed that a wildfire (or similar disruption) causes a temporary inability to treat water due to water quality or physical disruptions for a 6-month period.

The scenario includes assumptions that during the 6-month disruption period the capacity of treated water production from San Geronimo and Bon Tempe would be reduced to 50% of historical production. As with Scenario 2, the disruption was implemented at the end of the simulation period from September 2044 to March 2045 to match the timing of highest system demands.

Results for total MMWD reservoir storage from the stochastic simulations are shown in Figure 13. The figure shows the minimum, maximum, median, and 5th to 95th percentile range of storage results. As indicated in the figure, over 95 percent of the years result in minimum storage conditions above 40,000 AF. Less than 3% of the realizations (drought sequences such as realization #47 in the figure) resulted in storage lower 30,000 AF. At the same time, the simulation suggests that WSCP stage 3 restrictions would be triggered approximately 5% of the years. The lowest simulated storage for scenario is 9,074 AF in November 2045. The greatest water supply deficit over the 4-year drought period is 37,589 AF, or 9,397 AFY when averaged over the period of the drought. Note that the increase in deficit between this scenario and Scenario 2 is due to the assumed reduced water treatment plant production capacity.

Figure 13. Stochastic results of MMWD total reservoir storage for Scenario 4

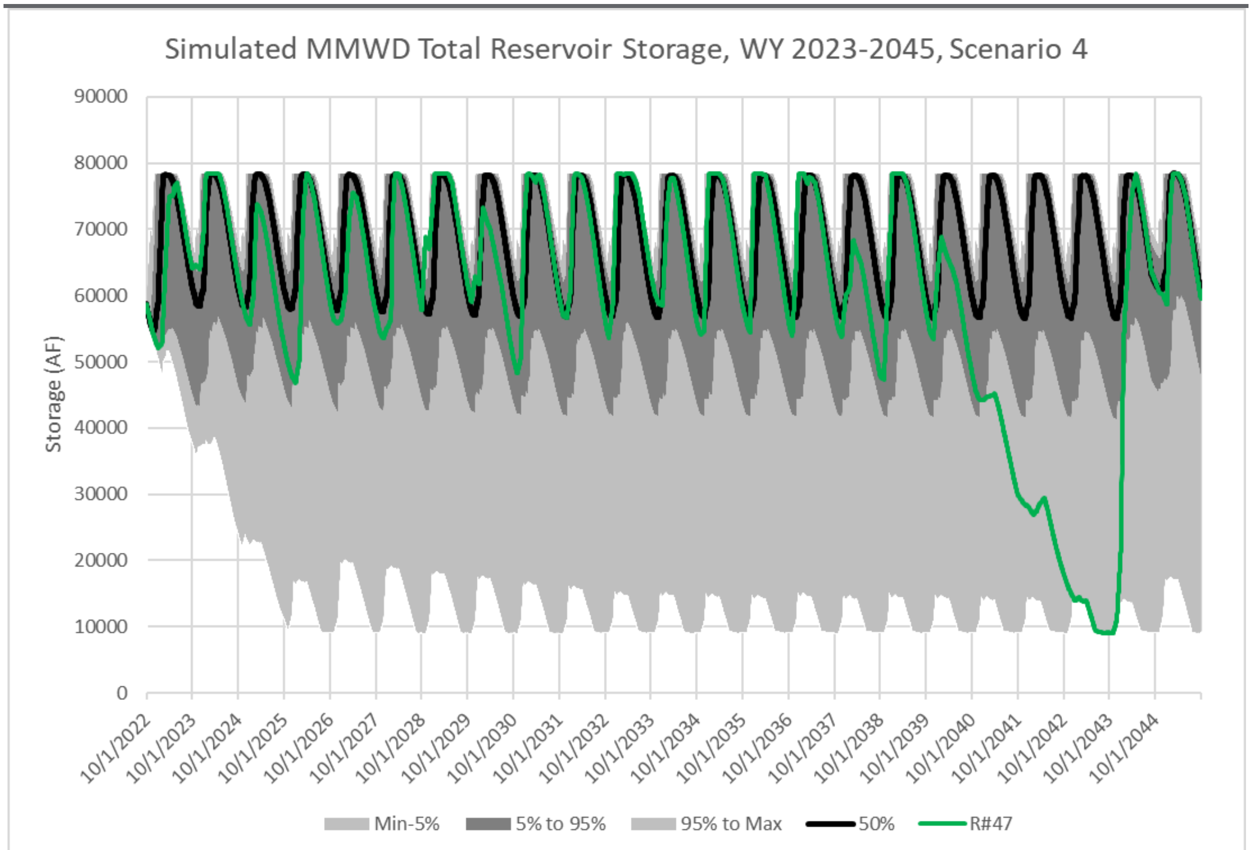


Table 7. Water Budget Summary for one realization (#49) for Scenario 4

Simulation Year	Hydrology Year	Lagunitas Rainfall	Reservoir Inflow	Reservoir Evaporation	Reservoir Spills	Env. Demand	Env. Releases	Waterer Demand	Adjusted Water Demand	Reservoir Deliveries	Sonoma Water Imports	Recycled Water Production	Total Deliveries	EOY Reservoir Storage	Shortage	Unmet Env. Demands
2023	1959	33.64	32,152	3,708	6,326	11,492	11,492	26,085	24,521	16,818	6,953	750	24,521	52,480	0	-
2024	1960	40.31	44,569	3,868	6,966	10,248	10,248	26,572	25,507	16,621	8,136	750	25,507	59,346	0	-
2025	1961	35.2	40,755	3,874	8,157	8,856	8,856	27,059	27,059	21,009	5,299	750	27,059	58,205	0	-
2026	1962	45.91	60,318	3,871	26,043	9,923	9,923	27,412	27,412	20,571	6,091	750	27,412	58,115	0	-
2027	1963	64.25	98,036	4,053	60,557	7,730	7,730	27,727	27,727	21,678	5,299	750	27,727	62,132	0	-
2028	1964	33.57	26,481	3,681	2,116	11,027	11,027	28,042	28,042	21,993	5,299	750	28,042	49,796	0	-
2029	1965	58.56	86,059	3,934	41,181	9,250	9,250	28,357	28,357	21,389	6,218	750	28,357	60,100	0	-
2030	1966	43.6	59,671	3,853	26,394	10,498	10,498	28,672	28,672	22,623	5,299	750	28,672	56,403	0	-
2031	1967	77.99	144,912	4,029	103,073	8,608	8,608	28,768	28,768	22,280	5,738	750	28,768	63,325	0	-
2032	1968	37.96	46,785	3,854	18,275	9,066	9,066	28,799	28,799	22,750	5,299	750	28,799	56,165	0	-
2033	1969	76.54	141,843	3,923	105,117	8,639	8,639	28,831	28,831	21,793	6,288	750	28,831	58,536	0	-
2034	1970	65.37	142,979	3,869	109,427	9,576	9,576	28,863	28,863	22,501	5,612	750	28,863	56,142	0	-
2035	1971	49.59	79,013	3,932	40,525	10,157	10,157	28,895	28,895	22,450	5,694	750	28,895	58,091	0	-
2036	1972	30.37	25,971	3,563	1,075	10,654	10,654	28,912	27,186	20,571	5,865	750	27,186	48,199	0	-
2037	1973	72.5	171,077	3,890	127,602	8,868	8,868	28,925	27,760	21,154	5,855	750	27,760	57,762	0	-
2038	2020	35.77	26,509	3,557	1,418	10,371	10,371	28,938	27,210	20,575	5,886	750	27,210	48,351	0	-
2039	2021	20.35	6,310	2,551	139	8,290	7,945	28,951	23,463	14,078	8,635	750	23,463	29,948	0	345
2040	1976	24.8	8,425	1,715	217	7,839	6,912	28,964	21,723	11,385	8,442	750	20,577	18,144	1146	927
2041	1977	25.28	4,132	1,012	111	6,636	4,087	28,994	21,745	7,870	3,323	750	12,049	9,197	9697	2,549
2042	1978	65.51	120,427	3,644	42,068	7,272	6,790	29,028	26,105	15,249	6,378	750	22,271	61,873	3834	482
2043	1979	43.66	50,669	3,935	21,383	9,529	9,529	29,063	29,063	18,336	7,991	750	27,077	59,359	1986	-
2044	1980	63.14	113,781	3,917	79,479	8,511	8,511	29,098	29,098	23,048	5,299	750	29,098	58,186	0	-
2045	1981	33.05	33,682	3,706	4,674	10,937	10,937	29,132	29,132	21,681	6,701	750	29,132	50,870	0	-

6.8 Summary of Drought Scenarios

A summary of the results for the four drought scenarios is presented in Table 8.

The future is uncertain, and it is important to recognize that extreme inter-annual variability which drives the characteristics of droughts is inherently rare and not predicted nor projected with great confidence with the current science. The use of scenarios is to explore a range of plausible drought conditions derived from information of past and future climate information.

Scenario 1 utilizes the more than 100 years from recorded climate and hydrology to project variability in the future. Two extreme 2-year droughts of 1976-1977 and 2020-2021 test the system to the greatest extent in these scenarios and suggest a maximum water supply deficit of about 5,100 AFY.

Scenario 2 is intended to stress the system further with a drought that combined the two sharpest droughts in the historical record (2020-2021-1976-1977 sequence). This drought is termed a synthetic drought in that it is not directly derived from either historical records nor future climate projections. However, sequences of 4-years of dryness do existing in these records albeit at less extreme flow reductions. Scenario 2 results in a maximum water supply deficit of approximately 8,500 AFY.

Scenario 3 was developed based on review of 20 future climate projections. Two projections were found to have droughts that were unique from the historical record and were selected to test the MMWD system. These projections display a persistence of low and below average flows for nearly a decade with some years of drier conditions within. This scenario triggers drought restrictions at a greater frequency than other scenarios, but does not result in the most extreme dry conditions or lowest storage.

Finally, Scenario 4 seeks to explore disruptions within the watershed that may lead to a reduced treatment capability at San Geronimo and Bon Tempe plants. This scenario assumes a 6-month reduced capacity combined with the drought assumptions in Scenario 2. Scenario 4 results in a maximum water supply deficit of about 9,400 AFY, but is unique in that the increase in deficit from Scenario 2 is largely caused by operational limits rather than supply. For planning purposes, the scenarios help display the shape of the problem, present the likely magnitude of drought supply deficits, and help in the development and evaluation of water management actions to address the uncertain future.

Table 8. Summary Results for Drought Scenario Analysis

	Scenario 1	Scenario 2	Scenario 3	Scenario 4

Drought Length (Yrs)	2	4	Decadal; 2 year within	4
Annual Frequency of Storage < 30,000 AF (%)	< 2%	3%	4%	3%
Lowest Storage (AF)	20,521	8,987	21,971	9,074
Maximum Storage Deficit (AF)	9,479	21,013	8,029	20,926
Maximum Shortage Deficit (AF)	685	13,001	297	16,663
Annual Water Supply Deficit (AFY)	5,082	8,504	4,163	9,397
Annual Frequency of Stage 3 Restrictions	4%	5%	17%	5%

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SECTION 7

Water Management Alternatives and Evaluation

7.1 Summary of Water Management Alternatives

As part of the Strategic Water Supply Assessment (SWSA), the project team was tasked with developing water management alternatives that could be considered for addressing dry period conditions in the future. Through review of previous reports and investigations, and through discussions with MMWD staff, a range of water management alternatives were developed to support the SWSA. Over thirty individual water management alternative options were developed across six categories:

1. Water Conservation
2. Sonoma-Marin Partnerships
3. Local Surface Storage
4. Water Purchases with Conveyance through Bay Interties
5. Desalination, and
6. Water Reuse.

A list of the water management alternatives developed and considered in the SWSA is shown in Table 9.

Table 9. Water Management Alternatives included in SWSA

Category	Alternative
Water Conservation	Water Conservation Program
Water Conservation	Regulatory Conservation Program
Sonoma-Marin Partnerships	Maximize Use of Sonoma Water with Existing Facilities
Sonoma-Marin Partnerships	Maximize Use of Sonoma Water Resolving System Bottlenecks
Sonoma-Marin Partnerships	Maximize Use of Sonoma Water with South Transmission System
Sonoma-Marin Partnerships	Maximize Use of Sonoma Water with Connection from Stafford to Nicasio/Soulajule reservoirs, no STS

Category	Alternative
Sonoma-Marin Partnerships	Maximize Use of Sonoma Water with Dedicated Conveyance from Aqueduct to MMWD Storages with STS
Sonoma-Marin Partnerships	Maximize Use of Sonoma Water with Dedicated Conveyance from Cotati to Hicks Valley
Sonoma-Marin Partnerships	Regional Groundwater Bank
Local Surface Storage	Soulajule Enlargement
Local Surface Storage	Nicasio Enlargement
Local Surface Storage	Kent Enlargement
Local Surface Storage	Halleck Site
Local Surface Storage	Devil's Gulch Site
Local Surface Storage	Movable Spillway Gates
Local Surface Storage	Soulajule Electrification
Local Surface Storage	Phoenix-Bon Temple Connection
Water Purchases with Conveyance through Bay Interties	East Bay Municipal Utility District (EBMUD) Intertie
Water Purchases with Conveyance through Bay Interties	Contra Costa Water District (CCWD) Intertie
Water Purchases with Conveyance through Bay Interties	North Bay Aqueduct (NBA) Intertie
Water Purchases with Conveyance through Bay Interties	San Francisco Public Utilities Commission (SPFUC) Intertie
Desalination	Marin Permanent Regional Desalination Plant (MPRDP)
Desalination	Marin Containerized Regional Desalination Plant (CRDP)
Desalination	Bay Area Regional Desalination Project (BARDP)
Desalination	Petaluma Brackish Groundwater Desalination Project (PBGDP)
Water Reuse	Non-Potable Recycled Water Expansion
Water Reuse	Regional Indirect Potable Reuse
Water Reuse	Central Marin Sanitation Agency Direct Potable Reuse
Water Reuse	Regional Direct Potable Reuse

Each of the water management alternatives is briefly described in the following sections. Additional detail of each alternative and assumptions are presented in Appendix D.

7.2 Approach to Evaluation Water Management Alternatives

In general, the potential yield of the water management alternatives is developed from the project definition, modeling analysis, or simplified analysis. For new, alternative supplies, the yield was derived from the capacity of the plant with assumptions of maximum operability during drought periods. For other supplies, it was necessary to make assumptions on storage or transfer of water, regulation within MMWD's system, and eventual delivery during drought years. For some of the alternatives, it was only possible to evaluate the yield with preliminary modeling analysis and integration within MMWD's system.

Unless indicated otherwise, the yields are estimates of the water made available during a drought period (4-year drought) and is the nominal size of the project, without potential limitations related to system operation or other system limitations. For example, for an alternative that proposes a reservoir expansion adding 10,000 AF of storage in an existing reservoir, the alternative description will list a potential yield of 2,500 AFY. The 2,500 AFY yield corresponds to the 10,000 AF of additional storage divided in 4 years of drought. However, this alternative yield will be subjected to system limitations such as variability of reservoir inflow and operation of the reservoir in conjunction to other water supplies. The alternative yield subjected to system limitations depends on modeling analysis for specific climate scenarios and could vary significantly. These yields will be further refined in the portfolio analysis.

Each water management alternative was evaluated for 12 different criteria, ranging from yield and cost to categories such as jurisdiction and public acceptance. For each criteria, each alternative was assigned a rating of 1 to 5 based on the characteristics of the alternative. This evaluation process was conducted to better compare and contrast alternatives for characteristics beyond yield and cost. Table 10 summarizes these rating criteria.

Table 10. Rating criteria to evaluate water management alternatives

No.	Criteria	Description	Criteria Measurement	Rating Criteria 1	Rating Criteria 2	Rating Criteria 3	Rating Criteria 4	Rating Criteria 5
1	Yield	Estimate of new supply or reduced demand option can provide during dry years.	AF	> 6000	< 6000	< 4000	< 2000	< 1000
2	Cost	Cost per acre-foot of supply or demand reduction.	$/AFY	< $1500	< $2000	< $2500	< 3000	> $3000
		Estimate of capital and annual O&M costs.	$M	< $5M	< $15M	< $30M	< $45M	> $45M
3	Timing	Estimate of time required before project could be implemented considering planning, design, permitting, and implementation.	Years before alternative could begin operation	< 2	< 5	< 7	< 10	> 10

No.	Criteria	Description	Criteria Measurement	Rating Criteria 1	Rating Criteria 2	Rating Criteria 3	Rating Criteria 4	Rating Criteria 5
4	Reliability	Reliability of supply during periods of dry year need	5-pt qualitive scale	Highly reliable; supply expected to be fully available at quantities estimated during dry years		Moderate reliability; supply expected to be available at quantities estimated during dry years, but some uncertainty exists		Reliability is significantly uncertain; questionable availability during dry years
5	Flexibility	Degree to which the option could be operated (or implemented) across a wide range of hydrologic conditions by having ability to adjust the magnitude of operation each year to meet required conditions	5-pt qualitive scale	Option can be operated/idled in any year with no financial implications	Option can be operated/idled in any year with limited financial implications	Option can operated/idled in any year with moderate financial implications	Option can operated/idled in any year with significant financial implications	Option does not have the flexibility to be operated or idled from year to year

No.	Criteria	Description	Criteria Measurement	Rating Criteria 1	Rating Criteria 2	Rating Criteria 3	Rating Criteria 4	Rating Criteria 5
6	Environmental	Anticipated positive or negative impacts on the natural environment.	5-pt qualitive scale	Positive impacts are likely to exist, and negative impacts are not readily apparent	Option does not have an impact or impacts are expected to be neutral with conventional mitigation	Moderate impacts anticipated, but likely to be temporary in nature; small or negligible long-term impacts anticipated	Significant impacts anticipated, some expected to be long-term in nature	Significant, multiple long-term negative impacts are likely to exist
7	Feasibility	Maturity of the concept and technical ability to implement.	5-pt qualitive scale	Regularly implemented at scale proposed	Occasionally implemented at similar scale	Regularly implemented but at smaller scales	Occasionally implemented at smaller scales	Not implemented elsewhere in CA
8	Energy	Estimated change in energy required to implement and operate.	KWH/AF	Requires no additional energy, or results in net positive generation	Minor increases in energy use (less than 5%).	Modest increases in energy use (less than 15%).	Large increases in energy use (less than 30%).	Major changes in energy use (greater than 30%)

No.	Criteria	Description	Criteria Measurement	Rating Criteria 1	Rating Criteria 2	Rating Criteria 3	Rating Criteria 4	Rating Criteria 5
9	Permitting/Legal	List of permits required and status if option has begun permitting process.	5-pt qualitive scale	Does not require an EIR or other major permits	Requires an EIR or other major permits, but similar projects of this scale have been approved in the past 20 years	Requires an EIR or other major permits, but similar projects of smaller scale have been approved in the past 20 years	Requires an EIR and no precedent exists for the option.	Requires an EIR and multiple challenging permits; few precedents
10	Social	Description of positive or negative socioeconomic effects.	5-pt qualitive scale	Positive impacts are likely to exist, and negative impacts are not readily apparent	Option does not have an impact or impacts are expected to be neutral	Negative impacts anticipated, but primarily associated with construction or other temporary impacts	Moderate negative long-term impacts anticipated; involves disproportionate impacts to communities	Significant negative long-term impacts anticipated; disproportionate impacts to communities
11	Jurisdiction	Primary jurisdiction for implementation	5-pt qualitive scale	Primarily involves Marin Water facilities and control	Requires Marin Water and other County department actions	Requires action by partners outside of the County	Requires utility or state agency/ federal actions	Requires actions by multiple federal, state, utility, and private citizens or landholders.

No.	Criteria	Description	Criteria Measurement	Rating Criteria 1	Rating Criteria 2	Rating Criteria 3	Rating Criteria 4	Rating Criteria 5
12	Public Acceptance	Anticipated public acceptance	5-pt qualitive scale	Little or no public acceptance challenges; current practice		Moderate public acceptance challenges; likely to be overcome with education and outreach		High public acceptance challenges likely; new, untested; perception issues; historical challenges

7.3 Evaluation of Water Management Alternatives

For each of the quantified alternatives developed for the SWSA characterization ratings were assigned based on the 12 evaluation criteria. The characterization provided a relative comparison of the alternative attributes and supported the analysis of alternatives and development of portfolios. The criteria and the alternative evaluation are primarily developed to provide more robust information to differentiate between alternatives. Four of the evaluation criteria were developed with both numeric values as well as letter rating: cost, quantity of yield, energy, and timing.

Table 11 summarizes the potential yield, costs, and timing for each of the main water supply alternatives. The yield estimates in the table present the anticipated yield of each alternative developed independently. However, for some categories such as Water Conservation or Sonoma-Marin Partnerships, the alternatives would either be phased or only one selected such that yields cannot be added. The alternatives with greatest yield are related to desalination of bay and brackish water and water reuse. Of these the only water management alternatives that would eliminate the largest water deficit as a single project are the two larger Marin Regional Desalination options.

Table 11. Potential yield, costs, and timing for each of the main water supply alternatives

Option Category	Option Group	Estimated Yield (AF)	Estimated Cost ($/afy)	Timing (years)
Water Conservation	Water Conservation Program	4,000	1,800	1-5
	Regulatory Conservation Program	5,500	4,000	3
Sonoma-Marin Partnerships	Maximize Use of Sonoma Water with Existing Facilities	2000	1,300	0
	Maximize Use of Sonoma Water Resolving System Bottlenecks	2,500	2,900	3
	Maximize Use of Sonoma Water with South Transmission System	2,700	3,600	5-6
	Maximize Use of Sonoma Water with Connection from Stafford to Nicasio/Soulajule Reservoirs	1,000	3,300	3-4
	Maximize Use of Sonoma Water with Dedicated Conveyance from Aqueduct to MMWD Storages with STS	4,000	3,050	5-6

Option Category	Option Group	Estimated Yield (AF)	Estimated Cost ($/afy)	Timing (years)
	Maximize Use of Sonoma Water with Dedicated Conveyance from Cotati to Hicks Valley	5,500	3,150	5-6
	Regional Groundwater Bank	1,250	2,400	5-6
Local Surface Storage	Soulajule Enlargement	5,000	1,650	8
	Nicasio Enlargement	5,000	1,650	8
	Kent Enlargement	5,000	1,650	8
	Halleck Site	2,500	8,100+	10
	Devil's Gulch Site	2,500	8,100+	10
	Movable Spillway Gates	1,320	2,150	3-4
	Soulajule Electrification	420	1,000	2
	Phoenix-Bon Temple Connection	260	1,400	2
Water Purchases with Conveyance through Bay Interties	East Bay Municipal Utility District (EBMUD) Intertie	5,000	2,750	5-6
	Contra Costa Water District (CCWD) Intertie	5,000	4,450	6-7
	North Bay Aqueduct Intertie	5,000	5,300	6-7
	San Francisco Public Utilities Commission (SFPUC) Intertie	1,000	3,050	6-7
Desalination	Marin Permanent Regional Desalination Plant (MPRDP) 5 MGD Non-expandable	5,045	4,750	9
	Marin Permanent Regional Desalination Plant (MPRDP) 5 MGD Expandable	5,045	5,150	9
	Marin Permanent Regional Desalination Plant (MPRDP) 10 MGD Expandable	10,089	3,700	9

Option Category	Option Group	Estimated Yield (AF)	Estimated Cost ($/afy)	Timing (years)
	Marin Permanent Regional Desalination Plant (MPRDP) 15 MGD Expandable	15,134	3,200	9
	Marin Containerized Regional Desalination Plant (CRDP)	5,145	3,100	6
	Bay Area Regional Desalination Project	5,044	3,965	10
	Petaluma Brackish Groundwater Desalination Project (PBGDP)	5,324	2,350	6
Water Reuse	Non-Potable Recycled Water Expansion	439	5,450	5-6
	Regional Indirect Potable Reuse	7,060	4,100	10
	Central Marin Sanitation Agency Direct Potable Reuse	4,030	4,280	10
	Regional Direct Potable Reuse	7,060	5,550	10

In addition to cost, yield, and timing, each alternative was provided with a five-point rating ("1" through "5") for the remaining 9 criteria. A rating of "1" generally represents the most favorable rating and "5" the least favorable. Figure 14 summarizes the resulting ratings for each of the option categories and groups. In some cases, multiple ratings are shown in this figure due to the assessment of large-scale options into smaller increments to capture the varying degree of difficulty of implementing larger options or degree of potential impacts.

Figure 14. Summary of Evaluation Criteria Ratings for Water Management Alternatives

Evaluation Summary of Alternatives

Measure Values: 1 – 5

Code	Name	Yield Rating	Cost Rating	Timing Rating	Reliability R..	Flexibility R..	Feasibility R..	Environmen..	Energy Rati..	Permitting/..	Social Rating	Jurisdiction ..	Public Accep..
DS1A	Marin Regional Desalination Facility- 5 MGD Stand Alone	2	5	4	1	4	2	4	3	5	2	2	3
DS1B	Marin Regional Desalination Facility - 5 MGD Expandable	2	5	4	1	4	2	4	3	5	2	2	3
DS1C	Marin Regional Desalination Facility - 10 MGD Expandable	1	5	4	1	4	2	4	4	5	2	2	3
DS1D	Marin Regional Desalination Facility - 15 MGD	1	5	4	2	4	2	4	5	5	2	2	3
DS2	Containerized Desalination Facility	2	5	3	1	4	3	4	3	5	2	2	3
DS3	Bay Area Regional Desalination Facility	2	5	5	1	4	2	4	3	5	2	3	3
DS4	Petaluma Brackish Groundwater Desalination Facility	2	3	3	3	3	2	3	2	3	2	3	2
LS1A	Soulajule Enlargement	2	3	4	2	4	3	4	1	4	5	4	4
LS1B	Nicasio Enlargement	2	3	4	2	4	3	4	1	4	4	4	4
LS1C	Kent Enlargement	2	3	4	2	4	3	4	1	4	3	4	3
LS2A	Halleck Reservoir	3	5	5	4	5	4	5	1	5	5	5	5
LS2B	Devil's Gulch Reservoir	3	5	5	4	5	4	5	1	5	5	5	5
LS3A	Movable Spillway Gates - Soulajule	5	2	2	2	2	2	2	1	2	2	1	1
LS3B	Movable Spillway Gates - Nicasio	5	2	2	2	2	2	2	1	2	2	1	1
LS3C	Movable Spillway Gates - Kent	5	2	2	2	2	2	2	1	2	2	1	1
LS3D	Movable Spillway Gates - Alpine	5	2	2	2	2	2	2	1	2	2	1	1
SM1	Maximize Use of Sonoma Water - Existing Facilities	4	1	1	3	1	1	2	2	1	2	2	1
SM2A	Maximize Use of Sonoma Water - Resolve Bottlenecks	3	3	2	3	1	1	2	2	1	2	2	1
SM2B	Maximize Use of Sonoma Water - Resolve Bottlenecks+Sout..	3	4	3	2	3	1	3	2	2	2	2	1
SM3A	Maximize Use of Sonoma Water - Dedicated Conveyance Sta..	5	4	2	4	2	1	2	2	2	2	2	2
SM3B	Maximize Use of Sonoma Water - Dedicated Conveyance Kas..	2	4	3	2	3	1	3	3	3	3	3	2
SM3C	Maximize Use of Sonoma Water - Dedicated Conveyance Cot..	2	4	3	2	3	1	3	3	3	3	3	2
SM4	Regional Groundwater Bank	3	2	3	3	3	2	2	2	3	2	3	1
WC1	Water Conservation Program	2	2	1	1	1	1	1	1	1	2	1	1
WC2	Regulatory Driven Program	2	5	2	2	1	1	1	1	1	2	1	3
WP1	EBMUD Intertie	2	4	3	4	4	1	3	3	4	3	5	2
WP2	CCWD Intertie	2	5	4	3	4	1	3	3	4	3	4	2
WP3A	NBA Intertie - MMWD	2	5	4	3	4	1	3	3	4	3	4	2
WP3B	NBA Intertie - Sonoma Aqueduct	2	5	4	3	4	1	3	3	4	3	4	2
WP5	SFPUC Intertie	4	5	4	3	4	1	4	2	4	3	4	3
WR1A	Recycled Water Expansion - Peacock Gap	5	5	3	1	3	1	2	2	2	3	1	1
WR1B	Recycled Water Expansion - San Quentin	5	5	3	1	3	1	2	2	2	3	1	1
WR2	Regional Indirect Potable Reuse (IPR)	1	5	5	1	5	4	4	4	4	3	2	4
WR3A	CMSA Direct Potable Reuse (DPR) - Raw Water Augmentati..	2	5	5	2	4	5	4	3	5	4	2	5
WR3B	CMSA Direct Potable Reuse (DPR) - Treated Water Augment..	2	5	5	2	4	5	4	3	5	4	2	5
WR4	Regional Direct Potable Reuse (DPR)	1	5	5	2	5	5	4	4	5	4	2	5

7.4 Water Conservation

The District has an established, ongoing Water Efficiency Program to support the goal of reducing water demands. For the SWSA water supply planning process, two water conservation options were developed as water management alternatives, which are a subset to the ongoing Water Efficiency Program. These two options, the Water Conservation Element and the Regulatory Driven Program, are described in the following subsections. In each of these options it is assumed that passive savings, due to natural replacement of inefficient fixtures along with code efficiencies, will occur to achieve water savings. Water savings beyond the passive level are achievable using incentives, policies, regulations, and innovative initiatives.

7.4.1 Water Conservation Program

The intent of the Water Conservation Element (WCE) is to develop a suite of incentive programs and associated quantifiable savings, using an anticipated level of participation, which provides a high level of confidence the water savings will be achieved. Since the water savings associated with the WCE option would reduce the water supply deficit, it is important that the level of participation and associated water savings have a high degree of confidence. It is broadly recognized that community engagement and public outreach result in an increased water awareness, and reduction in demands, yet the water savings are non-quantifiable. As noted above, the Water Efficiency Master Plan will provide a framework to maximize the community water saving potential beyond what is included in the SWSA.

This WCE was developed after extensive review of historic incentives, considering market saturation and the most recent drought response. The WCE assessment established a baseline of 2020 and projected implementation and savings through 2045. Utilizing a baseline of 2020 allows the investments made in demand reductions during the 2021 Drought are counted towards the overall reductions made by the community. The WCE results in a cumulative water savings of 22,515 AF and a savings in 2045 of 4,009 AFY. The total WCE program cost of estimated at $1,792/AF.

7.4.2 Regulatory Conservation Program

The intent of the Regulatory Driven Program is to estimate the additional water savings that could be achieved if water saving regulations were adopted and enforced. The Regulatory option assumes the incentive-based Water Conservation Element Option would be implemented in its entirety and a strong regulatory program would be developed in concert to maximize water savings. The specific regulations would include strict landscape codes and associated enforcement.

The final package of regulations would need to be developed and the water savings resulting in implementation of the regulations would vary based on how stringent the policies are, the impacted sectors and the level of enforcement. For example, the Regulatory Driven Program could expedite the removal of Non-Functional Turf through a policy requiring the non-functional turf be removed by a set deadline, resulting in the same projected water savings included in the WCE yet those savings would be achieved in fewer years.

Working with peer reviewers the water savings from implementing a Regulatory Drive Program were estimated to result in a reduction in per capita water use from 106 to 100 GPCD, District-wide. This equates to an estimated cumulative savings of 30,000 AF in 2045 and a reduction of 2045 demands by 5,500 AF compared to the 4009 AF savings achieved through the incentive-based program alone.

7.5 Sonoma-Marin Partnerships

7.5.1 Maximize Use of Sonoma Water with Existing Facilities

This alternative considers opportunities to import more water from Sonoma Water (up to maximum current contract of 14,300 AFY) without any facilities improvements, only based on operational changes that would allow MMWD to get maximum imported water from Sonoma and save its local storage. Opportunities to import more Russian River water can follow specific triggers or happen during winter months when the available Russian River flows (after minimum instream flows are considered) are orders of magnitude higher than the ability of Sonoma Water to divert from the river. This opportunity of importing more water could keep MMWD reservoirs full for a longer time but could also increase the chances of spills.

This alternative is anticipated to yield 2,000 AFY of additional dry year water supply. The associated cost is the cost of additional imported water from Sonoma water, currently priced at approximately $1,300 per AF.

7.5.2 Maximize Use of Sonoma Water Resolving System Bottlenecks

This alternative assumes imported water volume could be increased if all capacity limitations related to pump stations and boosters are resolved. The limitations to be resolved would be at Ely Booster, Kastania pump station (recent upgraded already) and Ignacio pump station. After resolving the pumping limitations, the pipe capacity would be the next constraint to moving flows into the MMWD service area. .

The assumption for costs related to this alternative are based on prorated dollars per MGD improvement of the recent Kastania expansion and estimates from the Bottleneck Study. This alternative is anticipated to yield 2,500 AFY of additional water supply. The associated cost of these improvements at Ignacio Pump Station and Ely Booster Station is approximately $4.5 million, plus over $40 million in recommended improvements downstream of IPS. The unit cost of water provided by this alternative is estimated at $2,400 - $3,400 per AF depending on the level of needed improvements downstream of IPS. Additional detail on this alternative is provided in Appendix D.

7.5.3 Maximize Use of Sonoma Water with South Transmission System

This alternative includes the improvements at the Ignacio pump station to resolve MMWD's system bottlenecks. In addition, this alternative also considers the South Transmission System (STS) pipeline, a connection that has been considered by Sonoma Water to reduce flow constrains in the Petaluma aqueduct. The STS would connect Cotati tanks to the Kastania pump station improving the ability of Sonoma Water to supply North Marin and MMWD demands.

The STS could have different alignments, along the highway 101 or following local surface streets.

This alternative uses the STS alignment that follows surface local streets to avoid complex costs related to the use of a major highway right-of-way (highway 101). It was assumed that the cost of the STS would be shared with Sonoma Water or other agencies and MMWD share would not exceed 50%. This alternative is anticipated to yield up to 2,700 AFY of additional dry period water supply for MMWD. The associated cost to MMWD is approximately $50 to $75 million, depending on pipeline sizing, alignment, and storage capacity. Annual O&M costs are estimated at approximately $6 million. The unit cost of water for this alternative is estimated at $3,400 – 3,800 per AF.

7.5.4 Maximize Use of Sonoma Water with Connection from Stafford to Nicasio/Soulajule Reservoirs

This alternative would use the current North Marin network of pipelines to fill up North Marin's Stafford reservoir with Petaluma aqueduct water. Stafford storage would then be exported to MMWD reservoirs (Nicasio and Soulajule) via new pipeline through Hicks Valley. The preference for this alternative would be to send water to Nicasio unless it is full, then send to Soulajule.

This alternative is anticipated to yield 1,000 AFY of additional dry period water supply. The associated cost to construct the connector pipeline is $29 to $37 million with an annual O&M cost of $1.7 million. The unit cost of water for this alternative is estimated at $3,100 – 3,500 per AF.

7.5.5 Maximize Use of Sonoma Water with Dedicated Conveyance from Petaluma Aqueduct to Soulajule/Nicasio Reservoirs (with STS)

This alternative assumes a construction of the STS and a new dedicated pipeline that will connect the North Marin aqueduct downstream from Kastania, in the proximity of North Marin's system, to Hicks Valley, Nicasio and Soulajule. This alternative offers potential future partnership with North Marin and extra connection to supply imported water to Stafford Lake without using North Marin's transmission lines.

This alternative is anticipated to yield 4,000 AFY of additional water supply. The associated MMWD cost is approximately $99 to $124 million with an annual O&M cost of $5.2 million. The unit cost of water for this alternative is estimated at $2,900 - $3,200 per AF.

7.5.6 Maximize Use of Sonoma Water with Dedicated Conveyance from Cotati to Soulajule/Nicasio Reservoirs

This alternative is a variation of the South Transmission System (STS). This alternative also starts at the Cotati tanks and also bypasses the limitations of the Petaluma aqueduct, however, it routes West of the STS and reaches Hicks Valley, where the water could go to Soulajule Lake or Nicasio Lake. The alternative assumes 37 MGD of pipe capacity to match the capacity assumed for the STS.

This alternative is anticipated to yield between 5,000 and 6,000 AFY of additional dry period water by allowing winter water to be delivered directly to MMWD reservoirs. The associated cost is estimated at $158 million with an annual O&M cost of over $6 million. The unit cost of water for this alternative is estimated at $3,000 – $3,300 per AF.

This alternative would greatly improve the transfer of water to regional storage. However, the distance between Cotati Tanks and Hicks Valley is significant and there is a large elevation difference. As a result, the cost of the project is a potential challenge. This project also excludes potential partnerships with Petaluma, North Marin, and Sonoma Water.

7.5.7 Regional Groundwater Bank

There are three different groundwater basins that could be considered on a regional groundwater bank project, Santa Rosa plain, Sonoma valley, and Petaluma valley. This project would oversee the development of a regional groundwater bank, combining each of these basins using facilities like ASR wells, connections to aqueducts, and water treatment. The purpose of this water bank would be to store water during the Winter months when there is a higher level of precipitation and surplus flows in the Russian River available for diversion. During drought years, this water would be pumped out of the bank and used for regional water needs. The delivery system for this project would be direct to clients, utilizing both participant pools and contributions to the basin as connection sources. The ability to create storage space in these groundwater basins with generally high groundwater levels may limit the size of such a groundwater bank.

This alternative is anticipated to yield approximately 1,250 AFY of additional dry period water supply (5,000 AF of storage extracted over 4 years) for MMWD. The associated cost is approximately for MMWD's participation is between $6 and $12 million with an annual O&M cost of approximately $5 million. As a whole, this is a cost range estimate of $2,300-2,500 per AF.

The inclusion of groundwater in this option creates a greater potential for water supply and connections to existing aqueducts. Key considerations include Groundwater Sustainability Agency developing plans, alignments with benefits for overlying pumpers, and exchange agreements between respective stakeholders.

7.6 Local Surface Storage

7.6.1 Soulajule Enlargement

This project alternative consists of raising the Soulajule Dam up to 49 feet to increase the amount of storage available to MMWD. Raising the Soulajule Dam can increase the reservoir storage between 10,000 to 30,000 AF. Current inflows into the Soulajule Reservoir are between 14,000 and 18,000 AFY (based on measured storage records from MMWD and model flows). The project alternative also includes the installation of permanent pumping infrastructure to meet potable water demands.

This alternative is anticipated to yield between 4,000 and 5,000 AFY of additional dry period assuming the extra amount of storage (20,000 AF) is full at the beginning of the drought and assuming a 4-year drought duration. water supply The associated cost is approximately $65 to $90 million. Based on the anticipated dry year water supply and cost, this alternative has a unit cost of $1,300 to $2,000 per AF. Currently, the same cost assumptions are used for Soulajule, Nicasio, and Kent enlargement alternatives and will need to be further refined if these options are advanced.

7.6.2 Nicasio Enlargement

Two options were considered to increase Nicasio storage, dredging the lake to recover some of storage, and increase of dam height. Dredging Nicasio Lake was initially evaluated as an option to expand the storage available to MMWD. The dredging alternative involved excavating Nicasio Lake and assumes that 1.6 million cubic yards of sediment must be removed from Nicasio Lake to increase capacity by 100 AF. This alternative was evaluated assuming a 100% yield return for the initial cost. When a cost per AF of storage created was calculated, the dredging option had a significant high cost and was rejected for further analysis. The increase of Nicasio dam height would be possible and with a less cost per AF of storage created.

This alternative is anticipated to yield between 4,000 and 5,000 AFY of additional dry period water supply. The associated cost is approximately $65 to $90 million. Based on the anticipated dry year water supply and cost, this alternative has a unit cost of $1,300 to $2,000 per AF. Currently, the same cost assumptions are used for Soulajule, Nicasio, and Kent enlargement alternatives and will need to be further refined if these options are advanced.

7.6.3 Kent Enlargement

Kent reservoir is approximately parallel and 2 miles East of the San Andreas fault. The reservoir is located in a steep area compared to other MMWD reservoirs. This geographic location of the reservoir allows for a substantial storage amount with minimal inundation area, less than 300 acres of new inundated areas for a 30,000 AF of storage increase, when Soulajule and Nicasio would have more than 700 acres of new inundated areas for the same amount of storage increase. No additional measures to reduce the additional inundated area, such as saddle dams and dykes, have yet been evaluated, but would likely be considered to reduce impact.

This alternative is anticipated to yield between 4,000 and 5,000 AFY of additional dry period water supply. The associated cost is approximately $65 to $90 million. Based on the anticipated dry year water supply and cost, this alternative has a unit cost of $1,300 to $2,000 per AF. Currently, the same cost assumptions are used for Soulajule, Nicasio, and Kent enlargement alternatives and will need to be further refined if these options are advanced.

7.6.4 Halleck Site (Proposed)

The Halleck site is a new site that has not been evaluated in previous reports. The site is located upstream of Nicasio reservoir and therefore would impact inflows to Nicasio. The watershed drainage area upstream of the proposed dam location totals approximately 2,895 acres.

This alternative is anticipated to yield no more than 2,500 AFY of additional dry period water supply. The associated cost is approximately $396 to $630 million. Based on the anticipated dry year water supply and cost, this alternative has a unit cost of $8,100 to $12,800 per AF. Currently, the same cost assumptions are used for Halleck and Devils Gulch proposed reservoir alternatives and will need to be further refined if these options are advanced.

This option for the creation of a reservoir at this site has the potential to create significant water storage for MMWD. However, a dam height of more than 180 feet would be needed for 10,000 AF and the site is located at the top of the watershed with minimal drainage area, requiring several years to fill the reservoir.

7.6.5 Devil’s Gulch Site (Proposed)

The Devil’s Gulch Site is located downstream of Kent reservoir in a tributary of the Lagunitas creek. The watershed drainage area upstream of the proposed dam location totals approximately 1,729 acres (approximately 12% of Kent’s drainage area).

This alternative is anticipated to yield no more than 2,500 AFY of additional dry period water supply. The associated cost is approximately $396 to $630 million. Based on the anticipated dry year water supply and cost, this alternative has a unit cost of $8,100 to $12,800 per AF. Currently, the same cost assumptions are used for Halleck and Devils Gulch proposed reservoir alternatives and will need to be further refined if these options are advanced.

This option for the creation of a reservoir at this site has the potential to create significant water storage for MMWD. However, the dam height would need to be too high for a relatively small storage area and the site is located at the top of the watershed with minimal drainage area (compared to other reservoirs in the region), requiring several years to fill the reservoir. Additionally, there is significant environmental impacts as a result of this project.

7.6.6 Movable Spillway Gates

Adjustable or “movable” spillway gates have been proposed to be installed at some of MMWD’s reservoirs to create additional, temporary water storage. These movable spillway gates would be installed as either inflatable bladders or spillway notch slide gates. These gates would be operated only under certain hydrological conditions to gain limited storage for carryover into a potential forthcoming dry season.

Movable spillway gates are being proposed for the Kent, Nicasio, Soulajule and Alpine reservoirs for a water surface elevation increase between 1 and 5 ft.

This alternative is anticipated to yield no more than 1,300 AFY of additional dry period water supply. The associated cost is installation of the movable gates at Kent, Nicasio, Soulajule, and Alpine reservoirs is approximately $31 million in total. Based on the anticipated dry year water supply and cost, this alternative has a unit cost of $2,000 - $2,300 per AF.

7.6.7 Soulajule Electrification

This alternative assumes that a permanent electricity supply would be added to the site resulting in a more consistent operation that moves water from Soulajule to Nicasio. Current operations assume that Soulajule is pumped to Nicasio only after Nicasio storage drops below 50% of its capacity. The alternative assumes that water will be pumped from Soulajule to Nicasio every year starting in April going to June but able to extend until October only if the pumping is not interrupted, there is available capacity at Nicasio, the pumping doesn't impact environmental releases from Soulajule and Soulajule storage is above 10% of its maximum storage.

When the assumptions of this alternative are included in the MarinDSM model, this alternative yields 420 AFY of additional water supply due to the increased flexibility to optimize storage operations between Soulajule and Nicasio reservoirs. The associated capital cost is approximately $6 million with an annual O&M cost of under $0.5 million. The estimated annual unit water cost is approximately $1,000 per AF for this alternative.

This option would add additional power to supply water via pump stations at both Soulajule and Nicasio dams. However, there is a risk that this water would be spilled at Nicasio reservoir because both reservoirs have average inflows greater than capacity.

7.6.8 Phoenix-Bon Tempe Connection

Lake Phoenix is one of the smallest reservoirs in the MMWD system (411 AF), however it is estimated that its inflows average 3,665 AFY. The lake is the only one of all MMWD storages that is located on the East of the main watershed divide. Phoenix Lake water is pumped to Bon Tempe WTP only under dry conditions. This alternative would establish a permanent connection between Lake Phoenix and Bon-Tempe reservoir to capture some of the excess inflows to lake Phoenix that would be otherwise spilled. This alternative currently assumes a 3 mgd pump to move water from Phoenix to Bon Tempe.

This alternative is anticipated to yield approximately 260 AFY of additional dry period water supply. The associated cost is approximately $5 million with an annual O&M cost of $0.1 million. The estimated annual unit water cost is approximately $1,400 per AF for this alternative.

This option would increase the amount of storage available for MMWD. However, a high water level in Lake Phoenix would indicate a high chance of excess flows in other reservoirs, limiting chances of flows from Lake Phoenix to be stored. Additionally, large pumps would be needed to capture excess inflows into Lake Phoenix. This project could have flood control benefits for Marin County who may be willing to partner with the District in an effort to move the project forward.

7.7 Water Purchases with Conveyance through Bay Interties

7.7.1 EBMUD Intertie (Sac Valley purchases)

This supply option includes the purchase of water from the Sacramento Valley (Yuba Water), diversion and conveyance through EBMUD's Freeport intake on the Sacramento River, treatment of supplies through EBMUD's facilities, and construction of a new pipeline across the San Rafael Bridge to allow MMWD to accept treated water through EBMUD's facilities. In addition to the purchase and wheeling operations and agreements with EBMUD, MMWD would construct a new 6-mile San Rafael Bridge Pipeline, new Richmond pump station, and storage of approximately 2 MG at the Pelican Way site, an interim pump station at Pelican Way site and a 3-mile pipeline to connect into MMWD distribution system.

It is assumed that MMWD could purchase up to 20,000 AF during a drought period and may take that supply over 4 years, resulting in approximately 5,000 AF of annual drought year supply. Anticipated annual water supply cost including capital and O&M cost of this option are $2600-$2900.

This option would add a new dry year supply to MMWD from watershed outside of the North Bay. However, agreement with multiple parties are needed to purchase water, treat, and deliver to MMWD.

7.7.2 CCWD Intertie (Sac Valley purchases)

Similar to the EBMUD Intertie option, this supply option includes the purchase of water from the Sacramento Valley (Yuba Water). Diversion would occur at CCWD's delta pumping plants and water would be conveyed through CCWD's system. Potential temporary storage of supply could be achieved in Los Vaqueros Reservoir. Delivery of supplies to MMWD requires an advanced connection of the CCWD's system and construction of a new pipeline across the San Rafael Bridge to allow MMWD to accept treated water through CCWD's facilities. In addition to the purchase and wheeling operations and agreements with CCWD, MMWD would construct a would construct a pump station and new 21-mile pipeline to convey water from Martinez Reservoir to Richmond, a 6-mile San Rafael Bridge Pipeline, new Richmond pump station, and regulatory storage of approximately 2 MG at the Pelican Way site, an interim pump station at Pelican Way site and a 3-mile pipeline to connect into MMWD distribution system.

It is assumed that MMWD could purchase up to 20,000 AF during a drought period and may take that supply over 4 years, resulting in approximately 5,000 AF of annual drought year supply. Anticipated annual water supply cost including capital and O&M cost of this option are $4300-$4600.

This option would add a new dry year supply to MMWD from watershed outside of the North Bay. However, agreement with multiple parties is needed to purchase water, treat, and deliver to MMWD as well a significant amount of permitting requirements.

7.7.3 North Bay Aqueduct (NBA) Intertie (Sac Valley purchases)

This intertie option considers developing a connection to the existing North Bay Aqueduct. Similar to the other intertie options, this supply option includes the purchase of water from the Sacramento Valley (Yuba Water). Diversion would occur at the NBA delta pumping plants and water would be conveyed through the existing NBA to Napa. Treatment would occur at Napa's Jameison Water Treatment Plant (if capacity is available) or additional treatment capacity would be added at this location. Delivery of supplies to MMWD requires a pump station and a 34-mile pipeline from Jameison Plant via Sonoma storate tanks to connect MMWD's system at Petaluma storage tanks. In addition to the purchase and wheeling operations and agreements with NBA users and Napa, MMWD would construct a new 34-mile pipeline and build/operate (or pay for) treatment for approximately 5 MGD capacity. An alternative would require a pump station at Jameison Plant and a 27-mile pipeline from Jamieson plant to connect into MMWD system at Novato.

It is assumed that MMWD could purchase up to 20,000 AF during a drought period and may take that supply over 4 years, resulting in approximately 5,000 AF of annual drought year supply. Anticipated annual water supply cost including capital and O&M cost of this option are $4800-$5800.

This option would add a new dry year supply to MMWD from watershed outside of the North Bay. However, agreement with multiple parties are needed to purchase water, treat, and deliver to MMWD.

7.7.4 SFPUC Intertie (Golden Gate Bridge)

This intertie option considers developing a connection to the SFPUC's system with a pipeline across the Golden Gate Bridge. Water would be purchased directly from SFPUC or purchased and exchanged in the Tuolumne River watershed, wheeled through SFPUC's existing system, connected to the new Bridge pipeline, and delivered to MMWD's southern service area at Sausalito. Treatment is assumed to occur through SFPUC's existing treatment plants. Delivery of supplies to MMWD requires a 5-mile pipeline from SPFUC's system to MMWD's treated water distribution system. Since the connection would occur at the end of both SFPUC's and MMWD's systems with small diameter pipelines, the area that could be served will be limited.

Due to restricted service area, it is expected that the ability to deliver would be limited to approximately 1,000 AFY. Anticipated annual water supply cost including capital and O&M cost of this option are $2900-$3200. Discussions with SFPUC have not yet occurred and further analysis would be required if this alternative is advanced.

7.8 Desalination

7.8.1 Marin Permanent Regional Desalination Plant

Information from a 2007 pilot program was used to develop a conceptual design and Class V costs for a permanent 5-mgd seawater-based desalination facility, both of fixed capacity and expandable to either 10 or 15 mgd, treating water from the North San Francisco Bay via an open intake. The proposed site for the facility is the 6.6-acre MMWD Pelican Way Storage Site in San Rafael. Desalinated (treated) water, following stabilization and disinfection, would be pumped into the existing MMWD distribution system at several locations. Brine from the RO system would be conveyed to, and blended with, secondary effluent for discharge into the Bay (at a location to the north and farther into the Bay) through the Central Marin Sanitation Agency (CMSA) existing outfall.

The yields and costs vary for this option based on the proposed size of the desalination plant and the desire to create an expandable facility. For a 5 mgd (5,045 AFY) flow fixed capacity facility, the cost is estimated to be between $4400-$4900 per AF including capital and O&M costs. For a 5-mgd expandable design, the cost is estimated to be between $4900-$5400 per AF including capital and O&M costs. For a 10-mgd (10,089 AFY) expandable facility, the cost is estimated to be between $3600-$3800 per AF. Finally, for a 15-mgd (15,134 AFY) facility, the annual cost per AF is estimated to be between $3100-$3300. Note that 90% operating capacities are assumed for developing annual yield estimates.

7.8.1.1 Considerations

Construction of the desalination facility will require a vote by, and approval of, MMWD rate payers. The 2017 EIR and CEQA will need to be updated, with considerable time required to obtain all necessary permits. Given the high plant operating cost, it is advisable to develop an operating strategy that best matches required plant water production while minimizing operating costs, noting that partial or intermittent operation requires special requirements (e.g., membrane biofouling control, exercising of equipment, maintenance of staff capabilities). This operation strategy is beyond the scope of this Strategic Water Supply Assessment.

7.8.2 Marin Containerized Regional Desalination Plant

In response to drought and declining reservoir levels, in April 2021 MMWD requested options to augment drinking water supplies on an emergency basis. The investigation evaluated use of containerized desalination units that would be installed at the District's Pelican Way Storage Site in San Rafael, receiving Bay water from a temporary intake and pump station For this option, one of the suppliers identified in the 2021 study was used as the basis for developing a containerized desalination plant as an alternative to a the permanent plant in order to expedite plant construction and commissioning. A 5.4-mgd containerized treatment system, comprising three 1.8-mgd containerized systems, is used as the basis for estimating costs and for populating the evaluation criteria listed below. The containerized system would be constructed offsite, shipped to site and then installed at the Pelican Way Storage Site, along with the remainder of required equipment and infrastructure. Like the Marin Permanent Regional Desalination Plant option, treated water would be pumped into the existing MMWD distribution system at several locations while RO brine would be discharged into the CMSA outfall pipeline after mixing with secondary effluent.

This option would yield approximately 5,145 AF per year. The containerized equipment is assumed to have a life span of 20 years while remaining facilities would have a life span of 30 years. The anticipated annual water supply cost including capital and O&M cost for this option is between $3000-$3200. Note that 85% operating capacities are assumed for developing annual yield estimates.

7.8.2.1 Considerations

Considerations for this option are similar to those for the prior option. Facility construction and operation will require a vote by, and approval of, MMWD rate payers. The 2017 EIR and CEQA will need to be updated and adapted to the containerized system; required time for obtain all necessary permits will be somewhat shorter. Given the high plant operating cost, it is advisable to develop an operating strategy that best matches required plant water production while minimizing operating costs, noting that partial or intermittent operation requires special requirements (e.g., membrane biofouling control, exercising of equipment, maintenance of staff capabilities).

7.8.3 Bay Area Regional Desalination (East Bay)

BARDP is a regional partnership between CCWD, EBMUD, SFPUC, Valley Water and Zone 7 Water Agency. The project, as currently envisioned, would provide a new, supplemental drinking water supply to these agencies. Although a number of locations for a desalination plant have been considered since the project's inception in 2003, the currently preferred location, based on minimizing new conveyance infrastructure, is the East Contra Costa Site where brackish water would be abstracted at CCWD's existing Mallard Slough intake and treated. The finished water would be stored in a two-million-gallon tank and pumped to the Mokelumne Aqueduct for conveyance to MMWD through the EBMUD system. Concentrate (brine) generated by the RO process is stored and conveyed to the Delta Diablo Sanitation District's WWTP for blending with effluent prior to discharge to Broad Slough via an existing outfall. In addition to the option for direct delivery through the Mokelumne Aqueduct, the desalinated water could be conveyed to Los Vaqueros Reservoir (LVR) for storage. This would provide MMWD and other partners with the ability to store water during wet weather periods when desalinated water is not required.

It is assumed that a yield of 5,044 AF per year can be generated from this option based on a 30-year cycle of life. Anticipated annual water supply costs, including both capital and O&M cost, are estimated to be between $3700-$4230. This includes the charges for water wheeling through the Mokelumne Aqueduct and use of the Mallard Slough Pump Station. Note that 90% operating capacities are assumed for developing annual yield estimates.

7.8.3.1 Considerations

Given the desalinated water would be shared by several other agencies, an interagency agreement would be required to allow MMWD to obtain the prescribed 5 mgd of capacity when needed. This may be challenging in an extended drought situation when other agencies want to maximize their take. Compared to other desalination option, this option does benefit from a reduced number of required permits, particularly for MMWD.

7.8.4 Petaluma Brackish Regional Desalination (North Bay)

This desalination option utilizes a reverse osmosis (RO) desalination plant designed to produce 5 MGD of potable water by treating shallow brackish groundwater from a series of wells to be installed near the Petaluma River south of the City of Petaluma. The desalinated water would be pumped into the Petaluma Aqueduct and mixed with water from Sonoma County Water District (SCWD) that is currently used to supplement MMWD's local water supply. To supply the brackish water, six new wells would be installed within a one-to-two-mile radius, with the water from these wells conveyed to the RO plant via a below-ground pipeline.

It is assumed that a yield of 5,324 AF per year can be generated from this option based on a 30-year cycle of life. Anticipated annual water supply costs, including both capital and O&M cost, are estimated to be between $1800-$2900. This includes a wheeling cost to account for the concentrate storage ponds and pump station. Note that 95% operating capacities are assumed for developing annual yield estimates.

7.8.4.1 Considerations

Given the late development of this option, a number of assumptions were made in order to develop the treatment concept and associated costs. As such there are many important considerations, including: well location, yield, and quantity; permitting of concentrate disposal to the river; land availability; and siting of the finished water pipeline.

7.9 Reuse options

7.9.1 Recycled Water – expansion of existing system (Peacock Gap, San Quentin Prison reuse)

This supply option involves the non-potable use of recycled water. The two largest reuse opportunities are included in this option: 1) Expansion of the MMWD RW distribution system to provide disinfected tertiary RW to Peacock Gap Golf Course (285 AFY); and 2) Installation of membrane (MF) at CMSA, provide disinfected tertiary RW to San Quentin Prison (154 AFY).

It is assumed that the expansion of the MMWD RW distribution system will add 285AF of annual drought year supply and will cost between $5,400-$6,200 per AF including both capital and O&M. The expansion of the RW system to San Quentin will add 154 AF of annual drought year supply with a cost between $3900-$4500 per AF including both capital and O&M.

7.9.1.1 Considerations

The use of recycled water for non-potable purposes is a well-established practice and both facilities currently provide recycled water for existing users. For the CMSA to San Quentin Prison project, however, a new disinfected tertiary recycled water production facility will be constructed as the current CMSA water reuse system only provides disinfected secondary 23 recycled water. Both LGVSD and CMSA non-potable reuse systems will yield seasonal water demand and provides a small volume of water relative to the cost of the project. Additionally, it will limit effluent availability for the potential IPR/DPR program.

7.9.2 Indirect Potable Reuse (IPR) – highly treated water pumped through reservoir system (Kent Lake)

The regional indirect potable reuse (IPR) concept conveys secondary effluent from SASM and LGVSD via 12-inch pipelines to CMSA, where Advanced Water Purification Facility (AWPF) will be constructed and treat a total of 8.8 mgd secondary effluent to the quality suitable for IPR. The AWPF will produce 7.0 mgd of purified water, and a 30-inch pipeline will be constructed deliver purified water to Kent Lake. The AWPF will receive secondary effluent from the three wastewater treatment plants (WWTPs), and treat with ultrafiltration (UF), reverse osmosis (RO), and advanced oxidation (AOP). Backwash and cleaning waste from UF will be sent back to the head of CMSA influent. Concentrate from the RO process will be discharged to the existing ocean outfall for CMSA.

The treatment plant will be designed to produce 7 mgd of purified water. Based on the available effluent flows, there is a risk that continuing water conservation may result in insufficient effluent flows available to produce 7 mgd purified water during summer. For the preliminary evaluation, the potable water yield was assumed to be 90 percent of the production capacity, or 7,056 AFY. Anticipated annual water supply cost including capital and O&M cost of this option are $3700-$4400 per AF.

7.9.2.1 Considerations

This option would require permitting for blended purified recycled water into Kent Lake water and RO concentrate discharge into the CMSA outfall. As purified water will be discharged to a reservoir, purified water will be required to meet the California Toxicity Rule (CTR), in addition to meeting the Surface Water Source Augmentation Project (SWSAP) treatment requirements. As of 2022, there is no operating surface water augmentation IPR in California although there are projects under construction or in design, for example, San Diego’s Pure Water program, the Las Virgenes-Triunfo Pure Water IPR project in Ventura County, and the Metropolitan Water District of Southern California’s Pure Water Southern California program in partnership with Los Angeles County Sanitation Districts. Reliability of secondary effluent supply to the regional IPR treatment facility may become uncertain when further water conservation measures are implemented and if other non-potable water reuse projects are implemented. The CMSA site has limited footprint and further evaluation will be necessary to identify the location to accommodate the AWPF. Use of CMSA effluent for IPR may affect the ability of the District to pursue desalinated bay water as the current concept for brine disposal involves mixing the brine with the CMSA effluent.

7.9.3 CMSA Direct Potable reuse (DPR) – highly treated water directly to customers

A direct potable reuse (DPR) system will provide purified water to either immediately upstream of the water treatment facility (WTF) (raw water augmentation), or existing water distribution system (treated water augmentation). In the CMSA DPR option, AWPF will be constructed at CMSA and purified water is provided for either of these two DPR schemes:

- 3A - CMSA DPR Raw Water Augmentation, in which the treated water augmentation DPR concept being investigated for CMSA is modified slightly to deliver purified water to Bon Tempe Lake instead of the water distribution system

- 3B - CMSA DPR Treated Water Augmentation, in which an AWPF will be constructed at CMSA to meet the DPR requirements and send purified water to the potable water distribution system.

It is assumed that the AWPF will have 4 mgd treatment capacity to provide an annual yield of water supply of 4,030 AF, accounting for the reduced production due to maintenance and repair. Anticipated annual water supply cost for the Raw Water Augmentation project would be $4400-$5100 per AF including capital and O&M costs. Anticipated annual water supply cost for the Treated Water Augmentation project would be $3500-$4100 per AF including capital and O&M costs.

7.9.3.1 Considerations

Regulations for DPR are under development in California and are targeted for adoption by the end of 2023. As there are no regulations for DPR projects yet, there is no DPR implemented in California as of 2022. There are raw water augmentation DPR projects in Texas and overseas, whereas there is no treated water augmentation DPR project in the world yet. Similar to the IPR project, this option would require a discharge permit for RO brine. For the raw water augmentation DPR, purified water will be required to meet the CTR requirements in addition to meeting the treatment requirements to be specified for the DPR projects. Use of CMSA effluent may affect the ability of the District to pursue desalinated bay water as the current concept for brine disposal for those options involves mixing the brine with the CMSA effluent.

7.9.4 Regional Direct Potable Reuse

This option will take secondary effluent from Las Gallinas Valley Sanitary District (LGVSD) and Sewerage Authority of South Marin (SASM) to CMSA, similar to the Regional IPR, and provide water purification meeting the DPR criteria for the combined flow from the three treatment plants and send the purified water to Bon Tempe Lake. The treatment train includes ozone/biological activated carbon (BAC), ultrafiltration (UF), reverse osmosis (RO), ultraviolet advanced oxidation (UV/AOP), water stabilization, and chlorine contactor. The expected feed water flow rate is 8.2 mgd to produce 7 mgd purified water and assumed 90 percent of the treatment capacity will be the estimated annual yield. Concentrate from the RO process is assumed to be discharged from the existing CMSA effluent outfall.

The Regional DPR project will be designed for the 7 mgd purified water production, and 6.3 mgd (7060 AFY) annual yield for the potable water source augmentation counting for the reduced production rate due to repair/maintenance and potential lack of secondary effluent to operate the plant at a full capacity. The anticipated cost for annual water supply is between $5100-$6000 per AF, including both capital and O&M.

7.9.4.1 Considerations

Considerations for the regional DPR project are the combination of factors identified for the regional IPR and CMSA DPR projects. Regulations for DPR is in development in California and will be adopted by the end of 2023. As there is no regulations for DPR projects yet, there is no DPR implemented in California as of 2022. This option would require a discharge permit for RO reject water, and purified water will be required to meet the CTR requirements in addition to meeting the treatment requirements to be specified for the DPR projects. Reliability to produce

7060 AFY purified water will be contingent on the effluent availability. The AWPF layout within the CMSA site will require further evaluation as the CMSA site is limited in available footprint. Use of CMSA effluent may affect the ability of the District to pursue desalinated bay water as the current concept for brine disposal involves mixing the brine with the CMSA effluent.

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SECTION 8

Potential Strategies and Portfolios (5-7 pp)

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SECTION 9

Recommended Roadmap for Water Supply Resiliency (3pp)

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SECTION 10

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Appendix A. Previous Reports

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Appendix B. System Model Description

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Appendix C. Drought Scenarios

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Appendix D. Water Management Alternatives

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