Marin Municipal Water District

WATER RESOURCES PLAN 2040

MARCH 2017

PREPARED BY:

RMC water and environment

WOODARD & CURRAN

National Experience. Local Focus.

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List of Acronyms

AF	Acre-feet
AFY	Acre-feet per year
BARR	Bay Area Regional Reliability
BFFIP	Biodiversity, Fire, and Fuels Integrated Plan
CDP	Criterium Decision Plus
CEQA	California Environmental Quality Act
CII	Commercial, Industrial, Institutional
CMSA	Central Marin Sanitation Agency
district	Marin Municipal Water District
DPR	Direct potable reuse
DSS	Decision Support System
EBMUD	East Bay Municipal Utility District
EO	Executive Order
gpcd	Gallons per capita per day
IPR	Indirect potable reuse
IRWMP	Integrated Regional Water Management Plan
LGVSD	Las Gallinas Valley Sanitation District
MG	Million gallons
mgd	Million gallons per day
MMWD	Marin Municipal Water District
NEPA	National Environmental Policy Act
NMWD	North Marin Water District
RBSD	Richardson Bay Sanitation District
RW	Recycled water
SASM	Sewerage Agency of Southern Marin
SCWA	Sonoma County Water Agency
SGTP	San Geronimo Treatment Plant
TAF	Thousand acre-feet
UWMP	Urban Water Management Plan
WRP	Water Resources Plan
WSCP	Water Shortage Contingency Plan

1.0 Executive Summary

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 (SCWA).

Historically, MMWD has successfully met demands during periods of extreme drought with a combination of rationing, conservation, and increased SCWA supplies. However, recent drought conditions that severely threatened water supply reliability have prompted the District to assess water resiliency and ability to meet future water demands in light of both chronic events (such as prolonged drought and climate change impacts on water supply) and acute events (such as earthquakes, water quality events, wildfires, etc.) that could threaten water supply resiliency.

To this end, the district prepared the Water Resources Plan (WRP) 2040 to evaluate resiliency in the face of a variety of threats to water resources in its service area and to identify options to enhance resiliency for its customers. The WRP 2040 provides valuable information to enable the district to make informed water supply planning decisions in the face of a variety of potential reliability threats.

BASELINE OPERATIONAL YIELD

In order to determine potential supply shortfalls under various resiliency scenarios, total available supply from the system must be estimated and compared to total projected demands on the system. Using Marin WaterSim, a model of the Marin water system that was built on the GoldSim modeling platform, the district defined the baseline operational yield of the reservoir system. Operational yield is defined as the maximum annual demand that can be met by the district's local water supply system during the hydrologic record, assuming 25 percent of supply capacity (beyond unusable storage) is reserved for emergency purposes. Analysis shows that the district's baseline operational yield of the reservoir system is 29,020 acre-feet per year (AFY).

EVENTS AND RELIABILITY THREATS

To understand potential changes in future supply availability under various future conditions, the district used WaterSim to simulate reliability threats or "events" and the "futures" that would result from those events that could impact baseline supply conditions. Events considered in the WRP 2040 included earthquakes, drought, climate change, wildfire, landslides, and water quality issues. For each event, specific conditions were developed, such as a Six-Year Severe Drought or an earthquake that interrupted service from a treatment plant for 30 days. These reliability threats were incorporated into Marin WaterSim using projected 2040 demand to evaluate the change from baseline conditions and identify the conditions under which the district may not be able to meet customer needs, or the resultant "future" condition.

The only reliability threats that resulted in supply shortfalls in MMWD's system were simulated droughts that are longer and drier than historical hydrology. Modeling indicated that MMWD's system would approach a shortfall condition if an earthquake disabled San Geronimo treatment plant for one peak demand month, or if Nicasio Lake was unusable due to water quality issues for six months. The Marin WaterSim modeling showed that MMWD could meet demand under these reliability threats, but storage would drop to levels near the 25% emergency storage reserve. Additionally, MMWD's system under projected climate change conditions would be expected to have overall lower levels of storage, which could increase MMWD's vulnerability to shortfalls from catastrophic events with short, intense impact periods such as earthquakes.

RESILIENCY OPTIONS AND ALTERNATIVES

A total of 40 resiliency options were developed that could improve the district's resiliency and ability to meet demands in times of potential supply shortages caused by variable hydrology or system disruption. The 40 options included a variety of approaches, including water use efficiency, reuse, expanded SCWA facilities, expanded storage, water purchases and groundwater, desalination, and emerging options. Each option was developed to include a preliminary description of the option, required facilities, cost, yield, reliability, implementation considerations, and conceptual maps or schematics.

Because no single option could address all potential reliability threats, options were combined into multi-option "alternatives" with specific emphases to better address resiliency needs. Five alternatives were developed, organized along the following themes: Expand Existing Programs, Minimize Infrastructure, Dry Year Actions, Maximize Reuse, and Maximize Resiliency.

FINDINGS

Each of the five alternatives was simulated in Marin WaterSim to determine its ability to improve the district's water supply availability and reliability under each reliability threat. A "No Action" alternative, representing current baseline operations, was also simulated under each reliability threat to provide a baseline for comparing the five alternatives. The alternatives were analyzed against nine metrics, including average annual deficit, maximum monthly deficit, and total system storage, to determine the effectiveness of each alternative.

Deficits were observed under the No Action alternative for the Six-Year Severe Drought condition. These deficits were eliminated by three of the proposed alternatives: Dry Year Actions, Maximize Reuse, and Maximize Resiliency. In addition, all alternatives increased storage under climate change as compared with the No Action alternative.

This analysis demonstrated that the district's current supply portfolio is sufficient to meet demands in each of the reliability threats modeled except the Six-Year Severe Drought. It should be noted that the probability of the Six-Year Severe Drought occurring is low. Should this type of drought occur, shortages would not be expected until the fifth year of the drought, which provides time to re-assess and move forward implementation of resiliency options after the drought starts. Further, use of supplies in emergency storage, combined with mandatory conservation / rationing, would allow the district to manage supplies through the Six-Year Severe Drought condition without shortfalls.

RECOMMENDATION

Because the district's current supply portfolio is sufficient to meet demands under the majority of conditions evaluated, there is no immediate need to invest in infrastructure to secure additional resiliency at this time. However, to continue strengthening the district's water supply resiliency, it is recommended that the district expand its existing water efficiency programs. This could involve implementing the Expand Existing Programs alternative, which would increase water conservation, expand watershed management, and explore opportunities associated with in-lieu groundwater transfers.

It is also recommended that the district update its Water Shortage Contingency Plan (WSCP) to include three additional triggers. The triggers, now five in total, are linked to the amount of water in the district's reservoirs and incorporate varying levels of rationing. The new structure of the WSCP provides the district with more flexibility in addressing dry periods early and allows the district to manage its supplies through a Six-Year Severe Drought as simulated in the WRP 2040. Recognizing that outside factors could generate a need for demand reduction, it is also recommended that the district include a trigger that, should an outside factor dictate a reduction, allows the district the flexibility in determining an appropriate level of reduction. These triggers have been incorporated in the updated WSCP, provided in Appendix J

NEXT STEPS

Using the information provided in this Water Resources Plan 2040, the district will decide what level of investment, and at what time, is required to achieve a desired level of resiliency. Should the district elect to implement one or more alternatives or options identified in this plan, an appropriate level of review and assessment will be completed as required by the California Environmental Quality Act (CEQA) and / or the National Environmental Policy Act (NEPA).

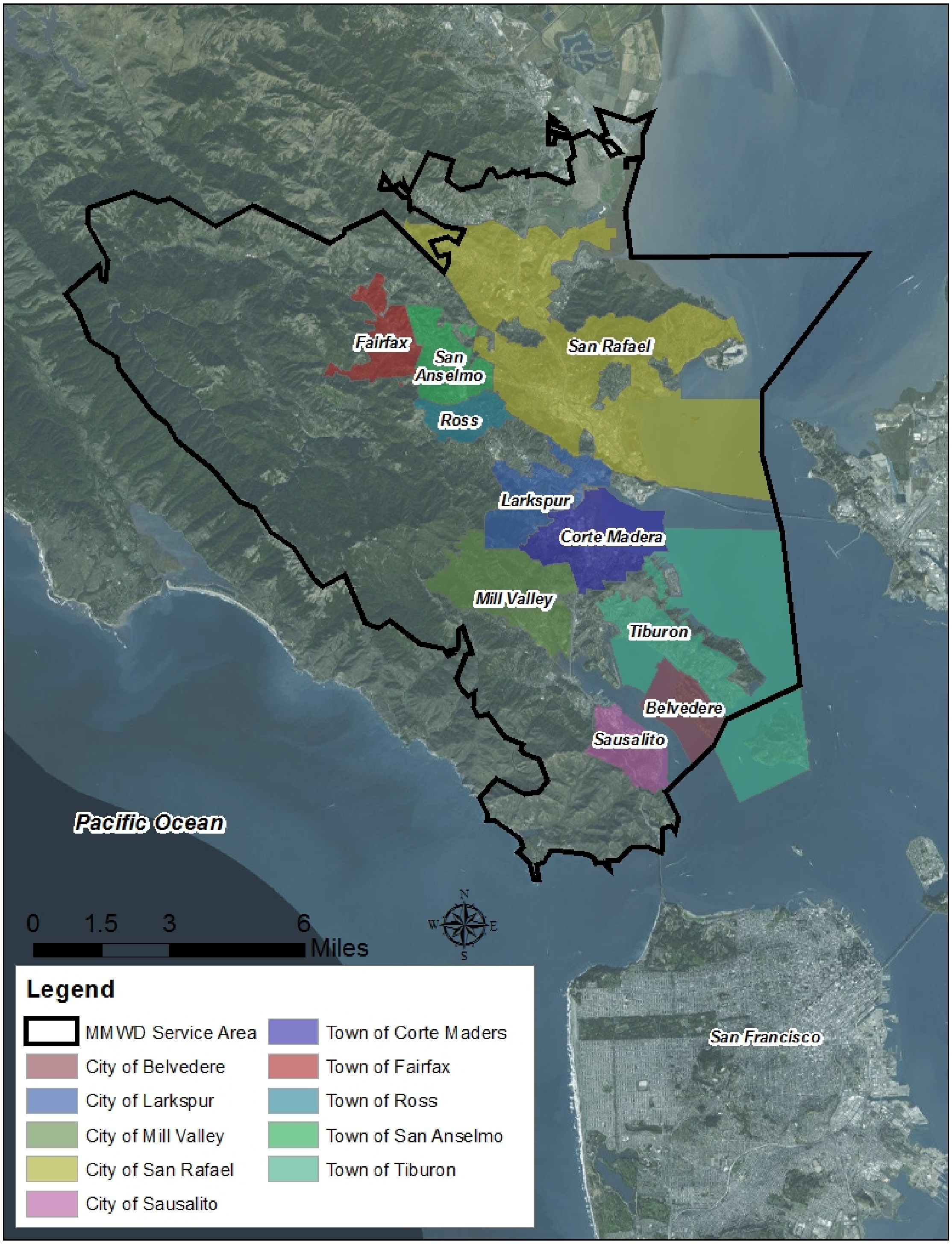
The district will review and update its Water Resources Plan every five years, in conjunction with its Urban Water Management Plan (UWMP) update. In addition to this regular review and update cycle, it is recommended that the WRP 2040 be re-assessed and additional resiliency actions implemented should district reservoir storage drop to a minimum threshold of 40 thousand acre-feet (TAF), or drop below 50 TAF three times in two consecutive years. As part of its adaptive management strategy, it is recommended that the district continue to explore other resiliency options in the intervening periods between Plan updates.

2.0 Background and 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 is bounded by the San Francisco Bay on the east, and stretches through the San Geronimo Valley to the Pacific Ocean to the west. The incorporated cities and towns of San Rafael, Mill Valley, Fairfax, San Anselmo, Ross, Larkspur, Corte Madera, Tiburon, Belvedere and Sausalito are within the district's service area. The district's service area is shown in **Figure 2-1**.

The district covers approximately 147 square miles and serves a population of approximately 190,000 customers through about 61,800 active service connections. Five of the seven district reservoirs (Alpine, Bon Tempe, Kent, Lagunitas, and Phoenix Lake) are located on the north slope of Mt. Tamalpais. The remaining two district reservoirs (Nicasio and Soulajule) are outside the district's service area in western Marin County. Pipelines range from 3/4-inch pipes connecting customers' water meters to the district's mains, to the 42-inch transmission mains that carry source water to the treatment plants. The pipes are made of various materials depending on when and where they were installed.

Figure 2-1: Marin Municial Water District Service Area



MMWD understands that water is a limited resource and that a long-term reliable supply of water is essential to protect the local and state economy. The district's water supply does not come from snowmelt nor from coastal aquifers, but rather from local runoff and the Russian River, a rainfall-driven river. This precipitation is stored in local reservoirs and released when needed to meet demands for water supply and year-round fish habitat enhancement. The district is storage-limited, with existing storage capacity representing about two years of demand. There are few to none remaining economically-feasible sites for new surface water storage facilities, and the potential to develop local groundwater resources is limited.

Historically, MMWD has been able to meet demands during periods of extreme drought with a combination of rationing, conservation, and increased purchases of imported water supply from the Sonoma County Water Agency (SCWA). Given that the district relies on stored surface water to meet the majority of demands, it can and has experienced changes in storage very quickly. From December 2012 to January 2014, MMWD experienced a period of very low precipitation, and its reservoirs reached low storage conditions that nearly triggered significant mandatory reductions. Water supply circumstances then changed in early February 2014 when the district received 15 inches of rain, more rainfall than the total rainfall during the prior 400 days combined.

In the future as the climate changes, less frequent, more intense storms are expected; these storms have an increased potential to cause flooding. Additionally, with less frequent and more intense storms, there will likely also be extended dry periods. Coping with inter-annual variability has always been a challenge for long-term water supply planning in the Bay Area, and climate change may intensify variability in the coming decades. With potential changes resulting from climate change, there will be a heightened need to evaluate and respond to increased water supply variability and reliability.

The district recognizes the importance of understanding these potential changes in supply variability and preparing for the resulting reliability challenges. The district's Water Resources Plan (WRP) 2040 evaluates resiliency in the face of a variety of threats to water resources in its service area, and identifies options to enhance resiliency for its customers. The WRP 2040 provides valuable information that will help the district make informed water supply planning decisions in the face of climate change and other reliability threats.

3.0 Water Resources Plan 2040 Development Process

The WRP 2040 was developed with three primary objectives:

1) Identify the reliability threats and analyze their impact on the district's ability to meet demands;

2) Develop options that would help the district improve its resiliency in the face of the threats; and

3) Recommend an option portfolio that provides increased resiliency and meets district priorities.

This process is shown on the diagram on the following page, and each of these activities is discussed in more detail throughout this Plan.

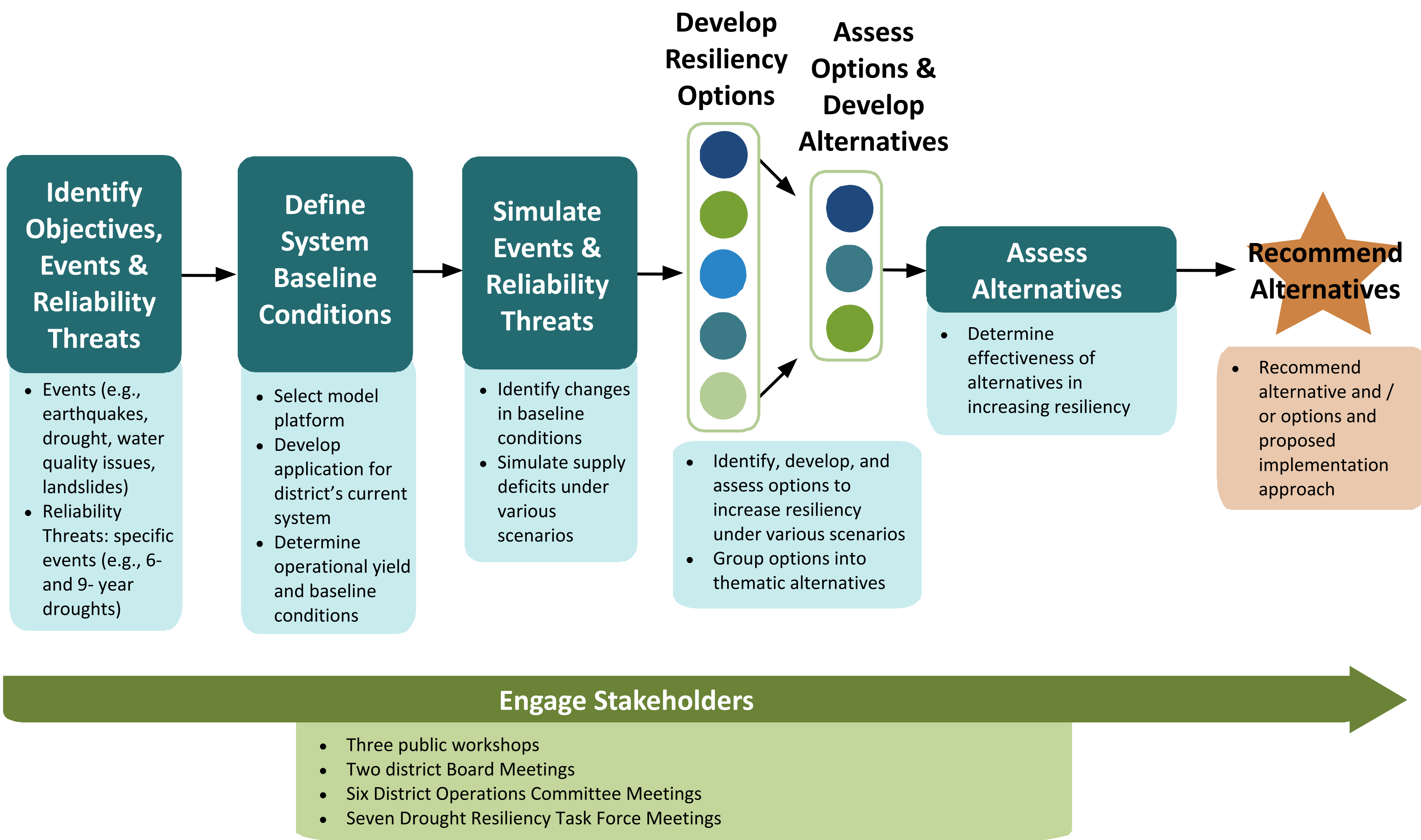
- **Identify Objectives, Events of Concern, and Reliability Threats**: Through discussions with district staff and stakeholders, a varied list of potential reliability threats was developed. Threats included events like earthquakes, drought, wildfire, and water quality issues. From these events, reliability threats were developed that brought specificity to the events, such as a Six-Year Severe Drought or an earthquake that interrupted service from a treatment plant for 30 days. More information on events and reliability threats is included in **Chapter 4.0 Potential Threats to Reliability**.

- **Define Baseline Conditions and Perform Modeling:** Defining baseline conditions is required to understand the magnitude and impact of the reliability threats. After exploring a variety of options, the district selected the GoldSim software to simulate its supply system. More information on the selection process and the district's GoldSim application, Marin WaterSim, can be found in **Appendix B** and **Appendix C**, respectively. Using Marin WaterSim, the district defined the baseline operational yield of the reservoir system. This analysis was performed to estimate the level of demand that the reservoir system could meet, based on historical hydrologic conditions. This analysis is included in **Appendix D**. With an understanding of baseline operational yield, the district then simulated the events and reliability threats identified above. This analysis helped determine the change from baseline conditions and identify the conditions under which the district may not be able to meet customer needs.

- **Develop Options and Alternatives:** With an understanding of how the reliability threats impact the district's ability to meet demands, staff developed an extensive list of resiliency options that could be implemented to increase the district's resiliency during those periods of supply shortage. Each option was modeled and analyzed. The subset of options considered to be most cost-effective in their ability to improve district resiliency were organized into thematic groups, or alternatives. These alternatives were then simulated in Marin WaterSim to determine how they performed under various reliability threats.

- **Recommend Alternatives:** The Marin WaterSim simulations provide information on how each alternative improves district resiliency under the reliability threats analyzed. Based on this analysis, an alternative was identified that best meets district needs and objectives. The selected alternative and an implementation approach was recommended to the Board of Directors, who will make a determination as to the district's path forward.

- **Engage Stakeholders**: Throughout the development of the WRP 2040, the district engaged stakeholders, the Board of Directors, the District Operations Committee, and the Drought Resiliency Task Force. District staff held three public workshops with a formal public review period for the Plan. Plan progress was presented at two Board meetings, six District Operations Committee meetings, and seven Drought Resiliency Task Force meetings. During each of these meetings, staff presented on the progress of the WRP and allowed time for questions and comments. Public comments received throughout the WRP process are provided in **Appendix A**.


Identify Objectives, Events & Reliability Threats
Events (e.g., earthquakes, drought, water quality issues, landslides)
Reliability Threats: specific events (e.g., 6- and 9- year droughts)
Define System Baseline Conditions
Select model platform
Develop application for district's current system
Determine operational yield and baseline conditions
Simulate Events & Reliability Threats
Identify changes in baseline conditions
Simulate supply deficits under various scenarios
Develop Resiliency Options
Identify, develop, and assess options to increase resiliency under various scenarios
Group options into thematic alternatives
Assess Options & Develop Alternatives
Assess Alternatives
Determine effectiveness of alternatives in increasing resiliency
Recommend Alternatives
Recommend alternative and / or options and proposed implementation approach
Engage Stakeholders
Three public workshops
Two district Board Meetings
Six District Operations Committee Meetings
Seven Drought Resiliency Task Force Meetings

4.0 Potential Threats to Reliability

Critical to the WRP 2040 is understanding how reliability threats could impact the district and its ability to meet the needs of its customers and the local environment. Multiple events that could potentially occur in the MMWD system were simulated using the Marin WaterSim application, built on the GoldSim platform. Marin WaterSim accounts for 2040 demand levels to determine how the events would impact the district's ability to serve its customers.

4.1 Projected Water Demands

As part of its 2015 Urban Water Management Plan (UWMP), the district reported current 2015 water demands and developed water demand projections through 2040 (MMWD, 2016a). The WRP 2040 demand assumptions build upon the UWMP demands, but address concerns and interest of the district and its stakeholders by including a "demand envelope" which reflects three demand scenarios – a low demands scenario, a medium demand scenario, and a high demand scenario – to provide flexibility in planning. In addition, all three demand scenarios in the WRP 2040 reflect planned conservation. The three scenarios were developed as follows.

Low Demand Scenario ("Lower Range")

- Projects demands using 2015 as a base year; reflects existing and planned passive and active conservation

Medium Demand Scenario ("Base Case")

- Projects demands using the average demand in 2008 - 2013 as base demand; reflects existing and planned passive and active conservation

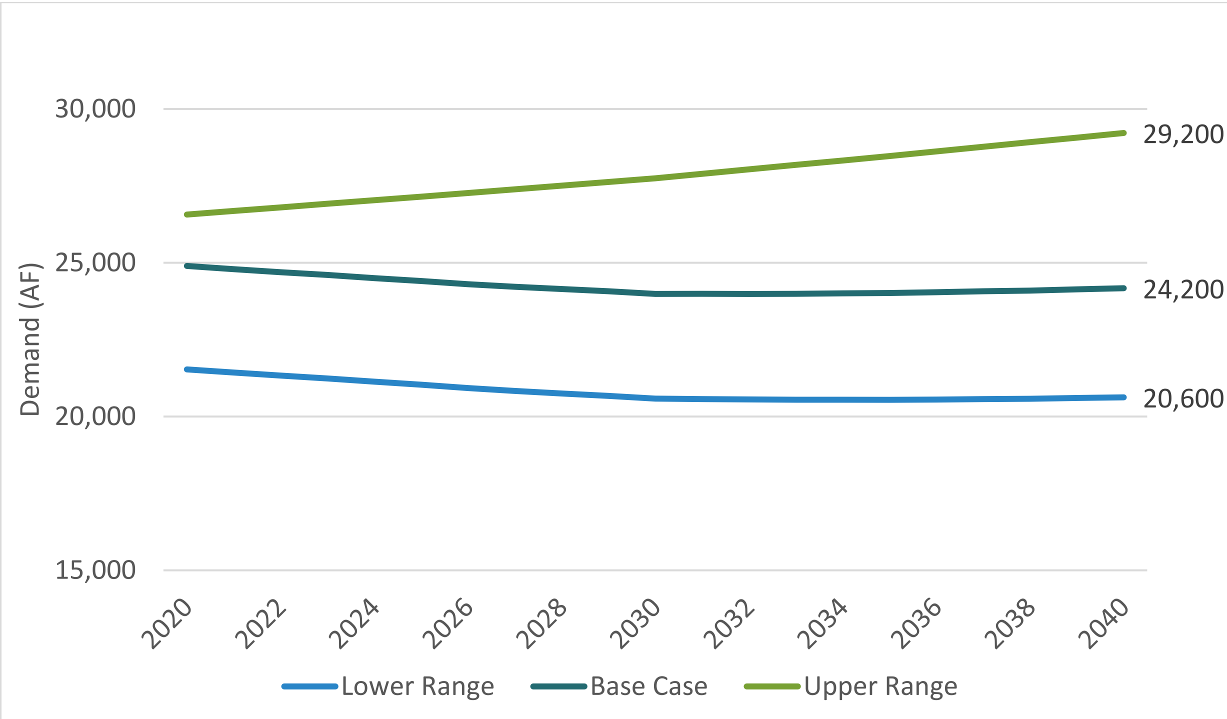
High Demand Scenario ("Upper Range")

- Projects demands assuming the district remained at the per capita water use level required by the Water Conservation Act of 2009 (124 gallons per capita per day), with demands increasing with population

Including all three scenarios in allows the district to account for uncertainty in water demands over time. For example, the level of customer conservation and water use efficiency may vary over time. Changes in the level of conservation will affect water use patterns which can affect total demand for district supplies. These uncertainties mean that past demand patterns may not necessarily be a good indicator for future demand. Presenting alternate scenarios allows for varying future demand based on uncertainties and provides valuable information related to resiliency planning.

Figure 4-1 below presents the projected district demand for each of the three demand scenarios.

Figure 4-1: Projected Demand Scenarios



4.2 Resiliency Events and Reliability Threats

An "event" is defined in this Plan as a condition that may happen that impacts the supply and demand balance within MMWD's system. A "reliability threat" is a probable condition that includes at least one event. The reliability threats evaluated for the WRP 2040 were developed to test how MMWD's water supply system would react under various medium- and long-term events with potential to interrupt system operations. Once potential reliability threats were defined, they were incorporated into Marin WaterSim using projected 2040 demand to evaluate how the system would react to each particular reliability threat. The reliability threat scenarios were tested to determine whether they would produce supply deficits with a projected 2040 demand of 24,200 acre-feet (AF) and with 25% emergency storage in MMWD's reservoirs.

The events and reliability threats analyzed in this Plan are summarized below. Detailed descriptions of these reliability threats are included in **Appendix E**.

Drought Reliability Threats

- Single Critical Dry Year (one year of impact)
- Extended Drought (five years of impact)
- Six-Year Severe Drought (six years of impact)
- Nine-Year Severe Drought (nine years of impact)

Climate Change Reliability Threat

- Climate change hydrology impacts to supplies and demands (89 years of impact)

Wildfire Reliability Threat

- Impacts to Lagunitas watershed (three months of impact)

Earthquake Reliability Threats

- Impacts to Bon Tempe WTP (three months of impact)
- Impacts to San Geronimo WTP (three months of impact)
- Impacts to Ignacio pump station and / or associated conveyance infrastructure (three months of impact)

Water Quality Event Reliability Threats

- Impacts to imported supply (one year of impact)
- Impacts to supplies at Nicasio Lake (six months of impact)
- Impacts to Kent Lake (six months of impact)
- Impacts to Alpine Lake (six months of impact)

Landslide Reliability Threat

- Impacts to Lagunitas watershed (six months of impact)

Power Failure Reliability Threat

- Power Failure Impacting San Geronimo WTP Pump Station (three months of impact)

4.3 Impacts of Reliability Threats on District Supply

Analysis of the reliability threats revealed that the following reliability threats generated the most severe impacts to MMWD's supply conditions:

- Severe Droughts
- Climate change
- Earthquakes
- Water quality events

Supply shortfalls in MMWD's system were nearly encountered under simulations during peak demand months of the reliability threats in which an earthquake disabled San Geronimo treatment plant for one month, or a reliability threat in which Nicasio Lake was unusable due to water quality issues for six months. The Marin WaterSim modeling showed that MMWD could meet demand under these reliability threats, but storage dropped to levels near the 25% emergency storage reserve. Additionally, MMWD's system under modeled climate change scenarios is expected to result in overall lower levels of storage, which may increase MMWD's vulnerability to catastrophic events with short, intense impact periods such as earthquakes.

Only the simulated droughts that are longer and drier than historical hydrology were found to lead to supply shortfalls. Simulations under the historical hydrology from the critically dry year (based on 2013 hydrology) and the driest historical five-year period (1928 through 1932) showed that MMWD's current system could continue to meet projected 2040 demands under these historical drought conditions. However, MMWD would likely face supply shortfalls if the modeled Six to Nine-Year Severe Drought occurred without a "savior storm" of more than three inches of rain occurring during this period. A simulated drought of these severity was developed using modified hydrology from the 1920s and through examining paleo hydrology from the Russian River Valley and from the Sacramento, San Joaquin, and Klamath River), as detailed in the Marin WaterSim TM included as **Appendix D**.

Although no reconstructions of streamflow or precipitation have been completed for the immediate watersheds supplying MMWD, a review of the research done in surrounding areas can be helpful for assessing the severity past droughts going back centuries, and understanding the range of conditions that may be expected under natural variability. The paleo record from these regions show that droughts lasting up to 10 years have occurred in the past throughout California, with six year dry periods occurring three or four times in 100 years and nine year dry periods occurring less than once in 100 years. The simulated Six and Nine-Year Severe Droughts in MMWD's watershed showed that annual supply deficits of up to 7,000 AF would be expected under this kind of Severe Drought, beginning as early as the third year of drought. While the probability of occurrence for a drought of this severity and duration is low, simulating this Severe Drought provides useful insight into the vulnerabilities of MMWD's system and a condition that can be used to test resiliency options against to determine their effectiveness.

5.0 Options to Improve Resiliency

A wide variety of resiliency options were developed to explore how MMWD could increase its resiliency and meet demands in times of potential supply shortages caused by variable hydrology or system disruption. A total of 40 resiliency options were developed and grouped into eight categories based on the type of option. The supply categories include water use efficiency, reuse, expanded SCWA facilities, expanded storage, water purchases and groundwater, desalination, and emerging options. Each option was developed at a conceptual level including a description of the option, required facilities, cost, yield, reliability, implementation considerations, and conceptual maps or schematics. The resiliency options are summarized by group below and described in detail in **Appendix F**.

5.1 Water Use Efficiency

Options in this group focus on residential demand management, and include conservation as well as reuse of rainwater and graywater onsite. Different levels of conservation are described in the conservation resiliency option, and are implemented through a combination of programs including education and surveys along with fixture and turf replacement. The rainwater and graywater use resiliency option allows MMWD's residential customers to take advantage of onsite water resources through partial rebates provided by MMWD. The annual unit cost and yield, in acre-feet per year (AFY), for these resiliency options are provided in **Table 5-1**.

Table 5-1: Water Use Efficiency Options - Unit Cost and Yield

Resiliency Option	Cost ($/AFY)	Yield (AFY)
Enhanced Conservation	$2,190	286 to 1,400
Residential Rainwater and Graywater Use	$4,300	60

5.2 Reuse

The reuse resiliency options focus on treating and reusing water from existing municipal wastewater treatment plants and recycled water facilities. The options include expanded levels and/or volume of treatment at plants operated by the Sewerage Agency of Southern Marin (SASM), the Central Marin Sanitation Agency (CMSA), the Las Gallinas Valley Sanitary District (LGVSD), and the Richardson Bay Sanitation District (RBSD). These resiliency options include four levels of treatment and reuse:

- Direct potable reuse (DPR), in which wastewater is treated to potable levels and added directly to the distribution system

- DPR through lakes, in which wastewater is treated to potable levels and added to MMWD's supply system through one of its smaller lakes

- Indirect potable reuse (IPR), in which wastewater is treated to potable levels and added to one of MMWD's larger lakes so that it has at least a 6-month residence time in that lake, consistent with draft surface water augmentation regulations

- Recycled water (RW), in which wastewater is treated and used for non-potable uses such as irrigation.

The maximum IPR option would include using the maximum amount of effluent possible from all three treatment plants and adding it to the supply system through Kent Lake. The annual unit cost and yield for each of these resiliency options is provided in **Table 5-2**.

Table 5-2: Reuse Options - Unit Cost and Yield

Resiliency Option	Cost ($/AFY)	Yield (AFY)
DPR SASM	$2,300	1,600
DPR CMSA	$2,400	2,200
DPR Las Gallinas	$4,500	900
DPR Through Lakes SASM	$3,100	1,600
DPR Through Lakes CMSA	$2,600	2,200
DPR Through Lakes Las Gallinas	$5,800	900
IPR SASM	$3,600	1,600
IPR CMSA	$3,000	2,300
IPR Las Gallinas	$5,500	900
RW SASM	$3,000	100
RW CMSA	$2,800	200
RW RBSD	$6,300	30
Maximum IPR	$3,300	7,900

5.3 Expand SCWA Conveyance

Options in this group would expand the infrastructure used to convey water from Sonoma County Water Agency (SWCA) to MMWD. Recent pipeline improvements implemented by the North Marin Water District (NMWD) substantially improved the reliability of the pipeline that was replaced, but the constraints that limit MMWD's ability to receive SCWA supply to approximately 10,000 AFY out of its 14,300 AFY allocation remain unchanged. The options in this group would either expand the Kastania pump station, increase the capacity of a portion of the pipeline between Kastania pump station and Ignacio treatment plant, or both. The annual unit cost and yield for each of these resiliency options is provided in **Table 5-3**.

Table 5-3: Expand SCWA Conveyance Options - Unit Cost and Yield

Resiliency Option	Cost ($/AFY)	Yield (AFY)
SCWA Kastania Pump Station Expansion	$1,100	4,300
SCWA Pipeline Expansion	$1,300	4,300
Expand SCWA/NMWD Transfer Facilities	$1,400	4,300

5.4 Expand Storage

Options in this group would increase the amount of storage available to MMWD. This would be accomplished by increasing the storage volume of MMWD's existing reservoirs through raising Soulajule dam, dredging Nicasio Lake, or increasing usable storage in Nicasio Lake; by implementing surface storage outside of MMWD's existing reservoirs, such as by implementing storage in the gravel quarry or participating in an expanded Los Vaqueros reservoir; or by implementing groundwater options in the Lagunitas Watershed and Ross Valley or conjunctive use with other SCWA users in Petaluma or Santa Rosa Plain. The annual unit cost and yield for each of these resiliency options is provided in **Table 5-4**.

Table 5-4: Expand Storage Options - Unit Cost and Yield

Resiliency Option	Cost ($/AFY)	Yield (AFY)
Reservoir Excavation/Dredging	$15,500	1,000
Pump Station Improvements at Nicasio	N/A	0
Raise Soulajule Dam	$2,100	4,000
Local Groundwater Ross Valley	$2,600	400
Local Groundwater Lagunitas Watershed	$3,900	300
Petaluma Valley Conjunctive Use	$6,100	200
Santa Rosa Plain Conjunctive Use	$2,600	300
Expand Los Vaqueros	$7,200	1,400
Gravel Quarry Storage	$2,200	1,900

5.5 Water Purchases

Options in this group would allow MMWD to purchase water from other water agencies to be transferred to MMWD. Potential transfers could come to MMWD through a pipeline built between MMWD and East Bay Municipal Utilities District (EBMUD) along the Richardson-San Rafael Bridge or through other new infrastructure. Possible sources of water could be EBMUD, a spot transfer from an agency north of the Delta, Yuba County, Humboldt County, Solano County, or Napa County. Annual unit cost and yield for each of these resiliency options is provided in **Table 5-5**.

Table 5-5: Water Purchases - Unit Cost and Yield

Resiliency Option	Cost ($/AFY)	Yield (AFY)
EBMUD Pipelines	$2,500	1,700
Yuba County Transfer	$2,300	2,500
Humboldt County Transfer	$28,600	500
Spot Market Transfer	$3,400	1,700
North Bay Aqueduct	$3,000	5,000

5.6 Desalination

Desalination resiliency options would include the construction of new desalination facilities to treat ocean or bay water to potable levels. These treatment plants could range from 1 mgd to 5 mgd and could be located near the Richardson-San Rafael Bridge, Richardson Bay or Muir Beach. Additionally, MMWD could choose to participate in the Bay Area Regional Desalination project through partially funding a 70 mgd desalination plant located in the East San Francisco Bay area. Annual unit cost and yield for each of these resiliency options is provided in **Table 5-6**.

Table 5-6: Desalination Options - Unit Cost and Yield

Resiliency Option	Cost ($/AFY)	Yield (AFY)
Bridge Desalination	2,600	4,200
RBSD Desalination	2,900	4,200
Ocean Desalination	3,500	4,200
Regional Desalination	4,500	4,000

Skid Mount/Packaged System Desalination	3,500	1,100

5.7 Emerging Options

Additional options were explored based on their implementation in other locations throughout California and the world, and emerging understanding of their potential effectiveness in improving resiliency. These options include fog capture, cloud seeding, and watershed management. Annual unit cost and yield for each of these resiliency options is provided in **Table 5-7**.

Table 5-7: Emerging Options - Unit Cost and Yield

Resiliency Option	Cost ($/AFY)	Yield (AFY)
Fog Capture	$25,000	10
Cloud Seeding	$7,400	200
Watershed Management	$4,800	200

6.0 Evaluation of Resiliency Options and Development of Alternatives

To help inform which resiliency options should be carried forward, the district developed a series of evaluation criteria, each of which was assigned a relative importance. Each resiliency option was then assessed against these criteria. This chapter summarizes this process and discusses the resiliency alternatives that were developed to address various reliability threats.

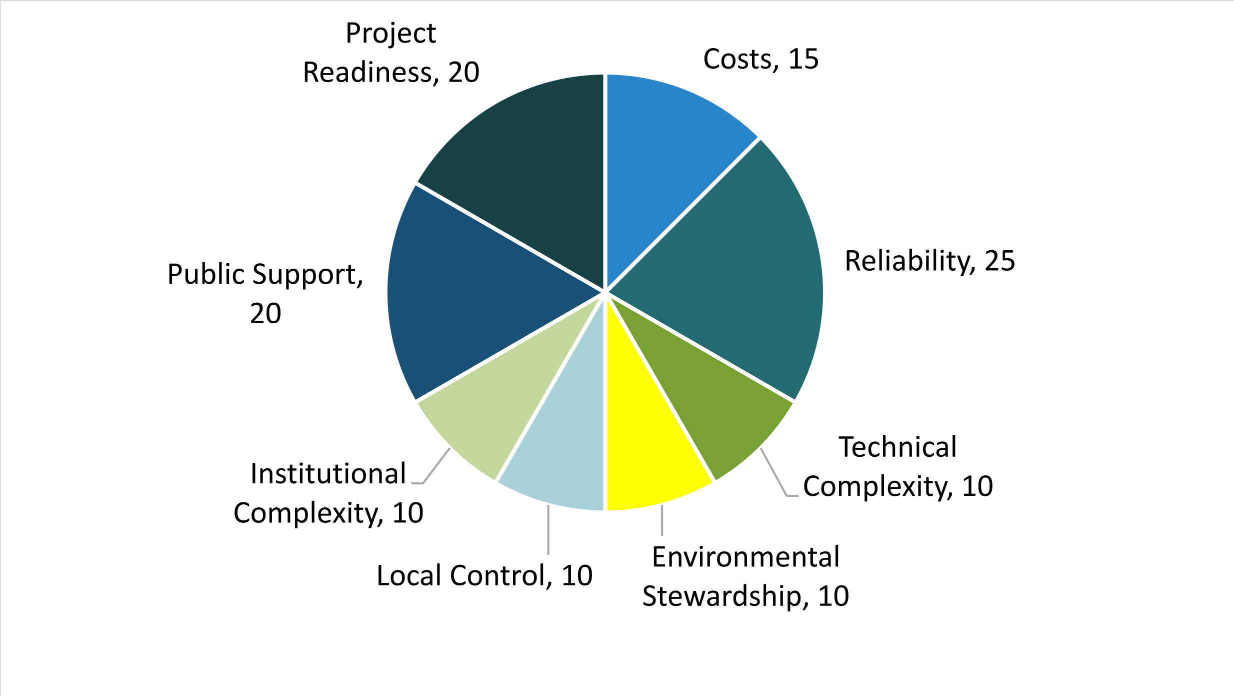
6.1 Evaluation of Resiliency Options

The district identified a list of eight criteria to be used to evaluate the resiliency options. These criteria included:

- Reliability – a measure of the option's expected average yield and its reliability under the different Reliability Threats
- Technical Complexity – assessment of operational complexity and feasibility
- Environmental Stewardship – measure of the degree of environmental benefit or impact of the option
- Local Control – assessment of the degree of control MMWD would have over implementation and operation of the option
- Institutional Complexity – assessment of the number and complexity of institutional cooperation and arrangements needed to implement and operate the project
- Public Support – general assessment of the degree of known public support or opposition to a project
- Project Readiness – assessment of the current status of the project and its readiness to proceed

Appendix G provides more information on the evaluation criteria. Each evaluation criterion was assigned a weighting factor, based on its relative importance. **Figure 6-1** shows the weight of each criterion. Reliability was identified as the most important criterion, followed by public support and project readiness.

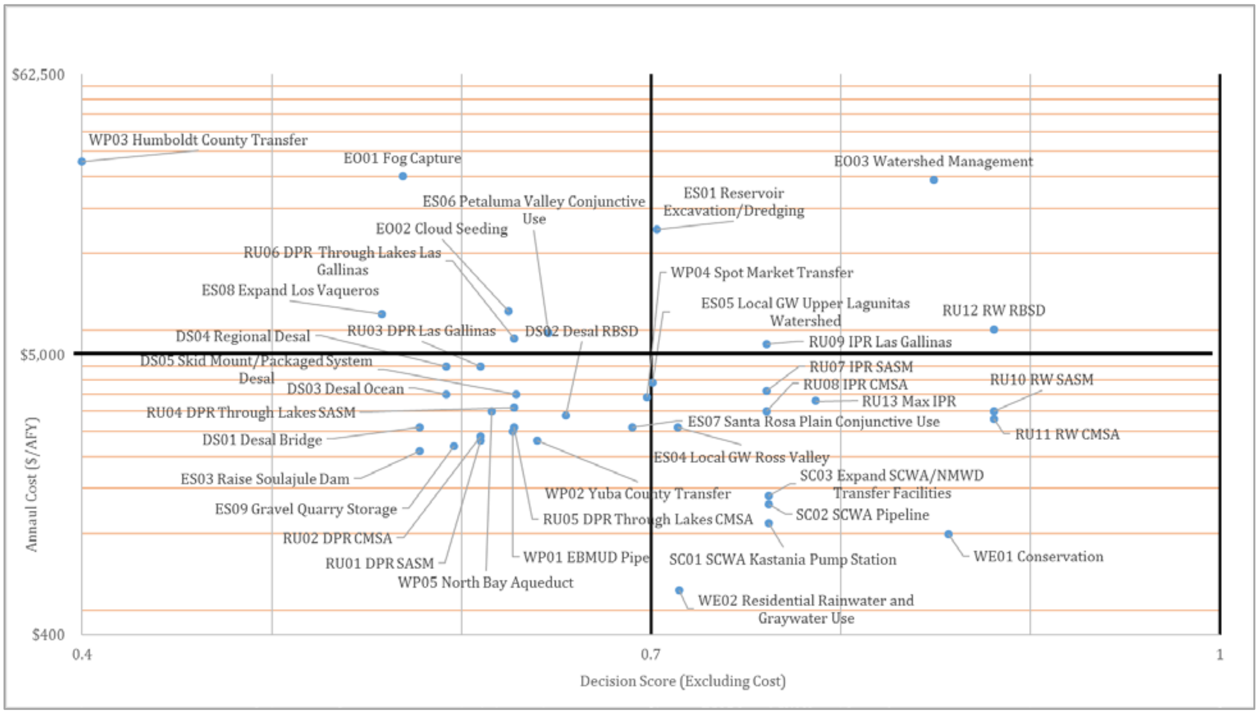
Figure 6-1: Resiliency Option Criteria Weights



To allow comparison across all criteria, scores were normalized, with a higher number indicating that the option performed better against that criterion. After each resiliency option was scored against the evaluation criteria, the option scores and evaluation criteria weights were input into Criterium Decision Plus (CDP) software. CDP computed a "decision score" for each option by applying the weight of each criterion to the option's score for that criterion. Two sets of decision scores were developed: one that considered costs and one that did not. More information on the evaluation criteria scoring and CDP results can be found in **Appendix H**.

Resiliency options were then analyzed using a four-quadrant methodology. **Figure 6-2** shows the results of the quadrant analysis. Each option was placed on the chart depending upon its decision score (without cost) and annual cost in dollars per acre-foot per year ($/AFY). This trade-off curve compared the decision score to the annual cost. Resiliency options that scored well include conservation, recycled water, watershed management, and groundwater. **Appendix H** presents additional information on the quadrant analysis.

Figure 6-2: Example Quadrant Analysis Results



6.2 Alternatives Development and Analysis

Alternatives, as defined for this Plan, are combinations of options to improve the district's resiliency under one or more of the reliability threats. Because no one option addresses all potential reliability threats, options were combined into multi-option alternatives around specific themes to better address resiliency needs. Five alternatives were developed, organized along the following themes:

- Expand Existing Programs
- Minimize Infrastructure
- Dry Year Actions
- Maximize Reuse
- Maximize Resiliency

The district grouped options into the alternatives, focusing on the highest benefit to cost options. Some options were used in more than one alternative and some options were not used in any alternative. **Table 6-1** below shows the composition of each alternative, as well as the associated costs and yields. More information on alternatives development is included in **Appendix I**.

Table 6-1: Water Resources Plan 2040 Alternatives

Options Included	Alternatives				
	Expand Existing Programs	Minimize Infrastructure	Dry Year Actions	Maximize Reuse	Maximize Resiliency
Enhanced Conservation	X	X	X		X
Regional IPR				X	X
SCWA Kastania Pump Station Upgrade		X			X
Santa Rosa Plain Conjunctive Use	X	X			
Spot Market Transfer			X		
Watershed Management	X				X
Total Dry Year Yield (AFY)	*2,000*	*3,900*	*6,000*	*7,900*	*11,000*
Total Average Year Yield (AFY)	*1,200*	*5,300*	*1,000*	*7,900*	*13,400*
Capital Costs ($M)	*$133.8*	*$5.9*	*$48.2*	*$359.3*	*$497.0*
Cost of Water ($M)	*$0.7*	*$5.0*	*$3.1*	*N/A*	*$4.3*
O&M Costs ($M/Yr)	*$0.6*	*$0.8*	*$0.8*	*$7.9*	*$8.7*
Total Annual Cost ($M/Yr)	*$10.4*	*$8.4*	*$8.6*	*$26.2*	*$40.6*

Each of the five alternatives was modeled in Marin WaterSim to determine its ability to improve the district's water supply availability and reliability under each reliability threat. A "No Action" alternative, representing current "business-as-usual" operations, was also modeled under each reliability threat to provide a baseline for comparing the five alternatives. All modeling was completed using the Base Case level of demand, as described in **Section 4.1**

Projected Water Demands. The alternatives were analyzed against nine metrics, including average annual deficit, maximum monthly deficit, and total system storage, to determine the effectiveness of each alternative. More information on the alternatives analysis is included in **Appendix I**.

6.3 Potential Resiliency Benefits

Simulating each alternative in Marin WaterSim provided information related to the alternatives' ability to improve resiliency under the various reliability threats and assuming the Base Case demand. The following sections summarize the resiliency benefits of each alternative in both demand scenarios. More information on the resiliency benefits of the alternatives is included in **Appendix I**.

6.3.1 Resiliency Benefits under Base Case Demand

Deficits were observed under the No Action alternative for the Six-Year and Nine-Year Severe Drought. The Six-Year Severe Drought deficits were eliminated by three of the proposed alternatives: Dry Year Actions, Maximize Reuse, and Maximize Resiliency. In addition, all alternatives increased storage under climate change as compared with the No Action alternative. **Table 6-2** below shows the resiliency benefits provided by each alternative under the Base Case demand.

Table 6-2: Deficits Observed with Base Case Demand

Alternatives	Reliability Threats									
	Single Year Drought	Extended Drought	Severe Drought (6 Yr)	Severe Drought (9 Yr)	Climate Change	Fire	Earthquake	Water Quality Impacts	Landslide	PG&E Outage
No Action	☐	☐	☑	☑	☐	☐	☐	☐	☐	☐
Expand Existing Programs	☐	☐	☑	☑	☐	☐	☐	☐	☐	☐
Minimize Infrastructure	☐	☐	☑	☑	☐	☐	☐	☐	☐	☐
Dry Year Actions	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐
Maximize Reuse	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Maximize Resiliency	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

7.0 Water Shortage Contingency Plan

As part of urban water management planning, water suppliers are required to provide a Water Shortage Contingency Plan (WSCP) that outlines how the supplier will prepare for and respond to water shortages. Responding to this requirement, the district included a WSCP in its 2015 Urban Water Management Plan (UWMP) outlining how the district would prepare for and respond to water shortages (MMWD, 2016a). Modeling work performed for the Water Resources Plan (WRP) 2040 provided updated information regarding potential shortages the district may face in the future. As a result of this effort, the district has opted to update components of its WSCP, which is provided in full in **Appendix J**.

The State is currently undergoing an effort to update the requirements for water shortage contingency planning. Executive Order (EO) B-37-16, issued on May 29, 2016, builds on the existing requirements from SB X7-7 and includes a provision to strengthen the requirements for urban WSCPs. Draft requirements will be publicly released by January 10, 2017. As a result, the current WSCP as contained in the district's 2015 UWMP will remain in place until the State's requirements are finalized. At that time, the district will revisit the proposed WSCP as presented in **Appendix J** to confirm compliance with the new requirements.

In 1999, the district developed a rationing plan (Title 13 sections 13.020.30-13.02.040), with updates in 2011, 2014, and 2015. The district's prior WSCP included three triggers at 10 percent, 25 percent, and 50 percent rationing levels. This new WSCP includes five triggers that were selected because they provide the district more flexibility in addressing dry periods early. They were developed as a result of the GoldSim modeling effort and designed to allow the district to manage its supplies through a Six-Year Severe Drought. **Table 7-1** shows the five stages of water shortage in the updated WSCP. The water rationing stages are linked to the amount of water in the district's reservoirs. These triggers

Table 7-1: Stages of WSCP

Stage	Percent Supply Reduction	Water Supply Condition
1: Advisory Stage (Voluntary Rationing)	10%	Total reservoir storage[1] is less than 60,000 acre-feet on April 1
2: Alert Stage (Mandatory Rationing)	20%	Total reservoir storage is less than 50,000 acre-feet on April 1
3: Severe Stage (Mandatory Rationing)	25%	Total reservoir storage is less than 40,000 acre-feet on April 1

Stage	Percent Supply Reduction	Water Supply Condition
4: Critical Stage (Mandatory Rationing)	30%	Total reservoir storage is less than 30,000 acre-feet on April 1
5: Emergency Stage (Mandatory Rationing)	50%	Total reservoir storage on December 1 is projected to be in the vicinity of, or less than, 25,000 acre-feet
NOTES: (1) Total reservoir storage includes emergency storage and dead storage.		

In addition to the stages above that are linked to local water supply conditions, the district has added an additional trigger that is decoupled from local supply conditions. Outside factors, such as executive orders, could require the district to implement water use reductions for reasons potentially unrelated to supply conditions. For example, Executive Order B-29-15 required the district to reduce demand by 20 percent, not because its local storage had reached a level that would dictate this reduction as necessary. Recognizing that outside factors could generate a need for demand reduction, the district has included a trigger that, should an outside factor dictate a reduction, allows the district to select a stage from one of the five stages in **Table 7-1** based on the level of reduction needed.

The full language of the updated WSCP can be found in **Appendix J**.

8.0 Conclusions and Recommendations

The analysis conducted in support of the district's WRP 2040 has determined the district's current supply portfolio is sufficient to meet demands in each of the reliability threats modeled except the Six-Year Severe Drought. It should be noted that the probability of the Six-Year Severe Drought occurring is low. Should this drought occur, shortages would not be expected until the fifth year of the drought, which provides time to re-assess and move forward implementation of resiliency options after the drought starts. As a result, there is not an immediate need to invest in infrastructure to secure additional resiliency at this time. However, to continue strengthening the district's water supply resiliency, it is recommended that the district expand existing water efficiency programs. This could involve implementing the Expand Existing Programs alternative as discussed in **Section 6.2 Alternatives Development and Analysis**, which would increase water conservation, expand watershed management, and explore opportunities associated with in-lieu groundwater transfers. More information on the recommended program is included below and in **Appendix I**.

8.1 Evaluate Increased Conservation

The district is currently maintaining an aggressive level of conservation throughout the service area, and has committed to continuing this investment in conservation and water use efficiency efforts in the future. The current level of commitment is referred to as "Program A" in the *2015 Urban Water Management Plan Water Demand Analysis and Water Conservation Measures Update* report by Maddaus Water Management (Maddaus, 2016). This program yields average annual savings of 1,180 AF at a cost of $700/AF. The report identifies two other potential programs, Programs B and C, each with increasing levels of conservation. If the district modestly increased its conservation program to implement Program C (which also includes Program B), the district could achieve an additional 265 AF in savings at an additional cost of $270/AF above Program A. If the district further maximized some of the measures included in Program C, the district could save 700 AFY above Program A at an annual cost of $1,080/AF. If the district maximized all measures, savings would be 1,000 AFY above Program A at an additional annual cost of $990/AF.

It is recommended that the district further evaluate implementing an enhanced level of conservation up to 1,000 AFY. While the alternative Expand Existing Programs reflects this maximum conservation level of 1,000 AFY, it is recognized that this level of conservation requires a significant investment that may be beyond current budgetary constraints. It is recommended that the district assess budgetary changes needed to further enhance conservation programs beyond current levels and allow for variations based on customer response, supply conditions, and desired level of investment. While managing demand does not provide resiliency in the case of supply interruptions such as earthquakes or water quality issues, it can help mitigate dry periods by reducing demand baseline demands.

On May 9th, 2016, the California Governor signed Executive Order (EO) B-37-16. This EO mandates that a draft framework outlining new water use targets be publicly issued by January 10th, 2017. At the time when guidelines are finalized, the district will need to reevaluate its current conservation measures to determine their effectiveness at meeting the new requirements.

8.2 Invest in Watershed Management

The district has published a draft Biodiversity, Fire, and Fuels Integrated Plan (BFFIP) that describes action that the district will take over the next several years to minimize fire hazards and maximize ecological health on its watershed lands (MMWD, 2016b). The 27 management actions outlined in the plan define and guide the methods to minimize risk from wildfires while preserving and enhancing existing significant biological resources.

Studies have shown that preventative management of fuels, while providing a wildfire benefit, can also increase the quantity of and protect the quality of water supply. The BFIPPs management action 23 improves forest stand structure and function by reducing accumulated fuels and brush. It is recommended that the district expand the implementation of management action 23, as budgetary constraints allow. The alternative Expand Existing Programs reflects a watershed management option that would increase the scope of BFFIP implementation to a level that would increase yield by 210 AFY at a cost of $24,200 per AF. As with increased conservation, it is recommended that the district assess increasing watershed management up to this level, allowing for variation based on supply conditions, outside funding, and desired level of investment. This option is recommended primarily because it is a multi-benefit option that will be implemented through the BFFIP, though on a smaller scale. Expanding the program provides multiple benefits both by reducing risk of fire impacts to the watershed and increasing supply availability and associated resiliency. Due to the multiple benefits of this option, it is assumed that cost sharing would be available.

8.3 Explore Groundwater Partnering Opportunities

The Santa Rosa Plain Conjunctive Use resiliency option includes partnering with a SCWA customer(s) that also uses groundwater supplies to implement an in-lieu groundwater recharge program. The option assumes that the cities of Rohnert Park and Santa Rosa would be potential candidates for the exchange, given their historical groundwater pumping. In this option, the district would allow a portion of its SCWA supply to be used by a partner agency in normal and wet years to offset local groundwater pumping, allowing the basin to recharge and store additional water in those years. The partner agency would then rely on this replenished groundwater supply in dry years, sending some or all of its SCWA supply to the district. The amount of additional SCWA supply received by the district in dry years would be approximately equal to the amount the district sent to the partner agency in normal and wet years, accounting for basin losses. This allows the district to functionally “store” water in the groundwater basin for use in dry years, with minimal to no infrastructure invested, optimizing the timing of its existing SCWA supply. Capital costs are estimated at $1,000,000 with annual costs of $431,000. For the purposes of this study, it was assumed that the district could increase dry year yield by 300 AFY on average at a cost of roughly $1,400 per AF. It is recommended that the district explore discussions with Rohnert Park and Santa Rosa to determine their level of interest in the project. Other potential partners include the cities of Petaluma and Sonoma, the town of Windsor, and the Valley of the Moon Water District.

9.0 Next Steps and Implementation Approach

Using the information provided in this Water Resources Plan 2040, the district will decide what level of investment, and at what time, is desired to achieve enhanced resiliency. Should the district elect to implement one or more alternatives or options identified in this plan, an appropriate level of review and assessment will be completed as required by the California Environmental Quality Act (CEQA) and / or the National Environmental Policy Act (NEPA).

9.1 Adaptive Management and Plan Updates

Adaptive management is a valuable tool that can help the district proactively respond to changing conditions. It is an iterative process that aims to reduce uncertainty over time through periodic monitoring. To this end, the district will reconsider, and update as needed, its Water Resources Plan every five years, consistent with its UWMP update. The reason for this timing is twofold: (1) a key part of the WRP Update and adaptive management will involve re-assessing the status of service area demands and conservation effectiveness, which drives demands on the system, and (2) periodic review and update will allow the district to capture newly identified risks as well as resiliency options without ending up in a position whereby too much time has passed between updates to make meaningful and proactive course corrections. Because the greatest resiliency threat identified is a Six- to Nine-Year Severe Drought, a five-year update cycle allows the district to remain ahead of a prolonged drought.

In addition to this regular review and update cycle, it is recommended that the WRP be re-assessed and additional resiliency actions implemented should any of the following conditions occur:

1) District reservoir storage drops to 40 thousand acre-feet (TAF); and

2) District reservoir storage drops below 50 TAF three times in two consecutive years.

These triggers provide for additional protection against severe droughts of an unanticipated and unprecedented nature. Plan updates will include confirming the district's current water supply portfolio, updating demand projections, confirming conservation effectiveness and remaining potential, updating climate and drought projections, and revisiting resiliency option decisions to confirm or modify the district's implementation approach.

9.2 Additional Study

As part of its adaptive management strategy, it is recommended that the district continue to explore other resiliency options in the intervening periods between Plan updates. This exploration will provide the district with additional information related to other resiliency options that can be incorporated into Plan updates. **Table 9-1** indicates various recommended activities as well as which resiliency options these activities would inform. Each of these activities is described in more detail below.

Table 9-1: Recommended District Activities

Activity	Water Use Efficiency	Reuse	Expand SCWA Conveyance	Expand Storage	Water Purchases and Groundwater	Desalination	Emerging Options
Monitor groundwater studies			✓	✓			
Engage in regional efforts		✓	✓	✓	✓	✓	
Conduct pilot studies	✓	✓				✓	✓
Understand property ownership within corridors		✓	✓	✓	✓	✓	
Survey public opinion	✓	✓				✓	
Map stormwater resources		✓		✓			✓

Monitor Groundwater Studies

While the district has engaged in a number of groundwater studies in the last 40 years, additional studies being conducted in Sonoma County could help inform the groundwater resiliency options considered in the Water Resources Plan 2040. Specifically, the district should monitor the progress of the studies that clarify the groundwater quality and safe yield in the Santa Rosa Plain Groundwater Basin and Petaluma Valley Groundwater Basin, both of which would be beneficial to understanding optimal recharge and extraction areas.

Engage in Regional Efforts

A number of regional efforts currently underway could potentially provide benefits to the district. In 2014, eight agencies, including MMWD, initiated the Bay Area Regional Reliability (BARR) effort. The purpose of BARR it to evaluate near and long-term reliability projects that could incorporate a regional approach to achieving water supply reliability. Currently, there are a number of projects emerging as a result of this regional work that could provide benefits to the district. In addition to BARR, updates to the Bay Area Integrated Regional Water Management Plan (IRWMP) could also provide opportunities for the district.

Conduct Pilot Studies

Pilot studies are useful for determining the feasibility of projects while avoiding the large capital cost associated with full construction and implementation. A pilot study could provide more information on residential rainwater and graywater use, indirect potable reuse, or desalination.

Understand Property Ownership within Corridors

A number of the resiliency options included in the Water Resources Plan 2040 require the construction of pipelines. A better understanding of the land ownership along major corridors that could support pipeline infrastructure would help the district determine which alignments could be more cost effective and less disruptive.

Survey Public Opinion

The most recent recycled water feasibility reports and master plans in the region were published in 2014, with work completed prior to the current drought. As many agencies are discovering, public acceptance of recycled water and potable reuse has changed as a result of the severity of the drought. Understanding current public opinion regarding the use of recycled water and potable water can inform water supply decisions in the future. In addition, the district cannot construct or approve funding for construction of any desalination project unless such construction is approved by the majority of district voters voting in an election. A survey would provide valuable information related to any changes in the public's opinion on desalination.

Map Stormwater Resources

As the climate changes, less frequent and more intense storms are anticipated. These storms, without the proper planning and infrastructure, will likely cause increased flooding. Understanding the stormwater infrastructure, including storm drains and stormwater basins, can inform the beneficial reuse of stormwater and reduce flood damage. Stormwater reuse can also help improve San Francisco Bay water quality by reducing the pollutant load during storms.

10.0 References

Marin Municipal Water District. 2016a. *2015 Urban Water Management Plan*. June 2016. Available at: http://marinwater.org/DocumentCenter/View/4016.

Marin Municipal Water District. 2016b. *Draft 2016 Biodiversity Fire and Fuels Integrated Plan*. September 2016. Available at: http://marinwater.org/DocumentCenter/View/4439.

Maddaus Water Management. 2016. *2015 Urban Water Management Plan Water Demand Analysis and Water Conservation Measures Update*. May 2016.

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Appendix A

Public Comments and Responses

MMWD WRP 2040 Comments and Responses

Comments	Responses
General Comments	
Will this process require CEQA?	This project is a planning project that does not commit the district to implement anything, so CEQA is not required; the document will reinforce that CEQA would be required prior to implementing any alternatives.
How does this work address the Governors order to show sufficient supply to address a five-year drought?	The report shows that Marin has sufficient supply to meet demand through a five-year drought if the district dips into its emergency storage.
How often will this work be updated?	It is recommended that the district re-evaluate every 5 years to coincide with Urban Water Management Plan updates.
60 gpcd is a more realistic solution to dry periods.	In other studies around the state, 55 gpcd has been noted as the lowest possible gpcd for indoor use. If demands were this low, outdoor use would be eliminated which would create severe economic impacts. These economic impacts would need to be weighed against the impacts of developing additional supply.
The district should consider developing drought preparedness kits similar to earthquake preparedness kits.	Yes, this could be used as an opportunity to provide drought information to customers.
Does 124 gpcd include all types of use, including industrial?	Yes, this number includes all municipal, commercial, institutional, and industrial demands.
Data and Methodology	
What source of data was used for the population estimate?	The population estimate comes from the district's 2015 Urban Water Management Plan. Current population is from Department of Finance data; projected population is from Association of Bay Area Governments data, which is derived from Census data.
How much rainfall characterizes a dry year?	In the analysis, a single critical-dry year (represented by 2013 hydrology) is characterized by 10.7 inches of rainfall.
Does the report evaluate less environmental releases?	No, the report assumes that the current level of environmental releases will be required in the future.
Events and Futures	
One of the Futures is water quality impacts. What specific water quality impacts were considered?	Water quality impacts could come from any number of incidences, including intentional contamination, landslide, or fire. For the purposes of this analysis, the exact impact was less of a concern. The more important aspect was the impact to the facility and the district's ability to meet demands.
Does the report consider events, like a major regional earthquake, that would cause a sharp rise in population due to people moving to Marin? Are there other efforts that are looking at this?	No, the report does not account for events that would cause regional displacement. We are not aware of any regional efforts to address this.

MMWD WRP 2040 Comments and Responses

Comments	Responses
The work performed by Pepperwood makes our situation seem more dire.	The district's analysis uses Pepperwood output to create a dataset specific to MMWD's supply and service area, which runs through 2100. The analysis uses Pepperwood's data through 2100 with the district's 2040 level of demand.
Does the report consider the likelihood of a decade long drought similar to what happened in Australia?	No. While it is possible that California could experience a decade long drought, the analysis shows that the probability of a 6-year drought is between 3% and 4%.
Resiliency Options	
Why is yield of potential conservation efforts so low?	Yield was determined from conservation modeling completed by Maddaus Water Management in May 2016.
What would the cost be to maximize conservation?	An option that further expands conservation will be added to the resiliency options evaluation.
EBMUD pipeline will face opposition.	These options were included to analyze a wide range of potential resiliency options; all options evaluated preliminarily will not be carried forward
Water from Yuba County may be limited in the future.	
Humboldt County faced opposition during last attempt at a transfer and a spot market transfer is unreliable.	
Cost of transfers must be included.	Assumptions related to cost of water for transfers is included.
Costs seem high for rainwater collection and gray water use efforts; what about cost sharing?	Costs have been adjusted to reflect more realistic implementation; we have assumed 50/50 cost share between the consumers and the district.
Consider work Tree People is doing in Los Angeles.	Option updated to include work from Tree People and renamed the option to Residential Rainwater and Graywater Use.
Why are we looking at expanding NMWD pipeline/Kastania? It was already expanded.	The option expands the remaining section of the NMWD pipeline and includes use of Kastania Pump Station.
Where does additional 4,000 AF come from?	Additional 4,000 AF is included in the current MMWD - SCWA contract (up to 14,300 AFY).
What about water from Lake Sonoma?	The additional 4,000 AFY is from Lake Sonoma.
Pull conservation and onsite reuse out of "other" category.	A "water use efficiency" category will be included in the resiliency evaluation.
For the reuse options, does the analysis account for decreased supply as a result of increased conservation?	No, the report does not account for this. If the district decides to implement reuse options, further study to determine a baseline supply will need to be conducted. However, it should be noted that if demands follow the upper range scenario, 2040 demands could decrease by 10% and supply available for reuse projects would be consistent with what is included in the analysis.

MMWD WRP 2040 Comments and Responses

Comments	Responses
The Ross Groundwater resiliency option would affect streams and cause irreparable groundwater depletion.	The WRP 2040 analyzed a wide-range of options, including the use of the Ross Valley Groundwater Basin. However, this resiliency option is not being recommended as part of the district's future resiliency portfolio. Even before it could be implemented, a full CEQA analysis would need to be completed.
Did you prioritize the list of resiliency options?	In evaluating the resiliency options against the evaluation criteria, the district developed a benefit-cost analysis for each option. However, the district did not prioritize the recommended options given that, based on the futures modeled, the analysis found no immediate need for increased resiliency. If, in the future, an unforeseen situation occurs, the district could use the analysis of the 40 options to determine which option most appropriately addresses the unforeseen situation.
Please provide lead time on all resiliency options so that its clear how long it would take to get the project implemented.	This will be added to the report for all resiliency options.
Does the report incorporate how reasonable it would be to implement the resiliency options?	Yes, this is included in the report related to the analysis of the options.

Appendix B

MMWD Model Selection Technical Memorandum

Technical Memorandum

MMWD Water Resources Plan 2040

Subject: **MMWD Model Selection**

Prepared For: Carl Gowan and Lucy Croy, MMWD

Prepared by: Enrique Lopezcalva and Katie Cole, RMC

Reviewed by: Alyson Watson, RMC

Date: October 23, 2015

Reference: 0041-010

The purpose of this Model Selection Technical Memorandum (TM) is to aid Marin Municipal Water District (MMWD/District) in the selection of a modeling platform for use in the Water Resources Plan 2040 and beyond. This TM documents modeling objectives, compares a variety of models, and recommends a modeling platform. These recommendations will be discussed with the MMWD project team in a conference call and meeting to provide clarification and additional information, as necessary, for MMWD to make a decision.

1 Background

The following subsections provide an overview of the project background, including modeling needs and MMWD's previous and current modeling tools and efforts.

1.1 Project Background

MMWD is preparing a Water Resources Plan (Plan) that will identify a range of alternatives for water supply resiliency through the year 2040. The Plan will evaluate those alternatives to make specific recommendations on projects and programs that, when implemented, will meet water demands under normal conditions as well as through extended drought, climate variability, long term maintenance projects, operational impacts of earthquakes and / or wildfires, and other factors that could potentially impact water supply. These types of disruptions could occur today and in the very short-term; thus the plan is to increase the District's resiliency.

The District's water supply is predominantly supported by a system of seven local lakes capturing runoff from local watersheds, and existing storage capacity represents only about two years of demand. From December 2012 to January 2014, MMWD experienced a period of very low precipitation, and their reservoirs reached significantly low storage conditions that nearly triggered significant mandatory reductions. Water supply circumstances then changed again in early February 2014 when the District received 15 inches of rain, more than the total rain during the prior 400 days combined.

As part of the Water Resources Plan 2040, RMC is tasked with developing a hydrologic modeling tool that can comprehensively model the District's system under a variety of hydrologic conditions and resiliency scenarios. The model will be used as an analytical tool for the development of the Plan and will also be adopted by MMWD to develop annual operating plans, refine those plans mid-year, as needed, and assess alternative operating strategies under potential extended periods of maintenance of key elements of the lake water system.

1.2 Previous and Existing Models and Modeling Efforts

The District developed a hydrologic model in 1989, which is no longer used. Recently, the District has used a mass balance tool developed in MS Excel to determine the operational yield of the water system under different conditions, using data and assumptions for lake water inflows into the reservoirs and demand and storage data. This tool was used several times during the current drought to assess conditions and to brief upper management and the District's Board on likely short-term conditions.

The District currently has two hydraulic models in use, one for the lake water system and one for the treated water distribution system. The lake water system model is a simple model developed in EPANet, which includes the reservoirs, pump stations, and force mains to simulate different operational conditions. For the treated water distribution system, the District developed and adopted a model in 2013 using Innovyze software. The Innovyze platform has the capability to model both the lake and treated water systems, though the District has mostly been using the tool for the treated system. Innovyze also produces a software suite for hydrologic modeling, but MMWD doesn't currently have that package and uses the tool for hydraulic modeling of the treated system only.

The District's Microsoft Excel tool has helped MMWD to develop its annual operations plan. This tool can be used to project available flow and storage in each reservoir based on various rainfall/inflow scenarios.

The District currently doesn't have a mechanistic model to generate inflows based on precipitation data and forecasts (no rainfall-runoff tool is available).

2 Modeling Needs and Objectives

This section documents the modeling needs and objectives of the District. Generally, the selected modeling platform should enable the District to simulate various different operating scenarios and use the simulation results to evaluate the best course of action for operating their lake water system on an annual basis. The following subsections cover the MMWD's needs related to a modeling platform, based on four sources of information: the project RFP, discussions during the August 24 kick-off meeting, information received during the September 8th, 2015 modeling meeting, and discussions during a modeling conference call on September 14th, 2015.

2.1 Geographic and Temporal Scope and Resolution

The geographic scope for the modeling tool should include MMWD's lake water system: the watersheds of all seven reservoirs, the reservoirs themselves, and the pump stations and water mains up to the water treatment plants.

Temporal resolution refers to the timestep of the modeling results. For the District's purposes, a monthly timestep is preferred. A daily timestep may provide some benefit, but is not a major need of the District at this time. The temporal scope, or the hydrologic period of record covered by the model, should be adequate to capture a variety of year types and the model should be able to run long-term simulations from one year to several decades (to be able to analyze the performance of the system, probabilistically, under long-term hydrology).

2.2 Questions the Model Needs to Answer

A critical step in selecting a modeling platform is defining the questions the model needs to answer, and the frequency with which the model needs to be used to answer those questions. Based on the information received in the project meetings and RFP, MMWD would like to be able to use the model to answer four categories or questions: 1) Questions related to defining an annual operating plan; 2) Questions related to operating modes under loss of service conditions; 3) Questions related to long-term system decisions; and 4) (lower priority) Questions related to water quality.

Operating Plan

MMWD will use the model to define its annual operating plan. The model will be used to optimize water use and storage, to the greatest extent possible, based on real/observed demand and storage data and expected/presumed inflow conditions for the coming few months. At a higher level of analysis, the model could also be used to optimize the cost of the overall lake supply operation. Related to the operating plan is the output of reservoir refill probability under different operating decisions (and a given set of inflow assumptions).

Loss of Service

The second category of questions is centered around loss of service during extended periods of time (one to several months), which could be triggered by long-term maintenance projects and some emergency scenarios. For instance, the model should allow the District to assess the short- and long-term risks associated with taking facilities off-line and be able to evaluate mitigation plans for planned outages. Additionally, the model should be able to assess how long MMWD could sustain service if a given reservoir, force main, or pump station were to be off-line due to planned or unplanned circumstances (i.e., earthquakes and wildfires).

Long-Term System Decisions

The third category is related to the definition of a safe yield for the system and the evaluation of its long-term performance under multiple operational decisions or scenarios. The model should be able to simulate baseline conditions with alternative hydrology, demand, or operating conditions. Additionally, the model should be able to simulate new facilities and sources associated with resiliency planning alternatives (additional imported supplies, desalination, additional recycled water, indirect potable reuse, additional water use efficiency measures, etc.). The model needs to evaluate the reliability (size and likely frequency of shortages) of the system under multiple long-term simulation conditions.

In this mode, the model will help MMWD assess the reliability and consequences of alternative emergency storage levels. The model should also be able to be used to conduct reliability analyses for historical drought conditions and climate change-related drought conditions. This is the main category of questions that will be asked during the Water Resources Plan 2040 process.

Another important consideration for model selection is the need to simulate climate change-impacted hydrology. The process to define stream flows under climate change conditions has not been completely defined but if the District seeks to generate stream flows based on precipitation assumptions, the model should have the ability to generate flows (as opposed to only using flows as inputs to the simulation).

Water Quality

A lower priority set of questions is related to water quality. Alkalinity and turbidity are parameters of interest since their variability can create treatment challenges for the District, which could lead to higher chemical / treatment costs or temporary reliance on other supplies.

2.3 Intended Users

The model platform should be designed with the end users in mind. For MMWD, the main users of the model would be Water System Planning and Special Projects. Operations staff may use the tool but are not the primary intended users since their focus is on the operation of the distribution system (treated water). The model should also be structured in such a way that MMWD staff can update the model, including adding new data and system components, without requiring consulting assistance.

3 Common Features and Types of Hydrologic Modeling

The term “hydrologic model” is used to refer to models that have a wide-ranging set of scopes and capabilities. The common feature of hydrologic models is that they include the modeling of flows generated from precipitation and/or snowmelt. Hundreds of models, however, can be used that include this feature to different degrees and that emphasize other aspects of the water resources (natural or engineered) system. Some useful distinctions in the context of this project include:

- Models limited to rainfall-runoff vs. models with rainfall-runoff and significant hydraulics elements vs. models with limited rainfall-runoff and heavy emphasis on hydraulics
- Event-based models vs. long-term simulation models
- Models better suited to engineered channels vs. models better suited to natural streams

These distinctions apply not only to the models themselves, but also to the use of a given modeling tool.

MMWD's modeling objectives will be best achieved with a modeling tool that has the ability to simulate hydrology (rainfall-runoff), long-term simulations, and natural settings (non urbanized watersheds). This last feature (ability to mode non urbanized watersheds) may be less important since there are no specific objectives related to flood management or predictions. The watersheds may be able to be simplified to the extent that the inflows into the reservoirs can be computed correctly. An additional key characteristic of the ideal model for MMWD is the ability to efficiently model a system of reservoirs (less emphasis on hydraulics and more emphasis on mass balance).

4 Criteria for Selection of Model Platform

MMWD's model should be able to address hydrologic processes as well as system operation, with a system that includes reservoirs, gravity flows, and pumped flows. Selection of one or more available software programs to implement the model must consider the technical capabilities of each software as well as key software characteristics, such as professional acceptability, availability, user-friendliness, and level of support.

Technical capabilities of a model that can meet the modeling needs and objectives described above include the capability to simulate the elements listed in Table 1.

Table 1: Model Required Simulation Capabilities

Identifier	Element to Simulate
1	Rainfall-runoff on tributary watersheds to each of the reservoirs (budgets to generate stream flow: evapotranspiration, irrigation, soil moisture storage, and deep percolation)
2	Evaporation from open water surfaces
3	Reservoir operations
4	Changes in urban water demand over a range of hydrologic conditions, from wet to very dry (directly or by preprocessing)
5	Changes in water supply availability from other sources (directly or by preprocessing of demands)
6	Demand-supply balance (reliability) directly or by post processing model results
7	Monthly unit time and long-term simulations of several decades
8	[Not critical, but desired]: some water quality parameters

The criteria recommended for selection of the modeling tool include the extent to which the modeling tool can simulate the conditions above, and how practically and efficiently it does it, plus the additional criteria listed in Table 2.

Table 2: Model Selection Criteria[1]

Identifier	Criteria
1	Ability to simulate elements in Table 1
2	User friendliness for running and processing results[2]
3	User friendliness for programming new elements or modifying model[2]
4	Size of user base
5	Level of support and documentation
6	Cost of license and license maintenance
7	Code ownership and openness[3]
8	Use in similar applications to MMWD

[1] Professional acceptability is a common criterion in model selection. For this MMWD project, all model alternatives evaluated are professionally accepted.
[2] User friendliness criteria include: graphical user interface to assist in inputs and output visualization, including post-processing model results; straightforward process for simulation setup and quick and manageable running times; easy generation of hydrographs, time series graphics for different variables, and other graphics for model outputs; easy generation of tabular reports; graphical user interfaces to program new features; and simple process for re-calibration and validation once new features are added to the model.
[3] Code ownership and openness refers to whether the model code is public domain and can be readily obtained from either a public agency or from standard technical software vendors.

The following section lists potential software tools for the MMWD model and Section 6 assesses each alternative against the required capabilities in Table 1 and criteria in Table 2.

5 Potential Options

More than ten software options were explored and considered for this project. Each tool's general characteristics and applicability was assessed based on how closely its main applications align with MMWD's modeling needs and objectives. The main characteristics of each model considered are tabulated in Appendix A. Of these initial options, six models were short-listed for further consideration by MMWD. These include models that are capable of simulating hydrology and hydraulics, models that can adequately simulate natural settings as well as engineered ones, models that are not only event-based but are adequate for long-term simulation and models that can simulate a system of reservoirs (features described in Section 3).

The following descriptions provide actual text describing the models taken from the software manufacturers' websites as well as a summary of RMC's experience with each tool.

HEC ResSim

From HEC website: "*The Reservoir System Simulation (HEC-ResSim) software developed by the U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center is used to model reservoir operations at one or more reservoirs for a variety of operational goals and constraints. The software simulates reservoir operations for flood management, low flow augmentation and water supply for planning studies, detailed reservoir regulation plan investigations, and real-time decision support. HEC-ResSim can represent both large and small scale reservoirs and reservoir systems through a network of elements (junctions, routing reaches, diversion, reservoirs) that the user builds. The software can simulate single events or a full period-or-record using available time-steps.*"

RMC analysis: HEC-ResSim has a sophisticated way of modeling the rules for operating reservoirs and it is built to deal with complex systems with multiple reservoir objectives. It can be used not only for water supply and flood control but also for power generation, navigation, recreation and environmental quality. The tradeoff is reduced user friendliness in programming simple systems.

Link:

http://www.hec.usace.army.mil/software/hec-ressim/

WEAP

From WEAP's website: "*[WEAP] provides a comprehensive, flexible and user-friendly framework for planning and policy analysis…WEAP can simulate a broad range of natural and engineered components of these systems, including rainfall runoff, baseflow, and groundwater recharge from precipitation; sectoral demand analyses; water conservation; water rights and allocation priorities, reservoir operations; hydropower generation; pollution tracking and water quality; vulnerability assessments; and ecosystem requirements. A financial analysis module also allows the user to investigate cost-benefit comparisons for projects.*"

RMC analysis: WEAP is a software tool for integrated water resources planning. WEAP is a common planning tool in water resources, becoming more common in United States and globally. Its main applications are decision support under uncertainty and "what if" scenarios. It is specifically designed for water resources and designed as a systems model. It is mass balance based and has no embedded hydraulic equations. It has a module for rainfall-runoff where stream flows can be derived mechanistically with rainfall data. WEAP is being adopted by the State of California to support updates to the California Water Plan.

Link:

http://www.weap21.org/

RiverWare

From RiverWare's website: "*RiverWare is a river system modeling tool. It is an ideal platform for operational decision-making, responsive forecasting, operational policy evaluation, system optimization, water accounting, water rights administration, and long-term resource planning. The wide range of applications is made possible by a choice of computational timesteps ranging from 1 hour to 1 year.*"

RMC analysis: RiverWare is a tool commonly used by the US Bureau of Reclamation. It has strong capabilities and sophisticated math to keep track of water rights priorities in complex river systems, and thus, it is the preferred tool for administrative models in rivers in Colorado, Texas, New Mexico and generally the western United States. It does include significant capability to simulate reservoirs.

Link:

http://cadswes.colorado.edu/creative-works/riverware

GoldSim

From GoldSim's website: "*GoldSim is a general purpose simulator that utilizes a hybrid of several simulation approaches, combining an extension of system dynamics with some aspects of discrete event simulation, and embedding the dynamic simulation engine within a Monte Carlo simulation framework…Water resources and hydrologic applications include municipal water resources management and water supply planning; simulation of the transport and fate of contaminants (or natural constituents such as microbes) in aquifers, wetlands, lakes and other ecosystems; and water balances and water quality management at constructed facilities.*"

RMC analysis: GoldSim is not a water resources modeling tool, specifically, but it is well suited for water resources and commonly applied to water resources settings. GoldSim is object-oriented programming with reservoirs as objects pre-programmed for customized models. The reservoir operating rules of simple systems can be easily simulated in GoldSim and the main advantage of this software is that anything can be programmed because it isn't constrained to pre-defined applications and corresponding equations. One of the main strengths of GoldSim over similar generic tools is its ability to model probabilistically.

Link:

http://www.goldsim.com/Home/

MIKE11

From MIKE 11's website: "*MIKE 11 includes a variety of computational methods for fully dynamic, unsteady river flow simulation as well as simpler hydraulic routing in branched and looped river channel networks. The range of applications includes steep river flows to tidally influenced narrow estuaries with seamless transition between alternating subcritical and supercritical flow conditions*."

RMC analysis: MIKE11 includes elements required to model reservoirs and dams but the emphasis of the simulation is, generally, the hydraulics resulting from the water control operations or dam breaks. Typical applications are event-based, or, when long-term, the emphasis tends to be on flood management, prediction and mitigation. Its tandem software, MIKE21, has strong 2D capabilities necessary for flood extent definition.

Link:

https://www.mikepoweredbydhi.com/products/mike-11/rivers-and-reservoirs

Innovyze

RMC analysis: The company Innovyze develops a large number of modeling platforms for multiple applications. They do not have a specific modeling tool tailored for natural reservoirs (only for treated water reservoirs) but coupling different modules and packages the simulation of MMWD would be possible. The tradeoff would be lack of practical and efficient multiple runs for decision support and scenario analysis. Innovyze resulted from the merger of two leading hydraulic modeling firms, globally, and has a significant emphasis on hydraulics.

Given that MMWD is a client of Innovyze, if this tool is of interest the specific combination of software modules and packages could be explored with them. In general, Innovyze is not commonly used for hydrologic watershed modeling in water supply applications, and is far more commonly applied for hydraulic modeling of distribution systems. Innovyze has been included primarily because the existing hydraulic model is in Innovyze and there may be a benefit to staying with a single software package.

Link:

http://www.innovyze.com/

6 Model Comparison Matrix

The general capabilities of these models to simulate the desired system elements are listed in Table 3. This table also presents a general assessment of each modeling platform's ability to achieve MMWD's requirements. This overall assessment has been carried forward into the main model comparison matrix presented in Table 4.

Table 3: Model Required Simulation Capabilities

ID	Element	HEC ResSim	WEAP	River Ware	GoldSim[1]	MIKE11	Innovyze
1	Rainfall-Runoff	Yes	Yes	Yes	Yes	Yes	Yes
2	Evaporation	Yes	Yes	Yes	Yes	Yes	Yes
3	Reservoir Operations	Yes	Yes	Yes	Yes	Yes	Yes
4	Demand	Yes	Yes	Yes	Yes	No	With Pre-Processing
5	Supply From Other Sources	With Pre-Processing	Yes	With Pre-Processing	Yes	No	With Pre-Processing
6	Demand-Supply Balance	With Post Processing	Yes	With Post Processing	Yes	No	With Post Processing
7	Temporal Scope/resolution	Yes	Yes	Yes	Yes	Yes	Yes
8	Water Quality	No	Yes	No	Yes	Yes	Yes
	General Assessment Scale: 5=Best; 1=Worst	4	5	4	5	2	3

[1]GoldSim is not specifically a water resources tool. It is a simulation tool that can be programmed to simulate a reservoir system (or any type of water resources application). It is commonly used in water resources.

Table 4 includes an assessment of each model against each of the criteria for modeling selection.

Table 4: Comparison of Modeling Tools for MMWD's Hydrologic Model

Criterion	Model Name					
	HEC-ResSim	WEAP	RiverWare	GoldSim	MIKE11	Innovyze
Ability to Simulate Elements in Table 1 Scale: 5=Best; 1=Worst	4	5	4	5	2	3
User Friendliness for Use Scale: 5=Best; 1=Worst	4 can have long simulation times of several minutes	5 with fast simulation times	3 can have long simulation times of several minutes	5 with fast simulation times	3 can have long simulation times of several minutes	3 can have long simulation times of several minutes
User Friendliness for Programming Scale: 5=Best; 1=Worst	3	4	3	4	2	4
Size of User Base	Medium Size	Large size (Medium in USA, large use globally)	Medium Size	Medium Size	Very Large Size	Very Large Size
Level of Support and Documentation	User Guide and documentation available, with most recent manual issued in 2013 (nothing more recent). No technical support available from software developers. Internet user groups limited.	User Guide and documentation available. Technical support available with annual fee.	User Guide and documentation available. Technical support available with annual fee.	User Guide and documentation available. Technical support available with annual fee.	User Guide and documentation available. Technical support available with annual fee.	User Guide and documentation available. Technical support available with annual fee.
Cost of License and License Maintenance	Free.	License $3,000 (two-year term). Technical support included in 2-year license term.	License $6,530 (includes first year's fees). Annual Maintenance Fee $3,300.	$4,450 for pro license. One year technical support and upgrades included. Additional years at $1,600/year.	Usually several thousand dollars but it will depend on package required. Multiple license types.	Usually several thousand dollars but it will depend on package required. Multiple license types.
Code Ownership and Openness	Non Proprietary. Public agency and academia.	Commercial software. Proprietary. Standard vendor.	Non Proprietary. Public agency and academia.	Commercial software. Proprietary. Standard vendor.	Commercial software. Proprietary. Standard vendor.	Commercial software. Proprietary. Standard vendor.

Criterion	Model Name					
	HEC-ResSim	**WEAP**	**RiverWare**	**GoldSim**	**MIKE11**	**Innovyze**
Use in Similar Applications to MMWD	Common tool for planning and operations of reservoir systems. Most common examples of this model's application are for large river systems with much more complex rules and more elements than MMWD (Columbia, Sacramento-San Joaquin, Savannah, Tigris-Euphrates). Scalable to small systems.	Very common planning tool with problems requiring monthly time steps and long term simulations. Very common in "what if" analysis and widely used in water supply planning for its ability to simulate multiple sources and for having a built-in scenario management module.	Common tool for planning and operations of river systems. RiverWare is a commonly used by the Bureau of Reclamation as a water rights administrative model. Strong capabilities for water rights priorities in complex river systems.	While not a water resources specific tool, it is a common tool in water resources planning, particularly under uncertainty and where probabilistic analysis is required. It includes a reliability module (purchased separately) and a contaminant transport model. Very common in mining applications with small system of reservoirs.	Not very applicable to planning operations with water supply emphasis. Its strong hydraulics capabilities make it more common in flood management/risk modeling and stormwater infrastructure.	The suite of modeling tools of Innovyze is very large and multiple modules and packages are available. It is likely that some combination of modules can be applied to MMWD. The emphasis of most packages by Innovyze is on hydraulics more than mass balance for a water supply annual operating plan.
Additional Notes and Considerations	Applications in California and adopted by a government agency and academics.	Applications in California and adopted by a government agency and academics. Great planning tool that allows for embedded cost analysis also.	Applications in California and adopted by a government agency and academics.	Applications in California. Very strong (unparalleled, compared to the other 5 options) probabilistic analysis features. Great planning tool that allows for embedded cost analysis. Great, personalized, technical support.	Great commercial success driven by solid analysis. Less applicable to hydrology and operations relevant to water supply.	Great commercial success driven by solid analysis. Less applicable to hydrology and operations of lake water systems relevant to water supply.

7 Recommendation

Based on Table 4, which compares all model options based on selection criteria, MIKE 11 and Innovyze are the least desirable options for the MMWD hydrologic model. While powerful tools for hydraulic analysis, these tools do not align well with the modeling objectives, which require less precision and resolution spatially from a hydraulic perspective and more flexibility to assess the storage and supply consequences of multiple management decisions.

HEC-ResSim and RiverWare are very comparable options due to their capabilities to model hydraulics and in how they score across all criteria in Table 4. A potential significant difference between these tools is the greater emphasis of RiverWare on river systems compared to the HEC-ResSim's focus on reservoir operations. Therefore, HEC-ResSim is a preferable tool to RiverWare, though it should be emphasized that no technical support is available from its developers.

WEAP and GoldSim are also very comparable options and are among the simplest tools analyzed since they were developed to be systems simulation models. With less emphasis on resolution and more emphasis on decision-making under uncertainty, WEAP and GoldSim are planning tools rather than day-to-day, short-term operations and administrative tools such as HEC-ResSim and RiverWare. Between GoldSim and WEAP, the latter has the marginal advantage of having a larger user base, and every application of WEAP is a water resources application. WEAP is being broadly embraced by the State of California which may provide benefits in terms of integration with statewide data, analysis, and tools.

Based on these considerations, WEAP and GoldSim are the two tools best suited to provide MMWD with the necessary features to fulfill the modeling objectives during the Water Resources Plan 2040 and for future use. Table 5 presents the trade-offs between the two models.

Based on RMC's experience using WEAP and GoldSim for water resources modeling and based on GoldSim's probabilistic analysis capabilities, RMC recommends that MMWD consider GoldSim for use in the Water Resources Plan 2040 and beyond.

Table 5: WEAP and GoldSim Direct Comparison

Model	Advantages	Disadvantages
GoldSim	• More flexibility to program customized elements that may be needed for the analysis • Strong probabilistic functionality, allowing probability distributions for variables within a time step • Can have an embedded optimization routine/module and/or command an optimization model during the simulation, if that is desired in the future • Can be programmed to run simultaneously with other models • Library of sub-models available to 'copy/paste' into model for common applications	• Relatively more complex to program • Higher price and annual tech support fee • Smaller user base • Lacks built in scenario manager
WEAP	• Includes built-in costs and a scenario comparison module • Slightly simpler to program and use • Includes built-in hydrology (rainfall-runoff) module • Specific for water resources with pre-programmed objects • Adopted by California Department of Water Resources as one of their modeling tools	• Pre-programmed objects can limit flexibility to program project-specific needs in water resources components • Scope of model dictated by WEAP scope of object library • No direct links to optimization tools although it can link indirectly • Not built for probabilistic analysis

8 Next Steps

The following steps are recommended as the modeling effort process:

1) MMWD makes final decision about desired tool;
2) RMC develops the conceptual model and continues data collection for model use;
3) RMC presents draft conceptual model;
4) After MMWD approval of conceptual model, RMC begins programming.

Appendix C

Marin WaterSim Technical Memorandum

Technical Memorandum

MMWD Water Resources Plan 2040

Subject:	**Marin WaterSim**
Prepared For:	Carl Gowan and Lucy Croy, MMWD
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Reviewed by:	Alyson Watson, RMC
Date:	October 24, 2016
Reference:	0041-010

This Technical Memorandum (TM) describes the Marin WaterSim (WaterSim) model. WaterSim is a systems model, built in the commercial software GoldSim, which simulates the Marin Municipal Water District's (MMWD/District) water supply system. Central to WaterSim are the components of MMWD's source and raw water system including seven lakes, two treatment plants, one imported water supply, and one recycled water supply. The model is used to simulate potential reliability threats and resiliency options under both historical hydrology and predicted hydrology under climate change.

1 Modeling Needs and Objectives

This section documents the modeling needs and objectives of the District excerpted (with the exception of some required updates) from the Model Selection TM submitted on October 23, 2015. Generally, the modeling platform was selected to enable the District to simulate various different operating scenarios and use the simulation results to evaluate the best course of action for operating their lake and imported water system on an annual basis. The following subsections cover MMWD's modeling platform needs, based on four sources of information: the project RFP, discussions during the August 24 kick-off meeting, information received during the September 8th, 2015 modeling meeting, and discussions during a modeling conference call on September 14th, 2015.

1.1 Questions the Model Is Programmed to Answer

A critical step in selecting a modeling platform is defining the questions the model needs to answer, and the frequency with which the model needs to be used to answer those questions. Based on the information received in the project meetings and RFP, MMWD would like to be able to use the model to answer four categories of questions: 1) Questions related to defining an annual operating plan; 2) Questions related to operating modes under loss of service conditions; and 3) Questions related to long-term system decisions.

Operations

MMWD will use the model to develop and inform its annual operating plan. The model will be used to optimize water use and storage, to the greatest extent possible, based on real/observed demand and storage data and expected/presumed inflow conditions for upcoming months. At a higher level of analysis, the model could also be used to optimize the cost of the overall lake supply operation. Related to the operating plan is the output of reservoir refill probability under different operating decisions (and a given set of inflow assumptions).

Loss of Supply Driven by System Disruptions

The second category of questions is centered around loss of service during extended periods of time (one to several months), which could be triggered by long-term maintenance projects and some emergency scenarios. For instance, the model should allow the District to assess the short- and long-term risks associated with taking facilities off-line and be able to evaluate mitigation plans for planned outages. Additionally, the model should be able to assess how long MMWD could sustain service if a given reservoir, force main, or pump station were to be off-line due to planned or unplanned circumstances (i.e., earthquakes and wildfires).

Long-Term System Decisions (Long-Range Planning)

The third category is related to the definition of a safe yield for the system and the evaluation of its long-term performance under multiple operational decisions or scenarios. The model should be able to simulate baseline conditions with alternative hydrology, demand, or operating conditions. Additionally, the model should be able to simulate new facilities and sources associated with resiliency planning alternatives (additional imported supplies, desalination, additional recycled water, indirect potable reuse, additional water use efficiency measures, etc.). The model needs to evaluate the reliability (size and likely frequency of shortages) of the system under multiple long-term simulation conditions.

In this mode, the model will help MMWD assess the reliability and consequences of alternative emergency storage levels. The model should also be able to be used to conduct reliability analyses for historical drought conditions and climate change-related drought conditions. This is the main category of questions addressed during the Water Resources Plan 2040 process.

Another important consideration for model selection was the need to simulate climate change-impacted hydrology, either by taking time-series inputs (deterministically) or by combining inputs probabilistically.

2 GoldSim Software

The Marin WaterSim model was developed using GoldSim software, which is a graphical, object-oriented modeling environment. Models in GoldSim are built by creating and manipulating built-in objects ("elements"), which represent the components of the system being modeled, data, and relationships between the data. GoldSim is not a water resources modeling tool, specifically, but it is well suited for water resources and commonly applied to water resources settings. One of the main advantages of this software is that any system can be programmed because it isn't constrained to pre-defined applications and corresponding equations. One of the main strengths of GoldSim over similar generic tools is its ability to model probabilistically.

This section includes language from the GoldSim User Manuals but is not intended as a user guide. It only describes the most fundamental characteristics and functionality of the software, required as background to understand some of the subsequent descriptions in this TM. The GoldSim Users Manuals can be accessed through the help files in the GoldSim software under **Help > Help** Topics in the model or at the following location:

http://www.goldsim.com/Web/Downloads/UserManuals/

GoldSim Player

GoldSim files can be viewed, navigated, and run using the GoldSim Player. The GoldSim Player can be requested for free at the GoldSim website.

http://www.goldsim.com/forms/playerdownload.aspx

GoldSim User Interface

Graphics Pane

The Graphics Pane is the primary portion of the GoldSim interface, where the graphical depiction of the model is shown. Elements are added to the graphics pane by right-clicking on an empty section of the graphics pane, and selecting the appropriate element from the context menu.

Simulation Settings

The Simulation Settings dialog can be displayed by selecting **Run > Simulation Settings** from the main menu, by pressing **F2**, or by clicking on the **Simulation Settings** button in the GoldSim toolbar. The Simulation Settings dialog allows the user to adjust the length of the simulation and the number of Monte Carlo realizations required.

Running the Model

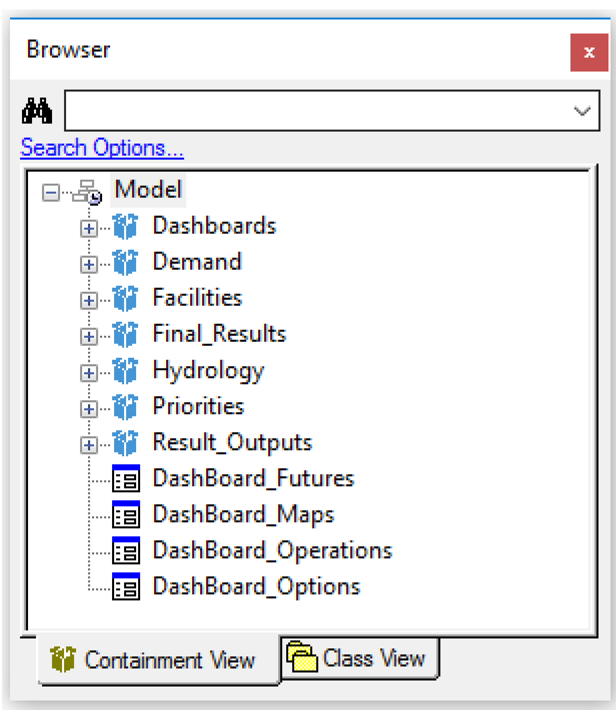
There are four modes that the model can be in: **Edit Mode**, **Run Mode**, **Result Mode**, and **Scenario Mode**. The model is in **Edit Mode** while it is being edited, the model is in **Run Mode** while the simulation is actually running, and the model is placed in **Result Mode** after results have been generated. **Scenario Mode** allows multiple scenario results to be compared.

A model is run by pressing **F5**, clicking the **Run** button in the toolbar, or by selecting **Run > Run Model** from the main menu. Results can be viewed by right-clicking on an element, or double-clicking on a Result element. The user can return to Edit Mode from Result Mode by pressing **F4**, clicking on the **Edit Mode** button or by selecting **Run** > **Return** to **Edit Mode**.

Model Browser

The Model Browser organizes the model into one of two views in a tree structure. The default browser view is **Containment View**, where elements are organized in a hierarchical manner, similar to the way that files and directories on a computer are organized. In **Class View**, rather than being organized by containment, the browser is organized by element type. An example of the model browser is provided in **Figure 2-1.**

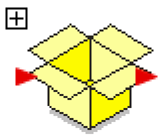
Figure 2-1: Model Browser Example



GoldSim Elements

GoldSim provides a wide variety of elements from which the user can construct models. GoldSim also provides dashboard tools to enhance accessibility and ease of use. This section provides a brief summary of the primary elements used in Marin WaterSim Model.

Container Elements

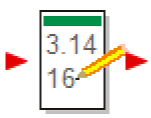

Container

Containers: An element that acts like a "box" or a "folder" into which other elements can be placed. It can be used to create hierarchical models, “top-down” models and organize models in which the level of detail increases farther into the containment hierarchy. WaterSim uses containers to organize the District system in discrete and manageable sectors.


DashBoard

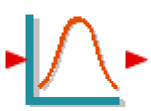
DashBoard: An element that allows the user to build custom interfaces. By adding controls (e.g., sliders, input edit fields, buttons, and result display) to a dashboard, users can directly interact with the model without having to be familiar with either the GoldSim modeling environment or the details of the specific model. WaterSim uses a series of DashBoard to set up and initiate the simulations.

Data Elements



Data

Data Elements: Elements intended to represent a constant inputs. A Data element can represent both values and conditions (i.e., True/False), and can represent a single scalar value, an array (1-dimensionsl), or matrix (2-demensional) data. WaterSim extensively uses this element for constants, rates, capacities, etc.


Stochastic

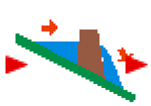
Stochastic: An element that can be used to quantitatively represent the uncertainty in a model input. GoldSim uses the Monte Carlo method to sample stochastic elements in order to carry out probabilistic simulations. WaterSim uses this element for temperature sampling in the demand sector of the model.

TimeSeries

Time Series: Data elements with time histories of data. Used in WaterSim for historical demand and hydrology. Data can be both time shifted or run in an index-sequential mode over multiple realizations.

Stock Elements

A class of elements that numerically integrate inputs, and are responsible for internally generating the dynamic behavior of systems such as reservoir operations.


Reservoir

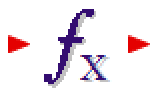
Reservoir: GoldSim includes reservoirs elements with pre-programmed rules for operating simple systems. Reservoirs allow the user to specify simple or dynamic values for the upper and lower bound, and the withdrawal rate. All lakes in WaterSim use this element.

Integrator

Integrator: Elements that integrate rates. These are used to integrate and track information, such as accumulated flows for mass balance calculations. WaterSim uses this element for quantification of some metrics.

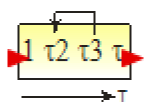
Function Elements

A function element produces a single output by calculating user-specified mathematical expressions.



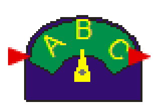
Expression

Expression: Typically the most common function element. A function element produces a single output by calculating user-specified mathematical expressions or equation. WaterSim uses this element extensively for model logic.



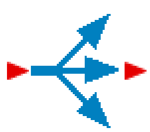
PreviousValue

Previous Value: An element that outputs the value of its input from the previous model update. WaterSim uses this element in some areas of the model logic to break circular references where feedback exists in the logic and/or system.



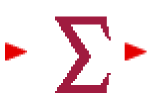
Selector

Selector: An element that allocates an incoming signal to a number of outputs according to a specified set of demands and priorities. Typically, the signal will be a flow of material (e.g., water), but it could also be a resource, or a discrete transaction. WaterSim uses this element in several sectors, primarily coupled with calendar elements.



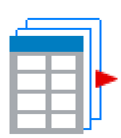
Allocator

Allocator Element: Allocates an incoming signal to a number of outputs according to a specified set of demands and priorities. Typically, the signal will be a flow of water, distributed among a series or prioritized demands. WaterSim uses this element in all of the lake total outflow elements to preserve the mass balance.



Sum

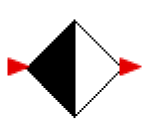
Sum Element: Summarizes the values of multiple elements. WaterSim uses this element for model logic.



Lookup_Table

Lookup Table Element: A function element that allows you to create a 1, 2, or 3-dimensional lookup table. Used, for example, for lake election-capacity tables. WaterSim uses this element for some of the model logic, such as the pump curves.

Event Elements



Status

Status: Tracks the status of a continuously varying systems, and creates a single discrete condition of True or False. This elements is used, for example, to trigger whether a pump station is on or off. WaterSim uses this element to drive model logic after events take place.

Delay Elements

Information Delay: Used to simulate delays in measuring, reporting, and/or responding to information. WaterSim uses this element for some model logic.

Navigating Marin WaterSim

The Marin WaterSim root container (the top level of the model) is provided in **Figure 2-2**. The model is organized into a series of linked containers that represent the hierarchical structure of the model. Those containers are described as follows:

Hydrology (**Figure 2-3**): The hydrologic data inputs for the model, including time series data for inflow, precipitation, and evaporation. This container also includes values for initial storage levels, lake capacity, and look up tables for lake surface area and volumes.

Demand (**Figure 2-4**): This container includes the data and calculations for determining the total monthly demand for MMWD.

Priorities (**Figure 2-5**): The model steps through a defined priority sequence for meeting monthly demand. The basic sequence for satisfying monthly demand is as follows: 1) Raw Water. 2) Recycled Water. 3) Sonoma County Water Authority (Take or Pay Contract). 4) Bon Tempe Treatment Plant. 5) San Geronimo Treatment Plan. 6) Sonoma County Water Authority (Remaining).

Facilities (**Figure 2-6**): The operation rules for all lakes and reservoirs, pump stations, and treatment plants in the MMWD system. Blue lines represent the movement of water through the MMWD system.

Final Results: This container includes results for delivered water, unsatisfied demands, and the mass balance calculations for the MMWD system.

Result Outputs: Contains Result Elements, including all results exported to excel and .csv file formats.

Figure 2-2: Marin WaterSim Root Container

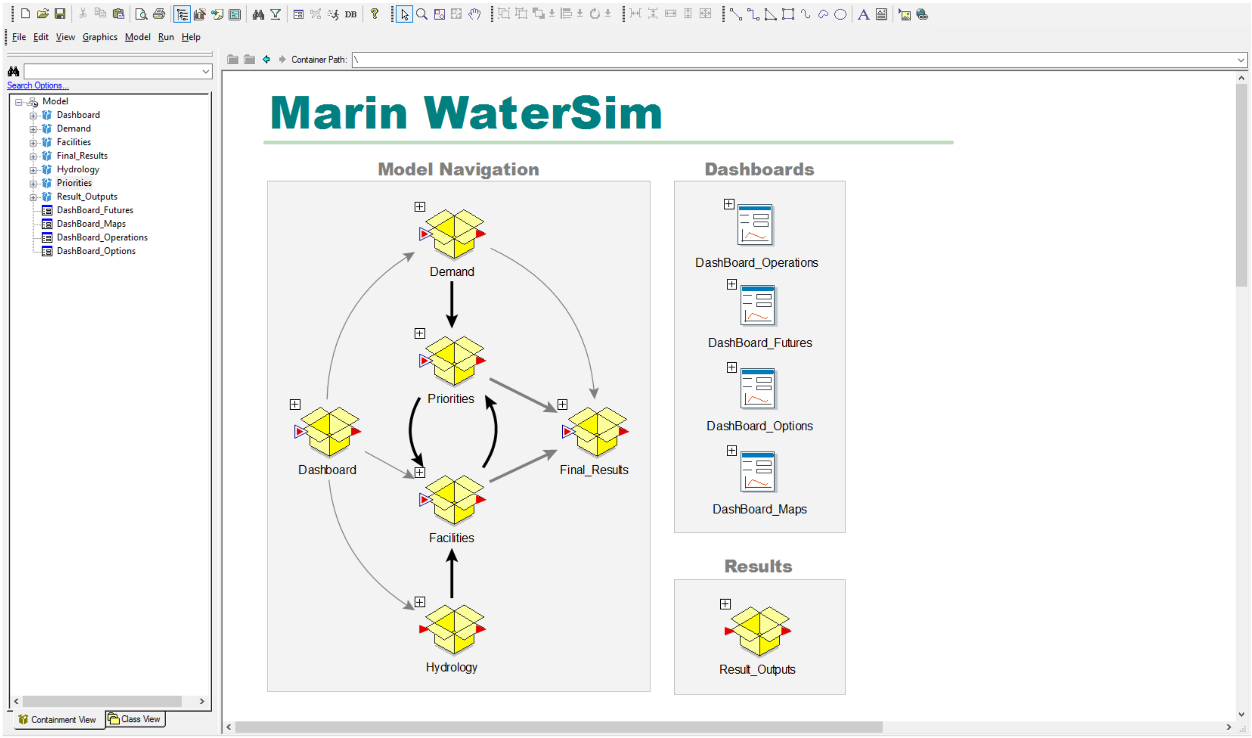


Figure 2-3: Hydrology Container

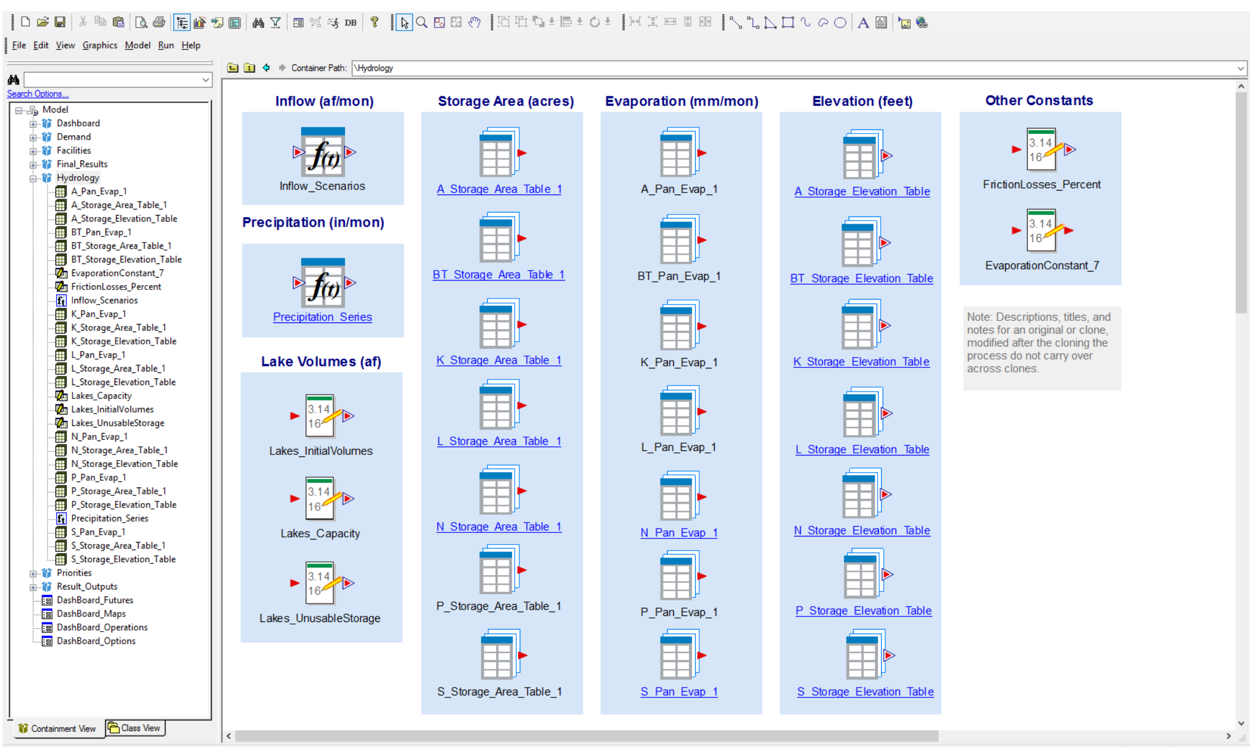


Figure 2-4: Demand Container

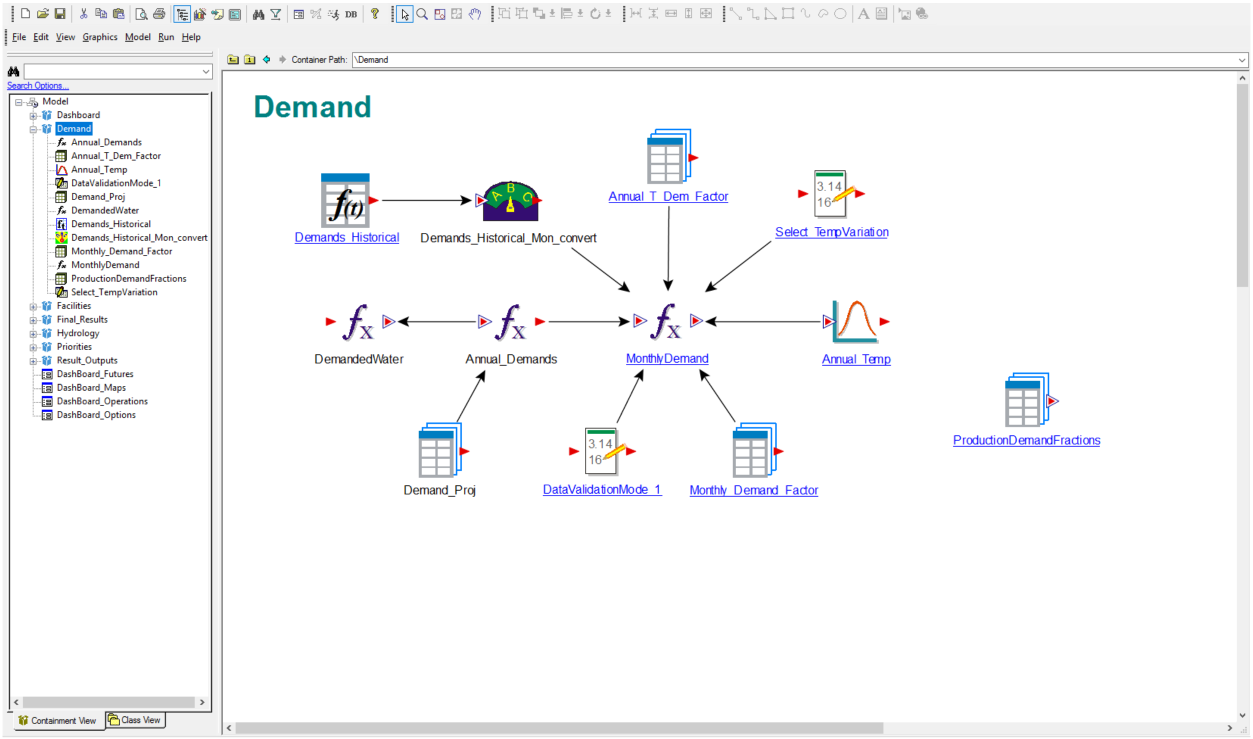


Figure 2-5: Demand Container

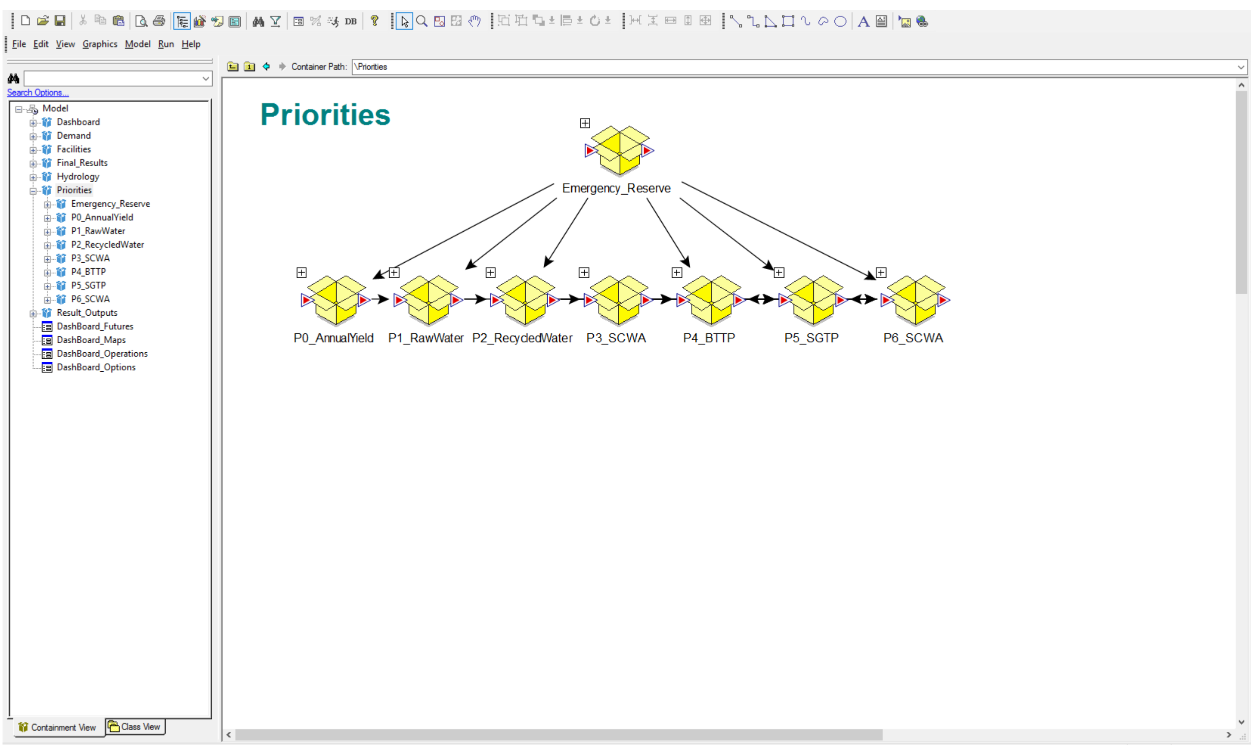
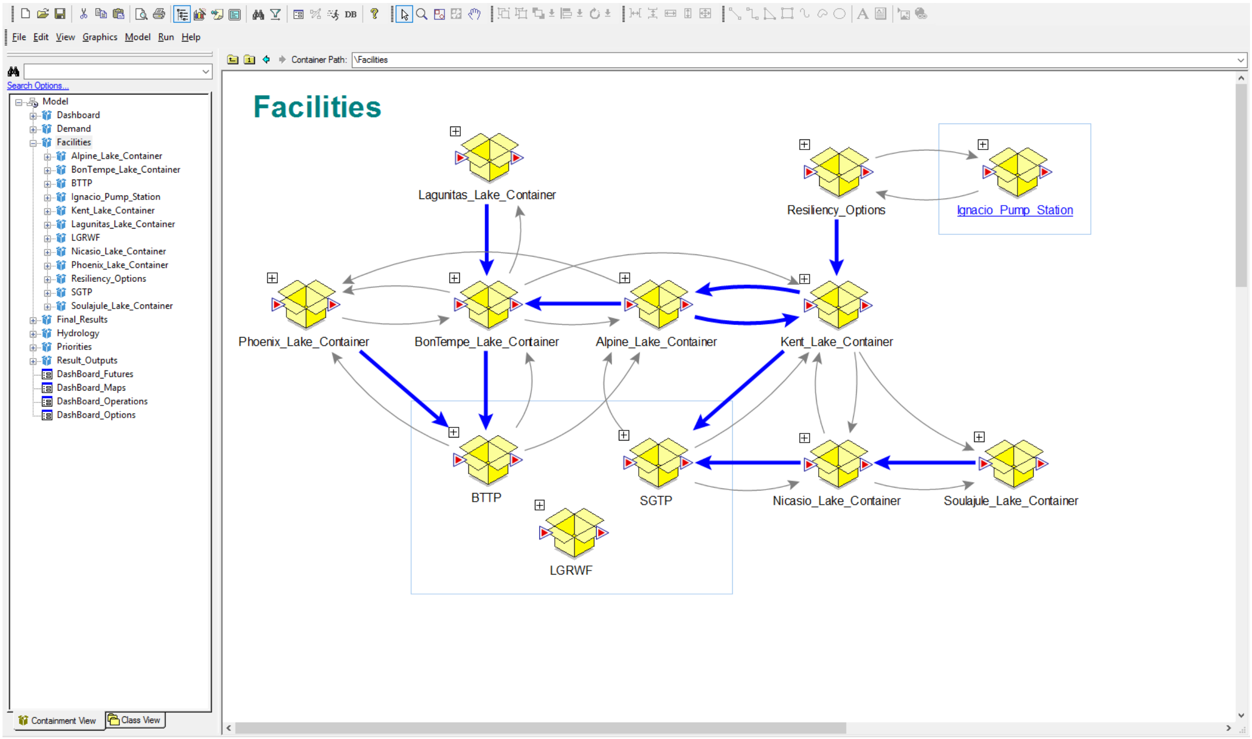


Figure 2-6: Facilities Container



Dashboards

Marin WaterSim is designed to accommodate a large range of reliability threats in order to identify and characterize risks and uncertainty faced by MMWD, and the series of resiliency options identified in Water Resource Plan 2040. The Marin WaterSim dashboards, shown in **Figure 2-7**, **Figure 2-8**, **Figure 2-9**, are a user friendly interface for users to build scenarios without any prior knowledge of GoldSim or access to the full GoldSim software.

Figure 2-7: System Operations Dashboard

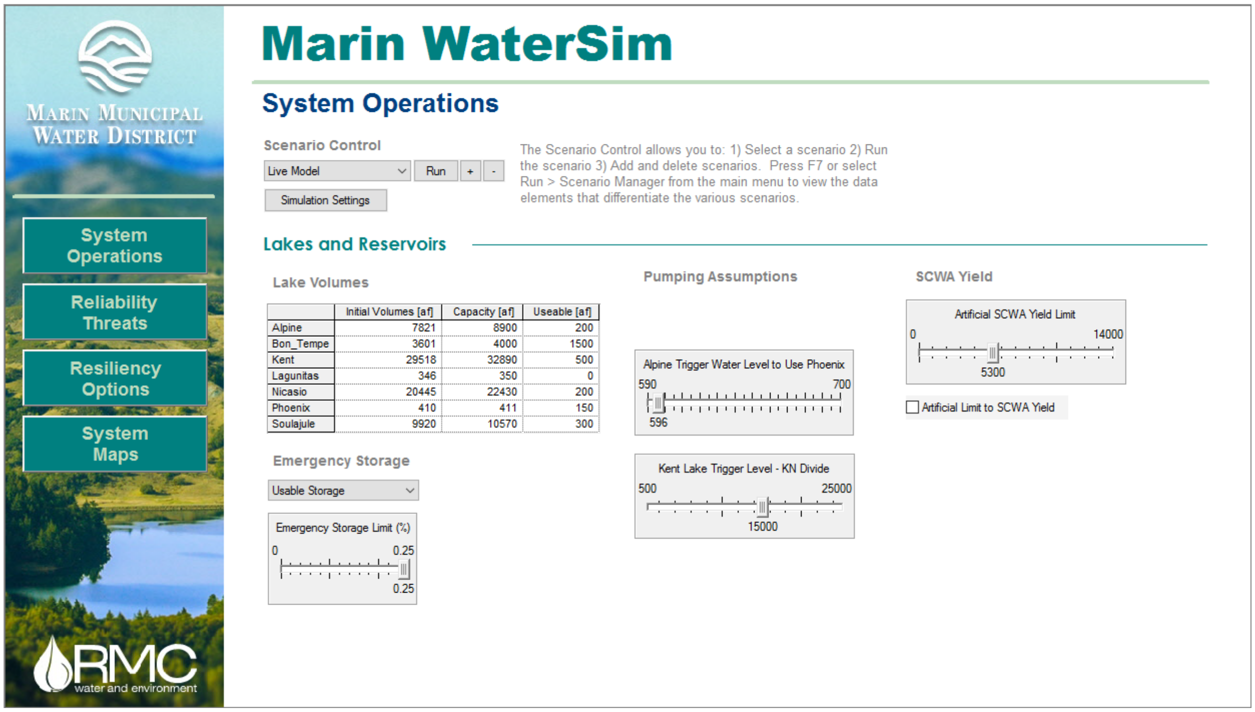


Figure 2-8: Resiliency Options Dashboard

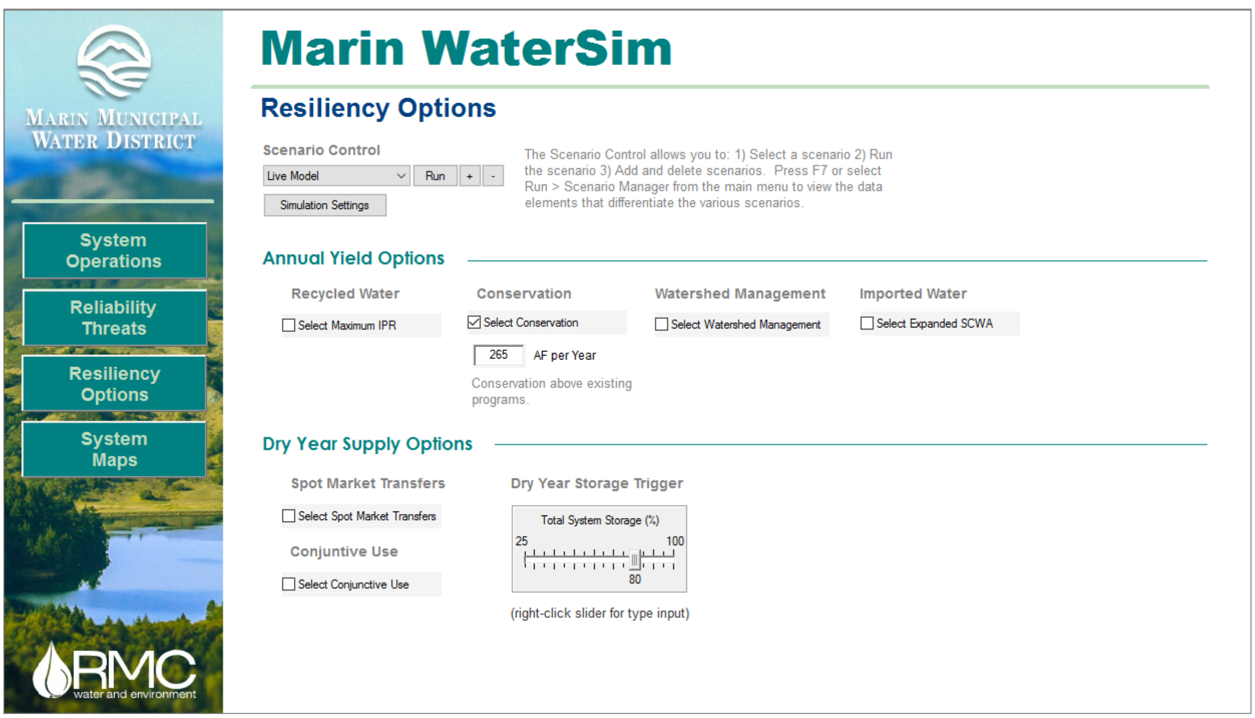
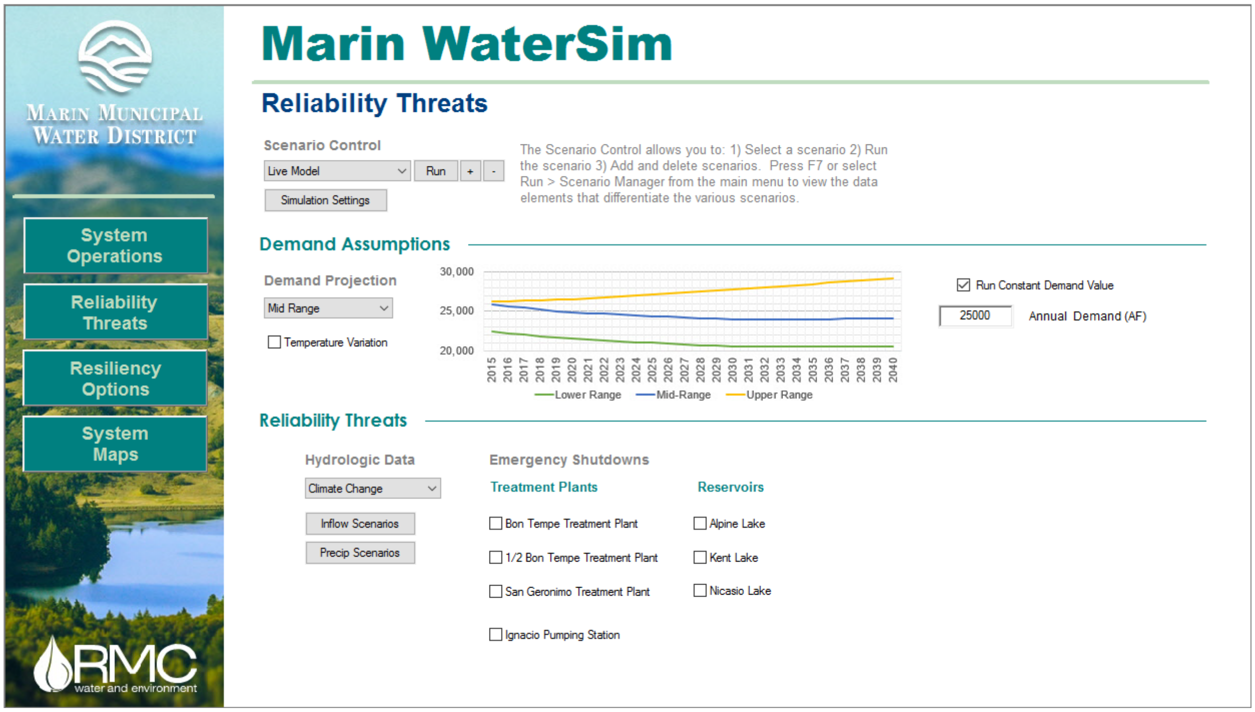


Figure 2-9: Reliability Threats Dashboard

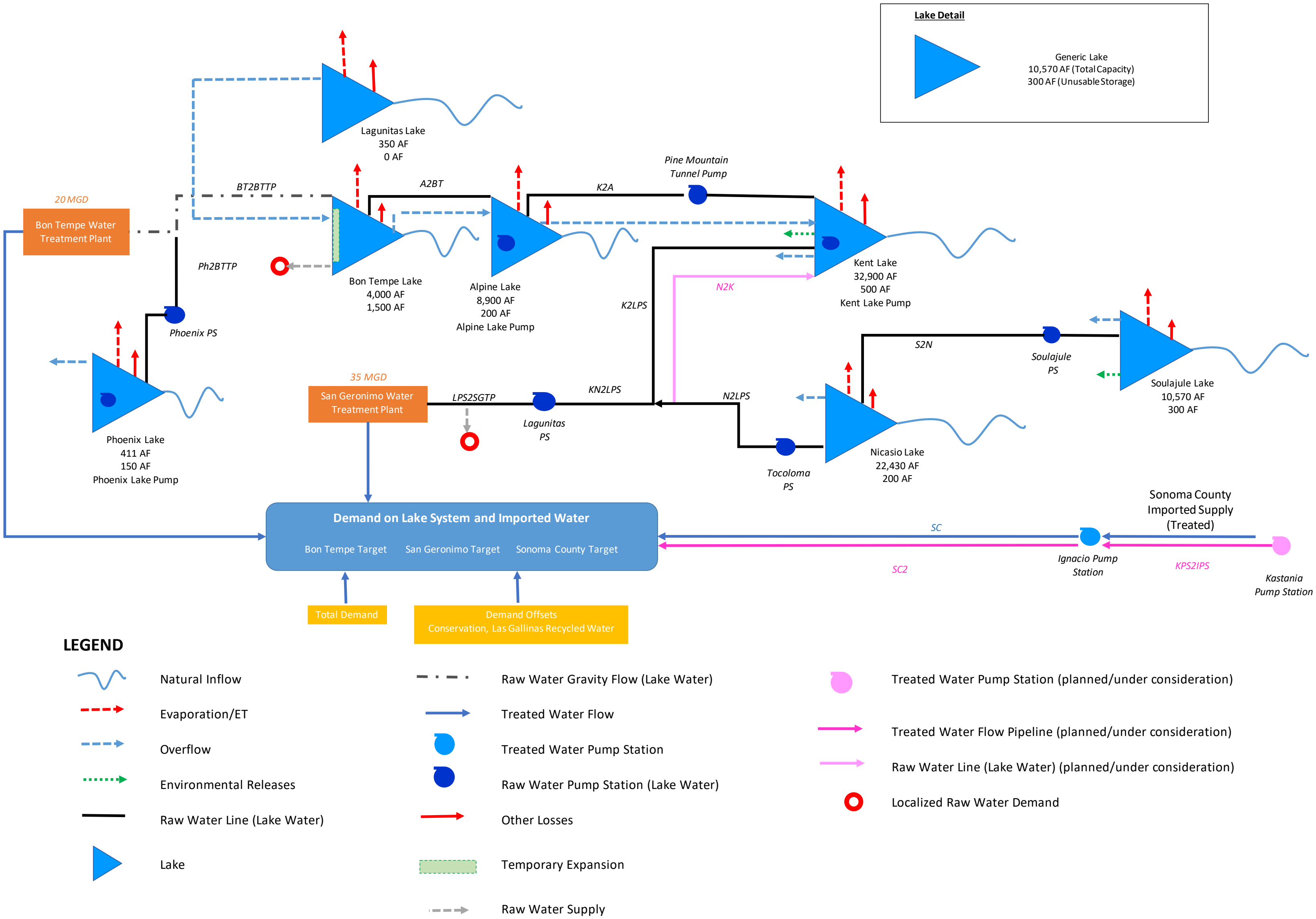


3 Conceptual Model

The following sections describe how the system has been conceptualized for programming in the simulation tool, not only in terms of the physical components of the system but also in terms of the most basic rules the model follows.

The systems model performs an overall water balance in the MMWD lake water system. The model was programmed to simulate water demands on MMWD's treatment plants and Sonoma County Water Agency (SCWA) imported water and routes water from lakes to the treatment plants, keeping track of storage and flows in relevant system elements. A conceptual representation of the system as it has been simulated is shown in **Figure 3-1**.

Figure 3-1: Conceptual Model



3.1 Geographic and Temporal Scope and Resolution

The geographic scope for the modeling tool encompasses MMWD's lake water system: the watersheds of all seven lakes, the lakes themselves, and the pump stations and water mains up to the water treatment plants.

Temporal resolution refers to the timestep of the modeling results. For the District's purposes, a monthly timestep is preferred. A daily timestep is used in the model, with results aggregated by month. The temporal scope, or the hydrologic period of record covered by the model, must be adequate to capture a variety of year types, and the model is able to run long-term simulations from one year to several decades (to be able to analyze the performance of the system, probabilistically, under long-term hydrology). A total of 115 years of synthetically created historical hydrology is used for most simulations, while 89 years of predicted hydrology under climate change is used for other simulations. Detailed information regarding the hydrology used in the WaterSim model can be found in Section 5 in this TM.

Seasonality has been included in several elements of the model, including demands, evaporation/ET, and environmental releases.

3.2 Lakes and Treatment Plants

Lakes

The lakes represent the central part of the systems model. Each lake has been modeled for: 1) its water balance; 2) its physical components (capacity, volume-elevation-surface area curves, key elevation data); as well as 3) administrative and operational components such as rules and pools.

The water balance is the central component of the model. The model uses raw or derived data for the inflows and outflows on each lake. While historical data is available for the lakes, storage is a critical endogenous (computed by the model) variable. Historical data on volume was be used for calibration of the model. See Section 4 of this TM for more information about data inputs and Section 9 for details on model validation.

The model includes functionality to add new inflows into each lake based on resiliency scenarios as part of the Water Resources Plan 2040, but the base runs have been completed with historical information on inflows and those data will be permanently loaded in the model database.

Figure 1 shows the inflows and outflows that have been modeled in each of the lakes (same for all lakes, generically). Environmental releases are included for Soulajule and Kent.

The physical components of the lakes will be included in the model with total capacity and unusable storage. Other important physical components include storage/elevation/surface area curves, which are used to determine evaporation levels, environmental release triggers, and pumping capacity due to minimum elevation constraints.

Treatment Plants

Treatment plants in the model are most relevant for their capacity, and the variable costs associated with treatment. There is no need in the model to simulate treatment plants with more level of detail than a physical capacity, with associated cost functions. How much water is treated in each treatment plant each month is computed by the model based on soft targets for supply from each plant and SCWA imported supplies, which in turn is dictated by overall demand and the overall lake system operation.

3.3 Transmission Facilities

The model does not simulate detailed hydraulics, but rather, volumes per unit time (flows) capped by known hydraulic capacities. While this is a mass balance model and not a hydraulic model, the horsepower required for pumping for different pump stations, at different lake elevations, is accounted for. The model tracks storage in the lakes, translates storage to elevation, and computes the required flows to be pumped based on demands and rules. With flows and lake elevations, the horsepower is derived from lookup tables.

Figure 3-1 shows the transmission lines and pump stations that are included in the model. The figure includes draft nomenclature for each of the lines that will be included in the model. The nomenclature uses the initials of lakes and pump stations with a number "2" separating the "from" element to the "to" element. For example, the line **S2N** is the line **from Soulajule Lake to Nicasio**. The line **N2LPS** is the line **from Nicasio to the Lagunitas Pump Station** (PS). Initials used include:

- S: Soulajule Lake
- N: Nicasio Lake
- LPS: Lagunitas Pump Station
- SGTP: San Geronimo Treatment Plant
- K: Kent Lake
- A: Alpine Lake
- BT: Bon Tempe Lake
- BTTP: Bon Tempe Treatment Plant
- L: Lagunitas Lake
- P: Phoenix Lake

Note that only the segments depicted in **Figure 3-1** are included in the model.

Pump stations (including Ignacio Pump Station) are also included in the model. As in the case of the treatment plants, the main attribute of a pump station in the model is its capacity. Costs associated with each pump station (variable and fixed) are accounted for. All named pump stations in **Figure 3-1** have been included in the model.

Figure 3-1 uses the term "Eq Capacity" for pipelines, treatment plants and pump station. The model generates monthly results to answer the types of questions that are necessary to define annual operating plans and to evaluate projects to increase resiliency as part of the Water Resources Plan 2040. The monthly model uses an "equivalent capacity (Eq Capacity)" computed by converting the daily and/or instantaneous capacities to total monthly volumes. Since the units of the "Eq Capacity" are not intuitive, they remain an internal element of the model for the analyst's benefit only.

4 Data Inputs

MMWD provided the majority of the data that were input into WaterSim. These data were supplemented by data from other sources such as the US Geological Survey and Maddaus Water Management (Pepperwood Preserve, 2015; Maddaus, 2016). **Table 4-1** lists every data input into the model, the temporal and spatial resolution of that data, the type of element used to incorporate the data, the source of the data, the calculations that the data contributes to, and the output derived from that data.

Table 4-1: WaterSim Data Inputs

Input	Resolution/Elements Effected	Source	Primary Use	Main Output Associated with Input
Historical Hydrology	Monthly Time Series, Each Lake	Developed by RMC based on historical precipitation and	Input as inflows into lakes	Storage, spills

		inflow data from MMWD		
Climate Change Hydrology	Monthly Time Series, Each Lake	USGS based on GCMs: CCSM4_rcp85, CNRM_rcp85, MIROC_ESM_rcp85 (Pepperwood Preserve, 2015)	Input as inflows into lakes	Storage, spills
Historical Precipitation	Monthly Time Series, Kent and Soulajule Lakes	Data from MMWD for Lagunitas, correlated and applied to Kent and Soulajule	Determines amount of release required for Kent and Soulajule based on regulatory requirements and calculated streamflow from other sources	Environmental releases
Climate Change Precipitation	Monthly Time Series, Kent and Soulajule Lakes	USGS based on GCMs: CCSM4_rcp85, CNRM_rcp85, MIROC_ESM_rcp85 (Pepperwood Preserve, 2015)	Determines amount of release required for Kent and Soulajule based on regulatory requirements and calculated streamflow from other sources	Environmental releases
Storage-Area-Elevation Curves	Lookup Table, Each Lake	MMWD Data (Roxon, 1992)	Used to determine evaporation from lakes, based on the surface area	Evaporation
Pan Evaporation Constants	Lookup Table, Each Lake	Based on pan evaporation data from Nicasio lake ’87-’96 (Smith, et.al, 1997)	Used to determine evaporation from lakes, based on month	Evaporation
Historical Temperature	Stochastic Element, System-wide	Historical monthly temperature from Weather Warehouse (Weather Warehouse, 2016)	Average and standard deviation used in stochastic element, multiplied by monthly factor to generate temperatures. Affects demands	Operational Flows
Total Potable Demand	Single Annual Data Input, System-Wide	Chosen by user, 2040 demand based on Maddaus model and RMC analysis (Maddaus, 2016; RMC, 2015)	Annual demand is multiplied by temperature and monthly factors to determine monthly demand	Operational Flows
Monthly	Lookup table,	Monthly average	Multiplied by	Operational

Demand Factor	System-Wide	based factor on MMWD Data	annual demand to determine potable demand for each month	Flows
Production Demand Factors	Look up table, BTWTP, SGTWP, SCWA	Monthly average factors based on MMWD Data	Generally determines how much of total demand should come from each source (BTWTP, SGTWP, and SCWA)	Operational Flows
Raw Water Demand	Lookup table, System-Wide	Monthly average based factor on MMWD Data	Raw water demand varies by month, but is the same for each year, no calculations done	Operational Flows
Recycled Water Demand	Lookup table, System-Wide	Monthly average based factor on MMWD Data	RW demand varies by month, but is the same for each year, no calculations done	Operational Flows
Infrastructure Information	Single Data inputs, Pumping Stations, water treatment plants	MMWD Data	Treatment plant, pipeline, and pump station capacities are input to insure that flows do not exceed actual capacity	Operational Flows

4.1 MMWD

Most of the data used in WaterSim was derived from MMWD's records. MMWD provided detailed monthly records of information such as natural inflow, evaporation, releases, spills, production, transfers, storage, runoff, and rainfall for each lake from 1992 through 2009. The detailed data from this time period were used in the WaterSim validation runs described in Section 9 of this TM. Information about the infrastructure of the supply system was also provided by MMWD. This information included pump station, pipeline, and treatment plant capacities.

Important operational information was also provided by MMWD. This information was garnered primarily through email and phone conversations with Carl Gowan (MMWD) and Lucy Croy (MMWD) and included operational details that are described in Section 6 of this TM. Additional operational information was obtained from the *Marin Municipal Water District System Operations Report* (Roxon, 1992), commonly referred to as the "Green Book". The Green Book included data such as storage-elevation curves, lake capacities, and general operation trends. Finally, environmental release requirements for Kent and Soulajule lakes were obtained from MMWD's respective regulatory agreements with the State Water Resources Control Board (SWRCB, 1995) and the CA Department of Fish and Game (CA DF&G, 1985).

4.2 USGS

The climate change precipitation, inflow, and temperature data used in WaterSim was derived from Pepperwood Preserve's Climate Ready North Bay initiative (Pepperwood Preserve, 2015). Pepperwood used a basin characterization model developed by USGS to downscale the impacts of the CCSM4_rcp85, CNRM_rcp85, MIROC_ESM_rcp85, and GFDL_A2 Global Circulation Models (GCMs) to MMWD's watershed (Pepperwood, 2015). The lowest inflow scenario from these GCMs, MIROC_ESM_rcp85, is used as the climate change reliability threat discussed throughout the WRP 2040.

Although it was not directly input into the model, USGS streamflow data from 1995 through 2015 for Lagunitas Creek and Walker Creek were used to model environmental releases from Kent and Soulajule lakes.

4.3 Other

Demand projections for 2040 used in WaterSim were developed by Maddaus Water Management Inc. for MMWD's 2015 Urban Water Management Plan (RMC, 2015). Annual demand projections from 2015 through 2040 were developed for low, base, and high demand were developed for the UWMP. The 2040 base and high demands were used in WaterSim.

Temperature data used in demand calculations in WaterSim was obtained from Weather Warehouse (Weather Warehouse, 2016). Monthly maximum temperature from 1949 through 2015 for San Rafael in Marin County was used in WaterSim.

Pan Evaporation data was obtained from the Tomales LMER/BRIE Research Program conducted by the University of Hawaii and San Francisco State University (Smith, 1997). Pan evaporate data from Soulajule Lake and Nicasio Lake from 1987 through 1996 was used as an input for all lakes.

5 Hydrology

This section explains the methodology and data sources used to create the synthetic hydrograph used in WaterSim prepared by RMC for MMWD's WRP 2040. This model represents MMWD's water supply system and will be used to determine the District's supply reliability given reliability threats such as climate change and earthquakes, and to evaluate potential resiliency options to increase reliability. This TM also details the methodology used to create the "Severe Drought" employed to test MMWD's water supply system under extremely dry conditions.

5.1 Purpose

A set of synthetic hydrographs was needed to determine inflows for each of the seven reservoirs that MMWD operates for the 115 year run time of the model. Data provided by MMWD varied in time periods, but complete and validated data was available for 1992-2009. The synthetic hydrograph models approximate inflow for 1900-2015.

5.2 Precipitation Record

Determining inflows into the supply system required a complete precipitation record for each reservoir, thus a synthetic rainfall record was created for each reservoir based off of the historical record for Lagunitas Lake.

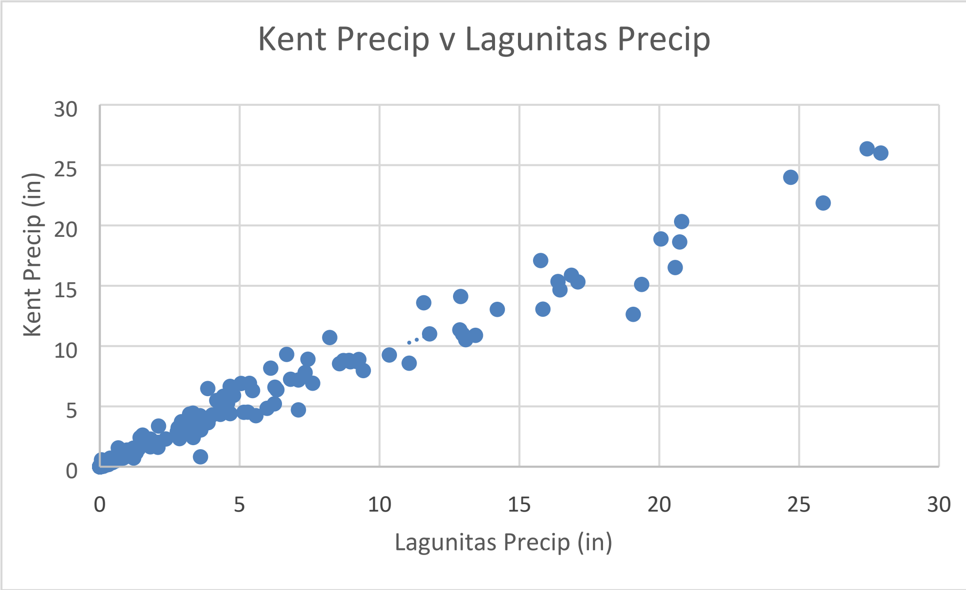
5.2.1 Data Sources

MMWD provided RMC with two sources of data on precipitation in the area. The first source, *Precipitation, Lake Lagunitas Record.xls* provided monthly precipitation readings from Lagunitas Lake from October, 1878 through September, 2015. The second source, *RAINFALL TOTALS.xls* recorded each precipitation measurement at each of the seven reservoirs managed by MMWD from August, 1999 through January, 2016.

5.2.2 Synthetic Precipitation Record Development

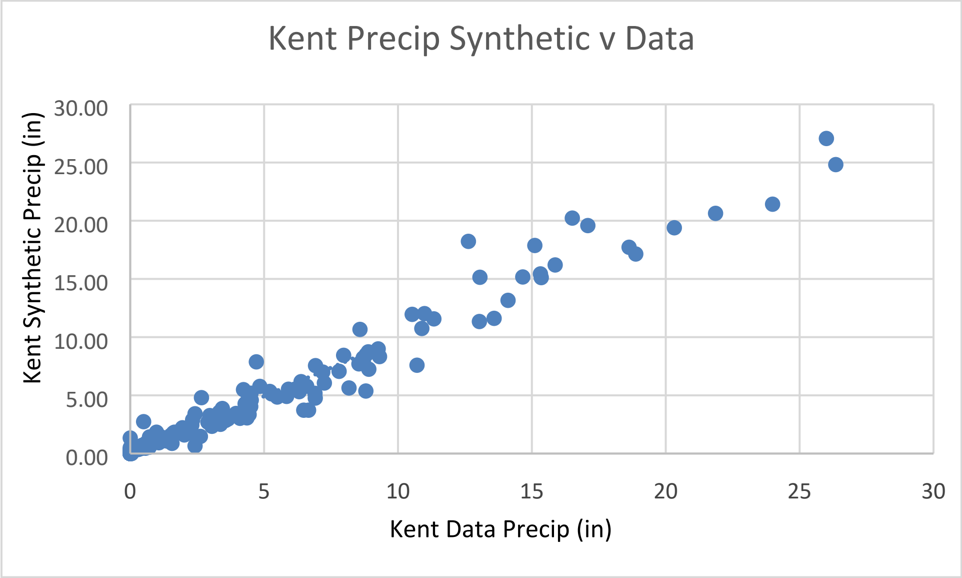
In order to synthetically extend the precipitation record for each reservoir, the precipitation records for each reservoir from *RAINFALL TOTALS.xls* were individually correlated to the Lagunitas precipitation record through scatter plots in Excel. An example of these scatter plots is shown in **Figure 5-1**. These scatter plots showed that the precipitation at each reservoir is strongly linearly correlated with the precipitation at Lagunitas, with the R^2 values of each linear trendline ranging from 0.95 to 0.98.

Figure 5-1: Inter-Lake Correlation Scatter Plot Example



The equation derived from the linear correlation between lakes was then applied to the long Lagunitas precipitation record from *Precipitation, Lake Lagunitas Record.xls* to create precipitation records for each lake for 1900 to 2015. The equation was modified such that when there was no precipitation at Lagunitas, there was no precipitation at any reservoir in order to eliminate the mathematical minimum precipitation created by the correlation equations. These synthetic precipitation data were checked against the historical precipitation data for the period where historical data was available (2000-2015) by using scatter plots. These plots showed that the synthetic data was strongly correlated with the actual historical data, with R^2 values of the linear trendlines between 0.95 and 0.97. **Figure 5-2** shows an example of this check between the synthetic precipitation and the precipitation from the historical record.

Figure 5-2: Synthetic Record Check against Historical Record Example



5.3 Synthetic Inflow Hydrograph

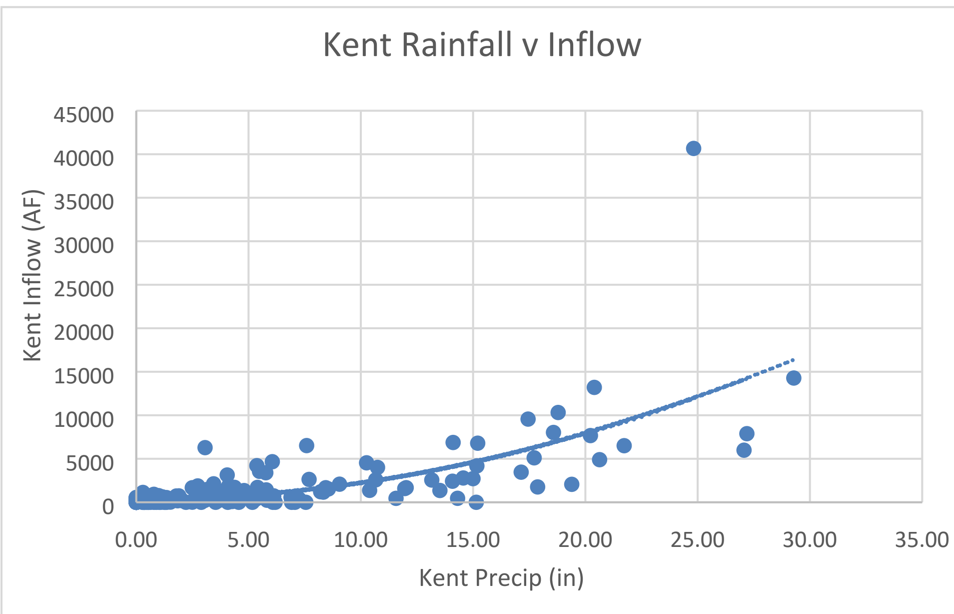
5.3.1 Data Sources

Inflow data from each reservoir was provided by MMWD in the form of *Monthly Summary* PDFs. These documents provided details for each reservoir for each month from June, 1991 through September, 2009, including inflow, evaporation, release, spill, production, etc. The inflow data from these PDFs was modified by eliminating occasional negative inflows, as the source of the negative inflows could not be determined and is assumed to be a calculation error. Some inflow data for Kent, Alpine, and Bon Tempe was further modified through the GoldSim model validation process, when occasional obvious errors, such as typos or decimal placement errors were found. A data set provided by MMWD called *Reservoir Local Inflows.xls* contained inflow data for each reservoir from October 1927 through May 2014 and was used to check the synthetic inflow hydrograph. This data set was not used in the development of the hydrograph as it could not be validated due to lack of other contextual data about the lakes during its time frame, but was considered useful as a check against the synthetic hydrograph.

5.3.2 Synthetic Inflow Hydrograph Development

To create a synthetic hydrograph for a 115-year period, the inflow data provided by MMWD and modified by RMC was correlated with the synthetic precipitation record described in Section 2 of this TM. Scatter plots and second-order polynomial trendlines were used to determine the relationship between precipitation and inflow as shown in **Figure 5-3**. The strength of the correlation between precipitation and inflow varied between lakes, with R^2 values ranging from 0.28 to 0.72 and an average R^2 value of 0.54. The equation of the second-order polynomial trendline was used to create a synthetic hydrograph based off of the 115-year synthetic rainfall record. The equation was modified such that months with no rain led to no inflow to eliminate the mathematical minimum inflow created by the correlation equations.

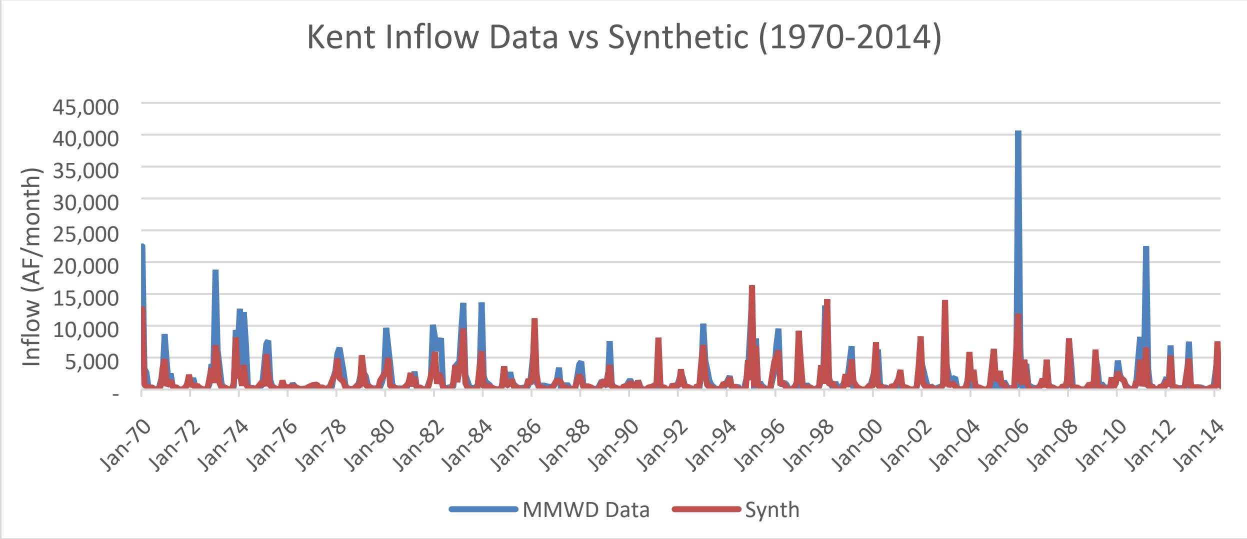
Figure 5-3: Inflow and Precipitation Correlation Example



5.3.3 Synthetic Hydrograph Check

Each synthetic hydrograph was checked against the *Local Reservoir Inflows* dataset for the period of 1970 through 2014 to determine its adequacy for use in the GoldSim model. An example of this check is shown in **Figure 5-4**. As seen in this figure, the synthetic hydrograph tends to underestimate extreme rainfall events. It is important to note that, MMWD's system would not be able to capture all of the rain in these extreme events to use as supply. In addition, because the model is primarily to be used for water supply planning, it is most important for the synthetic hydrograph to accurately capture average and low rainfall months, as these have a greater influence on MMWD's supply reliability. As such, the accuracy of the synthetic hydrographs for each reservoir were determined to be adequate for use in the GoldSim model.

Figure 5-4: Synthetic Hydrograph Check Example



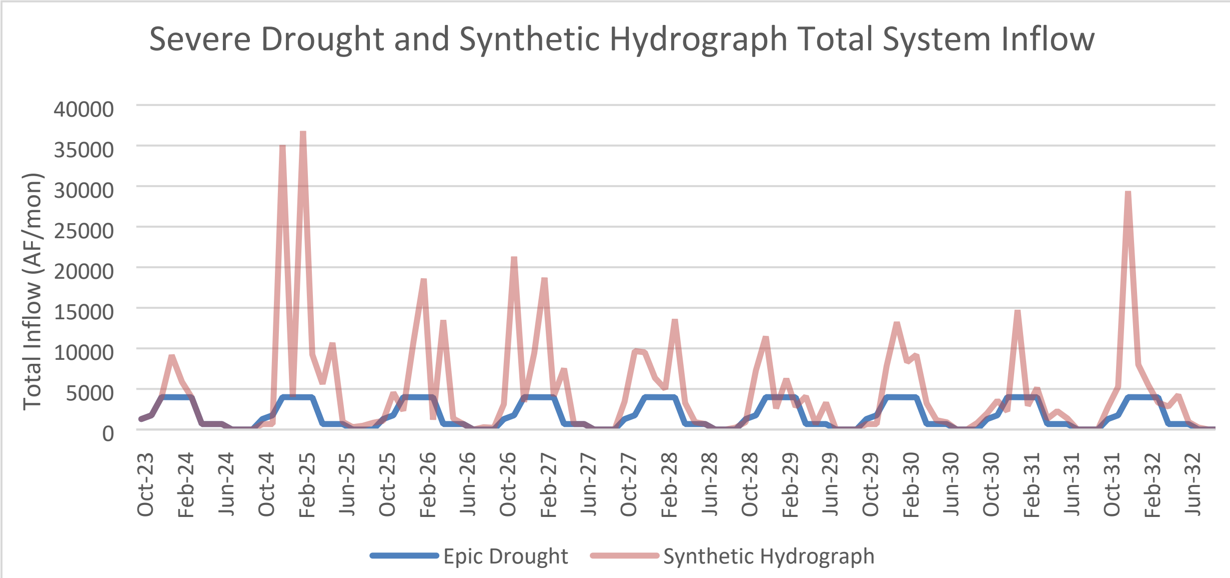
5.4 Six-Year and Nine-Year Severe Drought

A Six-Year and Nine-Year Severe Droughts were created to test MMWD's water supply system under more extreme dry conditions than have been seen in the 115 period of precipitation record. These synthetically created droughts aimed to show the magnitude of deficits that MMWD could experience under dry conditions with no "savior storms" for a period of either six or nine years, respectively. The drought was used to determine how varying the level of imports from SCWA and the level of emergency storage affects the number of years MMWD can fully meet demand under these extreme conditions and the magnitude of the deficits in years when MMWD could not fully meet demand.

5.4.1 Severe Drought Development

The Six- and Nine-Year Severe Droughts were created by first identifying which year in the historic record was most likely to produce droughts. Based on the GoldSim model output, WY1924 was the most likely to produce deficits under very high demand or reduced capacity scenario, so it was selected as the basis for the Severe Droughts. To further intensify the drought, inflows and precipitation during the two wettest months of the water year, January 1924 and February 1924, were reduced by 56% and 32%, respectively. This modified water year was then repeated either six or nine times to create the Six-Year and Nine-Year Severe Droughts, respectively. **Figure 5-5** shows the Severe Drought hydrograph compared to the synthetic hydrograph from the same period, illustrating the severity of this drought. The following section describes the analysis developed with paleo hydrology data to be able to relate the Severe Drought to past droughts in terms of severity and, particularly, the frequency of different dry spells.

Figure 5-5: Severe Drought Hydrograph



5.4.2 Related Droughts from Paleo Hydrology

Paleo records, such as tree-ring chronologies, have been used to generate hydrologic reconstructions throughout California. A review of this research can be helpful for assessing the severity past droughts going back centuries, and understanding the range of future conditions that may be expected under natural variability. Although no past hydrologic reconstructions currently exist for the watersheds within the MMWD system, three major reconstruction efforts have been identified based on proximity to MMWD and the availability of information.

Russian River

Researchers at the University of Arizona completed a 423 year (1582-2004 CE) reconstruction of precipitation and streamflow for the Russian River Valley, which includes parts of Sonoma, Mendocino, and Marin Counties. The results were presented at a drought workshop in 2008 (Griffin, 2008). This presentation included information on both the frequency and severity of past droughts.

Sacramento, San Joaquin, and Klamath Rivers

In 2014, the California Department of Water Resources (DWR) released a report, *Klamath/San Joaquin/Sacramento Hydroclimatic Reconstructions from Tree Rings*, with 1,113 year (900-2012 CE) reconstructions of unimpaired runoff in the Sacramento and San Joaquin River basins, and 497 year (1507-2003 CE) precipitation and streamflow reconstructions for the Klamath River (Meko, 2014a). The report was prepared for DWR by researchers at the University of Arizona. The report and all of the reconstructed data is available for download at DWR's website.

Palmer Drought Severity Index

The Palmer Drought Severity Index (PDSI) is a widely used measure for the intensity, duration, and location of drought conditions. In 2004, reconstructions of the PDSI were expanded to include 286 points in a 2.5 degree grid covering most of North America. These reconstructions are based on an expanded network of 835 tree-ring chronologies (602 western). The data below is from Gridpoint 36 located in San Mateo County. Data for this gridpoint extends 2004 years (0-2003 CE). This data is available on the website of the National Climate Center of the National Oceanic and Atmospheric Administration (NOAA)

Severity of Past Drought

The severity of past droughts is measured below as a percentage of the mean hydrology over a running 10 year period. **Table 5-1** ranks the five driest drought periods in the Russion River and Klamath River as measured by precipitation. **Table 5-2** ranks the five driest drought periods in the Sacramento, San Joaquin, and Klamath River as measured by reconstructed streamflow. In each of these reconstructions, researchers found that some of the driest periods were within the observed record. This was summarized in the 2014 report to the DWR: "Analysis of droughts in the reconstructions for the three basins indicates the 1920s-30s and 1990s contained periods of drought notably severe, even in a centuries- to millennium-context." (Meko, 2014a).

Table 5-1: 10 Year Running Mean Drought Events - Precipitation

Rank	Russian River		Klamath River	
	Year	%	Year	%
1	1619	80%	1660	82%
2	1783	83%	1150	84%
3	1846	86%	1485	85%
4	1757	76%	1944	85%
5	1994	87%	1174	86%

Table 5-2: 10 Year Running Mean Drought Events - Streamflow

Rank	Sacramento River		San Joaquin River		Klamath River	
	Year	%	Year	%	Year	%
1	1933	68%	1933	65%	1661	54%
2	1580	74%	1461	66%	1933	68%
3	1482	74%	1482	68%	1583	72%
4	1148	75%	1783	68%	1656	72%
5	1783	76%	984	69%	1926	76%

Duration of Past Droughts

The frequency and duration of past droughts is measured in **Table 5-3** as consecutive years below the median hydrology. All of these reconstructions include periods of 10 consecutive dry years. The Klamath River stands out as having a greater frequency of droughts. The results for the Klamath River included one severe drought of 21 consecutive dry years, including four years with flows lower than any in the observed record. The reconstruction of this drought is shown in **Figure 5-6**.

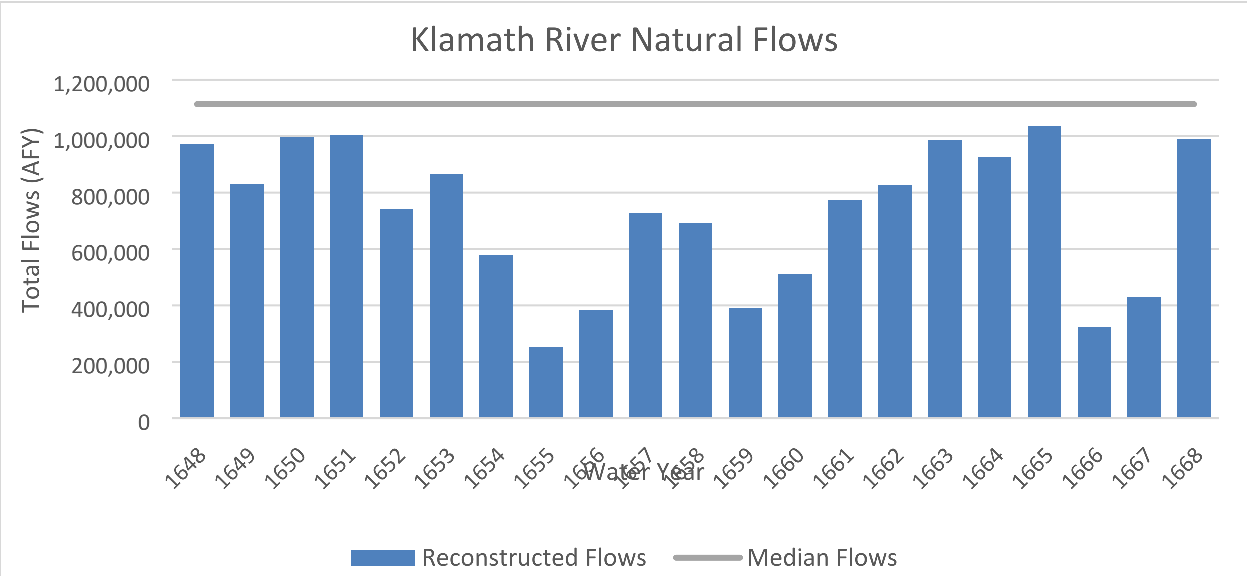
Table 5-3: Frequency of Consecutive Year Dry Periods in the Paleo Record

Consecutive Years	Russian River[a]	Sacramento River [1]	San Joaquin River [1]	Klamath River [2]	PDSI [3]
2 Years	23%	27%	25%	31%	26%
3 Years	12%	15%	14%	21%	13%
4 Years	6%	9%	7%	14%	7%
5 Years	3%	6%	4%	10%	4%
6 Years	2%	4%	3%	7%	2%
7 Years	1%	3%	2%	5%	2%

8 Years	0.7%	2%	1.2%	4%	1.2%
9 Years	0.5%	0.8%	0.8%	3%	0.8%
10 Years	0.2%	0.4%	0.6%	3%	0.6%

a. Russian River statistics compare years below mean hydrology. All other areas compare years below median hydrology. As such, Russian River data was not used in estimating probability of severe drought duration.
[1] Meko, 2014b
[2] Malevich, 2013
[3] Cook, 2004

Figure 5-6: Klamath River Severe Drought Reconstruction



5.4.3 Probability of Severe Drought Durations

The frequency and duration of past droughts is presented in **Table 5-3**. As indicated, Russian River statistics compare years below mean hydrology, while all other areas compare years below median hydrology. As such, Russian River data was not used in estimating probability of severe drought duration. Based on the data presented, the probability of a Six-Year Severe Drought occurring in any given is year is between 3% and 7%. The probability of Nine-Year Severe Drought occurring in any given year is estimated to be between 1% and 3%. Given the higher probability of a six-year drought occurring, analyses presented in the WRP 2040 have focused on this drought duration, though the Nine-Year Severe Drought simulations are provided for informational purposes.

6 Modeling Assumptions

The main modeling assumptions will be discussed in this section.

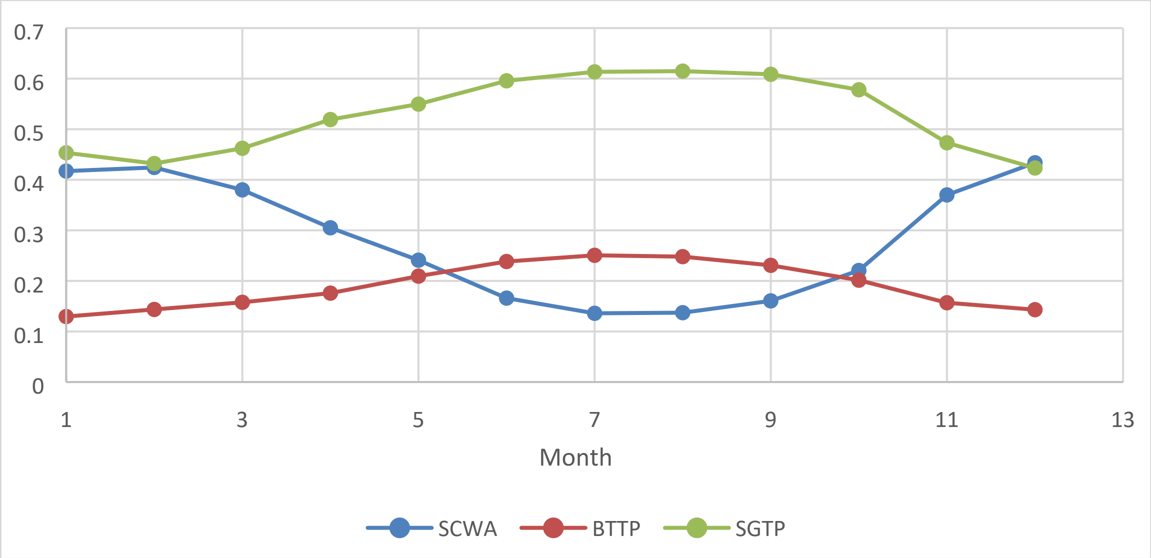
6.1 System Operation

The system model was designed to mimic anticipated operational patterns followed by MMWD. These included use of the 5,300 AFY take-or-pay SCWA water whenever possible, use of BTTP to maximum extent possible followed by SGTP with its larger storage, and use of the more expensive imported water for periods of high demand where local sources and the 5,300 AFY of take-or-pay are unable to satisfy it's the District demands. This general priority sequence results in a supply mix from sources that closely follows average historical operation. Non-potable water demands – namely raw water and recycled water, are considered first and separately, as the satisfaction of these demands of lower priority than potable demands.

6.1.1 Demand Seasonality

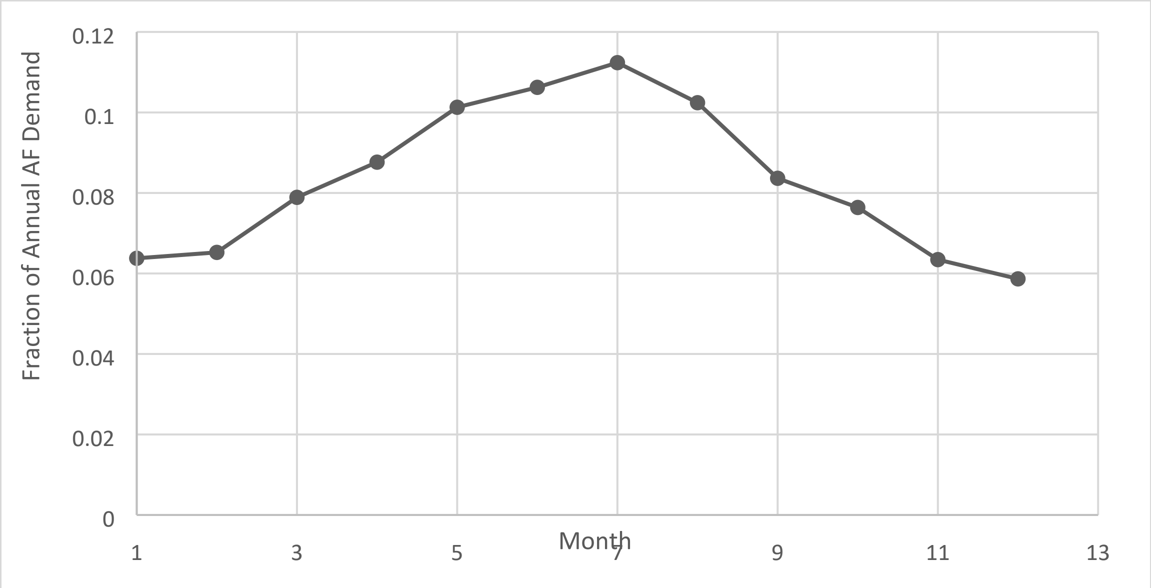
In normal operations, the full base demand is allocated to be satisfied by potable supply sources following a monthly seasonality based on long-term average historical operations. This seasonality can be seen in **Figure 6-1**.

Figure 6-1: Monthly Proportion of Demands from Existing Water Sources



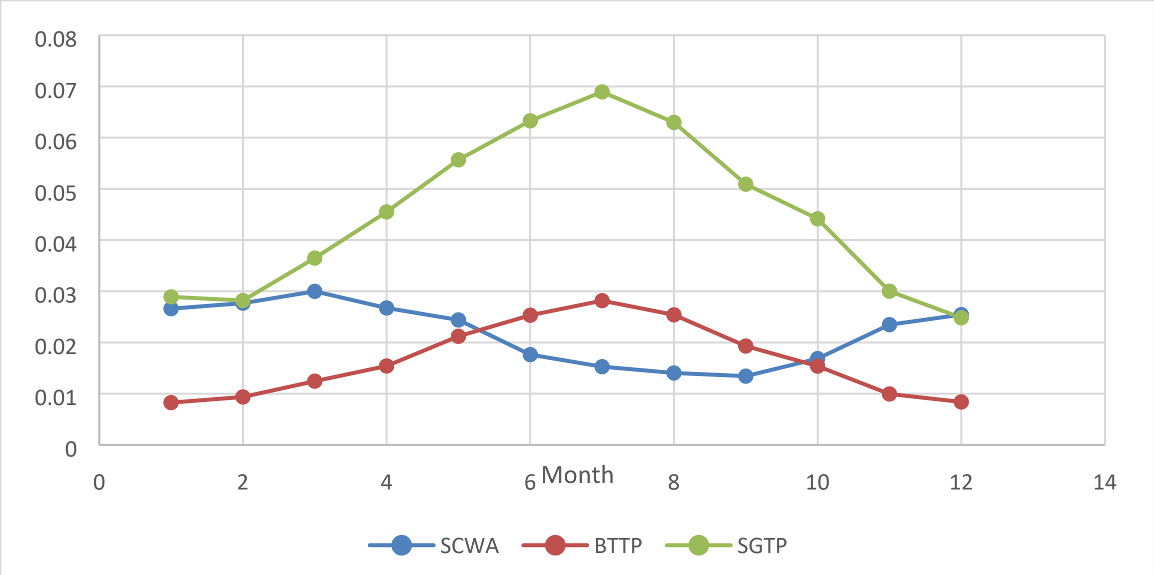
As depicted in Figure 6-1, SGTP typically fulfills the majority of potable demand, especially in the summer months. During this period, SCWA's contribution significantly declines, in part due to restrictions on availability in those months. BTTP's contribution increases during this time to offset the declines in SCWA's proportional contribution. These varying demand fractions are further amplified by the monthly variation in demand seen in **Figure 6-2**.

Figure 6-2: Monthly Demand as a Fraction of Total Annual Demand



As Figure 6-2 illustrates, demand peaks in the summer months. The combination of these two graphs results in the net demand curve shown in **Figure 6-3**.

Figure 6-3: Net Monthly Demand Fraction



6.1.2 Supply Sequence in WaterSim

WaterSim follows a logic that is generally based on historical operations as described above. With the introduction of new supply projects (options), a prioritization of sources is required for the model. The water supplies are prioritized as seen in Table 6-1.

Table 6-1: WaterSim Supply Priority

Priority	Description
0	Resiliency Options
1	Raw Water
2	Recycled Water
3	Sonoma County Water Authority (SCWA) Imported Water – Take-or-Pay (5,300 AFY)
4	Bon Tempe Treatment Plant (BTTP)
5	San Geronimo Treatment Plant (SGTP)
6	Sonoma County Water Authority (SCWA) Imported Water

This prioritization is applied in every time step in the simulation and it is meant to ensure that resiliency option water is used first (Priority 0), given that supply from new options, when triggered by system conditions, would be constructed to alleviate demands on the system resulting from drought or system shutdown conditions. One of the "supply" options included in the model is water conservation. This is applied in the model as a reduction in demand.

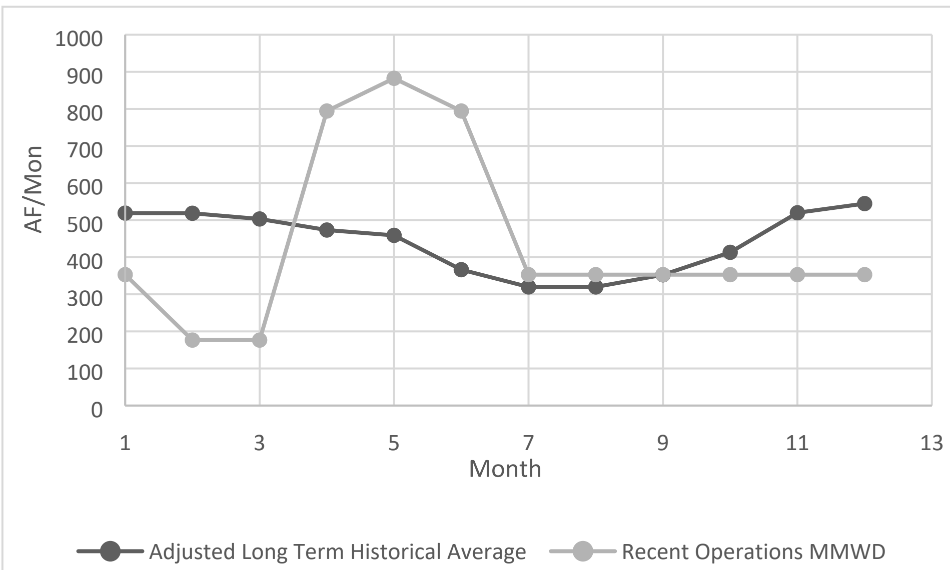
Following the resiliency options, non-potable demands are considered (Priorities 1 and 2). In cases where these demands are not satisfied, the unsatisfied demand is not considered to be fulfilled by potable supplies, in the current version of WaterSim. It is anticipated that these demands would not be satisfied in cases where their source is unavailable, especially in times of a drought.

SCWA Take-or-Pay supply is then utilized (Priority 3), in order to ensure the usage of this purchased water. BTTP supplies are used next (Priority 4), due to the combination of higher elevation and smaller storage for Bon Tempe Lake and Alpine Lake compared with SGTP's primary lakes of Kent Lake and Nicasio Lake. This priority is also in-keeping with the smaller portion of demand BTTP satisfies on an annual basis, relative to SGTP. SGTP is the final local source (Priority 5), supplying water primarily from Kent Lake and Nicasio Lake, and pulling from Soulajule Lake when Nicasio Lake is significantly drained. The final source is the remaining SCWA imported water right –volumes over the 5,300 AFY take-or-pay (Priority 6). This water is heavily constrained, especially in summer months. It is anticipated that this source would also be heavily constrained in times of drought (not firm).

SCWA Take-or-Pay (5300 AFY)

The SCWA Take-or-Pay of 5,300 AFY is included to ensure that the purchased water right is used to its full extent. A proportional demand was developed from the 1992 – 2009 data to act as the validation minimum take-or pay demand. A seasonal pattern provided by MMWD that more closely follows the recent patterns observed was used for simulations. This demand only acts as a minimum while total SCWA usage for the water year is below 5,300 AF, after which it no longer impacts operations. A graph of the seasonality of the two options is shown in Table 6-2.

Table 6-2: SCWA Take-or-Pay Demand (5,300 AFY)



BTTP Operations

BTTP operates primarily using water from Bon Tempe Lake as well as from Alpine Lake, delivered through Bon Tempe Lake. Water can be delivered from Lagunitas to Bon Tempe Lake, as well as directly from Phoenix Lake. These two delivery paths (from Phoenix and Lagunitas lakes) are not frequently used and represent a small amount of available water. Lagunitas Lake holds a maximum of 350 AF, with overflow water spilling into Bon Tempe Lake. Phoenix Lake holds a maximum of 411 AF which must overcome over 400 ft. of elevation to be used, 261 AF of which are strictly not usable.

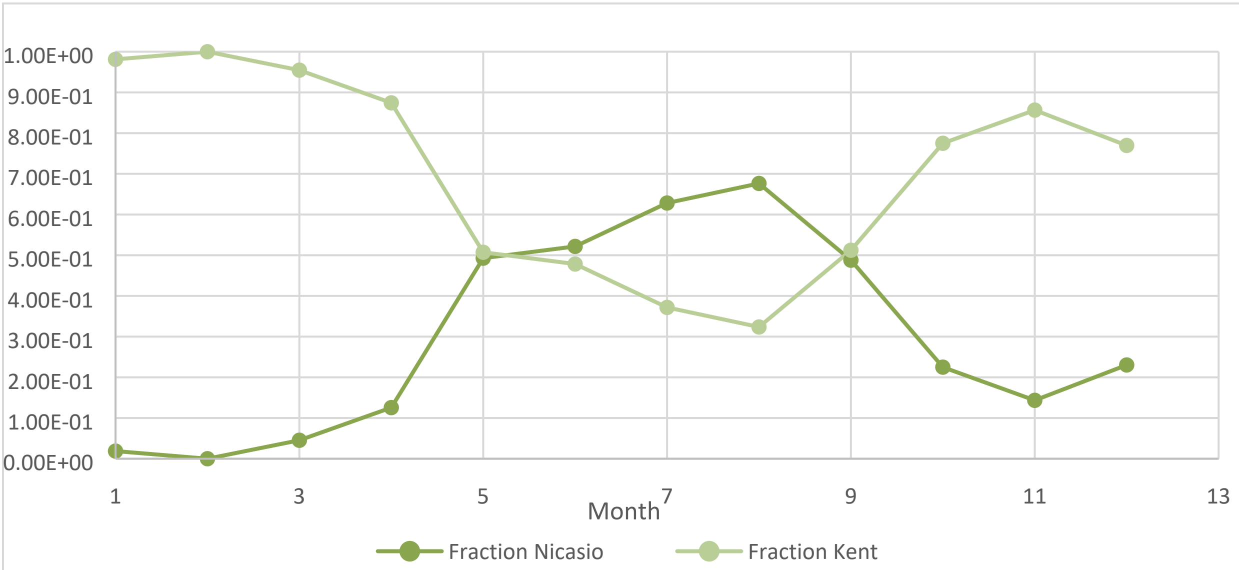
Lagunitas does not currently operate under any simulated conditions. This reflects existing usage rates, as well as lake volumes. The storage in Lagunitas is counted as part of the emergency storage targets for the district.

Phoenix will be used in cases where Alpine Lake's elevation dips below 600 ft. (2131 AF). It pumps to satisfy as much BTTP demand as possible. This rule in WaterSim results in usage only when severe droughts are observed (matching historical usage).

SGTP Split

SGTP operated using water from Kent Lake and Nicasio Lake. These two lakes hold the majority of the surface water in MMWD's reservoir system. They are operated on a seasonal basis in WaterSim based on a general historical pattern following that seen in Table 6-2.

Figure 6-4: SGTP Production Fraction between Kent and Nicasio



Deviation from this pattern occurs when Kent Lake falls below 15,000 AF of total storage, at which point the division in demand is based strictly on available storage. As Kent Lake's storage level decreases, Nicasio Lake provides more and more supply, as it can draw from Soulajule Lake, the third biggest reservoir in the system.

Resiliency Options

Resiliency Options are implemented with the intent of being used in evaluation of long-term alternatives. The resiliency options currently modeled include: A04 Spot Market Transfers, B13 Max IPR, C07 Santa Rosa Conjunctive Use, D01 Expanded SCWA, F01 Conservation, and H03 Watershed Management.

6.1.3 Internal Transfers

In order to fulfill demands, internal transfers are often necessary to ensure the water treatment plants receive sufficient water. The MMWD surface water system has two primary transfers, from Alpine Lake to Bon Tempe Lake, and from Soulajule Lake to Nicasio Lake. Transfers can also be made between Alpine Lake and Kent Lake, though these are much less common.

Alpine Lake to Bon Tempe Lake (Pumping)

Transfers from Alpine Lake to Bon Tempe Lake occur very frequently. Due to the small amount of storage in Bon Tempe Lake that can be gravity fed to BTTP, Alpine Lake begins pumping to Bon Tempe Lake once Bon Tempe Lake's level falls below 711 ft. Pumping stops once the lake reaches 716.5 feet. The pumping is the minimum of the capacity of the pump and 1.5x the demand. This multiplier of demand is taken to replenish Bon Tempe Lake.

Soulajule Lake to Nicasio Lake (Pumping)

Transfers between Soulajule Lake and Nicasio Lake only occur when Nicasio is significantly depleted, at a capacity below 40% of total storage. At this point, Soulajule Lake transfers as much as it can to Nicasio.

Kent Lake to Alpine Lake (Pumping)

Kent Lake delivers to Alpine only if the month is September or October, or SGTP is down. The pumping only occurs when the difference in elevation s between the two lakes is less than 400 feet, Alpine Lake's elevation is below 596 feet and Bon Tempe Lake is below 714 feet.

Alpine Lake to Kent Lake (Releases)

Alpine Lake releases to Kent Lake when Alpine Lake's water level is below 596 feet or BTTP is down; and Kent usable storage is less than 2000 AF. This operating mode will not be observed in WaterSim unless extremely dry conditions are observed.

6.2 System Elements

Pumps and Pipeline Constraints

After discussions with MMWD, it was determined that pump stations would be the limiting factors on delivery of flows between lakes and from lakes to treatment plants. For cases where facilities delivered under gravity flow and data was not received, placeholder capacities were noted and flows were based on demands from treatment facilities. The capacity of the gravity fed pipe was assumed to be non-limiting with respect to BTTP for the Bon Tempe Lake to BTTP connection.

Certain pump stations were described by a horsepower, but lacked an operating procedure and/or pump curve. Where missing, a synthetic pump curve was developed. The curve was then used to develop an operating procedure. Should the data become available, these can easily be updated in WaterSim. The pumps for which operating procedures were developed include: Ignacio Pump Station, Kent to Alpine Booster Station, and Soulajule to Nicasio Booster Pump Station.

Costs

The model includes costs associated with pumping. Other costs are incorporated via the excel output manager to compute the overall cost of the supply portfolio in $/AF. Costs are separated out into fixed and variable. Conservation is considered a resiliency option to properly account for its benefits and costs.

7 Supply Planning Elements

As explained in Section 1, the model has two main uses in the short- and mid-term: 1- as an analytical tool for the completion of the resiliency analysis in the Water Resources Plan 2040, and 2- as the tool to do annual operating plans and to periodically streamline and optimize the system of lakes. For these purposes, some elements need to be included in the model to assist in decision making.

Demands

Water demands dictate the water required from storage, LGWRF and from SCWA. Nonpotable demands include raw water and recycled water. Raw water demands are satisfied by raw water coming off the SGTP as well as water from as from Bon Tempe Lake. This water serves two local golf courses. Recycled water is provided by the LGWRF. The entire potable demand is aggregated into a single "demand node" for the model. Demands are satisfied with the supply priorities described above.

There are three demand forecasts included in the model, these are the low, middle, and high range estimates of future water use. These demand forecasts come from MMWD's 2015 Urban Water Management Plan. Simulations primarily focus on the middle and high range estimates, to be conservative and to anticipate worst-case scenarios.

New resiliency options will be assessed as part of the resiliency analysis and the Water Resources Plan 2040 that have the potential to reduce the demand on lake water. The demand box in **Figure 3-1** is thus labeled "Demand on Lake System and Imported Water" to indicate that Resiliency options assessed may offset the demand that triggers the use of imported and lake water.

Resiliency Options and Alternatives

There are six resiliency options modeled in WaterSim. They are: WE01 Enhanced Conservation, RU13 Max IPR, SC03 Expanded SCWA, GW07 Santa Rosa Plain Conjunctive Use, WP04 Spot Market Transfers, and EO03 Watershed Management.

They are modeled as follows:

WE01 Enhanced Conservation

Conservation in the GoldSim model represents the highest considered conservation level, which would allow 1,000 AFY of conserved water. Conservation is modeled in the supply-demand balance as a supply in WaterSim, representing a constant "supply" of conserved water.

RU13 Max IPR

Max IPR provides 7,885 AFY of IPR water to Kent Lake to supplement storage. This project is assumed to operate constantly in baseload mode. Currently, the supplemental water continues to flow even if Kent Lake is spilling, allowing the option to contribute to environmental flows.

SC03 Expanded SCWA

Expanded SCWA option allows for increased use of SCWA water. This is accomplished through infrastructure improvements that allow for MMWD to use a greater portion of its SCWA water right. The improvement is anticipated to allow for 4300 AFY of increased water availability, resulting in a total of 14,300 AFY. The available water continues to follow a water right seasonality. This option is a modification of the existing SCWA supply (Priority 3 and 6). WaterSim seasonal curve of imported water use is adjusted during this option.

GW06 Santa Rosa Conjunctive Use

The Santa Rosa Conjunctive Use option allows for the storage of 1,080 AF of water in the Santa Rosa groundwater basin. Accounting for anticipated losses of 20%, this allows for a maximum positive balance of 900 AF of usable water to be available to MMWD. This water would be pumped by Santa Rosa in lieu of SCWA water, allowing for MMWD to increase their deliveries from SCWA in times of need. The usage of the banked water is triggered to happen during the Severe Drought, as well as when the system is in a dry year (80% or less storage on Dec 1^{st}). This metric for 'dry year' designation can be easily modified in WaterSim.

WP04 Spot Market Transfers

Spot Market Transfers allows for the import of water from a new source through wheeling and arriving to the District's service area through the EBMUD pipeline project. The supply is limited to 5,000 AFY. This supply is used when the MMWD system is considered to be in a dry year. A dry year is defined as a year in which the total storage on December 1^{st} is at 80% or less. The year extends from the test date until the next December 1^{st}. This metric for 'dry year' designation can be easily modified in WaterSim.

EO03 Watershed Management

Watershed Management increases net inflows into the MMWD system by 200 AF. As the location of the Watershed Management is not assured, the impact of the increase has been implemented as a multiplier on all inflows to increase the net by 200 AF on an average year. The multiplier further increases inflow on wet years, and has a muted effect in drier years.

Reliability Threats

There are 11 reliability threats that are considered in this model. They are: Earthquake or Water Quality Event (SCWA), Wildfire, Earthquake (BTWTP), Water Quality (Kent), Water Quality (Nicasio), Water Quality (Alpine), Earthquake (SGWTP) (3 months), Climate Change (Lowest Inflows Scenario), Six-Year Severe Drought, Nine-Year Severe Drought, and the Historical Hydrology. Options with a water source in parenthesis involved losing the functionality of that source/facility. The Six-Year and Nine-Year Severe Droughts are artificially created hydrologies. In order to have comparable results, the hydrology immediately following the end of the Severe Drought in September is followed by average year hydrology as defined by the year 2004 from that October through till the December of the following year. The climate change reliability threat uses MIROC5 hydrology.

As many of these alternatives do not result in deficits, they were frequently considered as constantly occurring, despite actual anticipated durations occurring on a timescale of months. For certain events, like the Earthquake SGWTP (3 months), keeping the alternative on constantly results in deficits. For this reason, the shorter realistic period of incidence is considered.

Table 7-1 describes the facilities that would be impacted by each alternative.

Table 7-1: Reliability Threats and Impacted Facilities

Reliability Threat	Operational Constraint/Challenge
Earthquake or Water Quality Event (SCWA)	SCWA down
Wildfire	BTTP at half demand, Kent Lake unusable
Earthquake (BTWTP)	BTWTP down
Water Quality (Kent)	Kent Lake unusable
Water Quality (Nicasio)	Nicasio Lake unusable
Water Quality (Alpine)	Alpine Lake unusable
Earthquake (SGWTP) (3 months)	SGWTP down for 3 months
Climate Change (Lowest Inflows Scenario)	Hydrology with significantly reduced inflows
Six-Year Severe Drought	6 year artificial hydrology of extremely low inflows
Nine-Severe Drought	9 year artificial hydrology of extremely low inflows
Historical Hydrology	Baseline historical hydrology

These inputs are controlled by switches inputs. Each of the individual facility/reservoir outages has their own switch. The hydrology switch has the options of Historical Hydrology (referred to as synthetic hydrology), Six-Year Severe Drought, Nine-Year Severe Drought, and Climate Change. These can be accessed via the dashboard.

8 Types of Simulations by Marin WaterSim

Marin WaterSim can be run using two approaches to simulating hydrology and annual water demands. The first approach is to use a single simulation of the full hydrologic sequence while using a single planning year demand assumption. The second approach is to run a full demand projection scenario across multiple realizations using the index sequential resampling technique.

The settings used to run these two approaches can be found in the Simulation Settings dialogue, which can be accessed directly from the main menu under **Run > Simulation Settings**, by pressing **F2**, or by clicking on the **Simulation Settings** button in the standard toolbar. Under the Monte Carlo tab, the user can select whether the simulation will be deterministic (single run) or probabilistic (multiple runs) and select the number of realizations.

The purpose of the first approach is to test the performance of the system across the full hydrologic sequence while other assumptions such as demand remain static. This approach is more intuitive, less data intensive, and it is the basic type of simulation used for Water Resources Plan 2040. Under this approach, a hydrologic scenario is selected in the dashboard, and the time setting in the Simulation Settings dialogue are adjusted, if necessary, so the full hydrology can be run. For example, historical hydrologic record is contains 115 years of data, and the time settings would be set to run for 115 years. The user does not need to adjust the start time of the model because the start date of the hydrologic time series element is time shifted to correspond with the start of the model. In order to select a single planning year demand assumption, the user also selects the Run Single Year check box, from the reliability threats dashboard. The user then selects a demand series and a single demand year.

The purpose of the second approach is to simulate one of the three demand scenarios developed by Maddaus (Maddaus, 2016). These demand projections run from 2015 to 2040. When using this approach, the user should select the corresponding dates in the Simulation Setting dialogue. In order to run the full hydrologic sequence across this shorter simulation time, the model runs multiple realizations using the indexed sequential method. This is a stochastic modeling approach in which the hydrologic sequence is time shifted one year at the start of each new realization. The hydrologic time series is also run on a loop so that the last year is followed by the first year of data. To run the model using this approach, the number of realizations should correspond with the number of years in the hydrologic sequence. For example, if the historical hydrologic record is selected, the simulation settings be set to run 115 realizations.

9 Model Validation

Validation is the process used to determine the predictive capability of a computational code through comparison with a set of data, modifying parameters, rules and assumptions until agreement is reached on the adequacy of the code. Validation is common for **systems models** where the most critical equations reflect decision-making. It differs from **calibration**, which is used in numerical models to adjust a set of parameters associated with a computational science and engineering code so that the model agreement is maximized with respect to a set of data.

The best and most complete data set received from MMWD from October 1992 to September 2009 provided a basis for comparing results to historical operations. This data set was validated in excel to correct for clear errors that would generate a loss of conservation of mass, as well as extrapolating from adjacent years where data was missing.

9.1 Validation Inputs

Validation Inputs are those inputs that are known inflows or demands from the system. These inputs include precipitation, inflows, pan evaporation constants, demands, potable water, recycled water, and raw water. They provide the historical basis on which system operations are decided.

9.2 Validation Results

Validation proved very successful, as the data sets corresponded well with the GoldSim output. This is a reflection of the accuracy of the known data on the water system. The system also benefits from refreshing when most or all lakes are filled and spilling, resulting in a clearing of any accumulated storage level errors.

9.2.1 Storage

As seen in **Figure 9-1** through **Figure 9-6**, the simulated storage closely follows the historical storage record. Deviations between the data and simulated storage levels are related to magnitude, likely due in part to issues with the historical record and those impacts on model outputs. The Lagunitas and Phoenix Lakes are not used, for which reason their graphs are not displayed.

Figure 9-1: Kent Storage

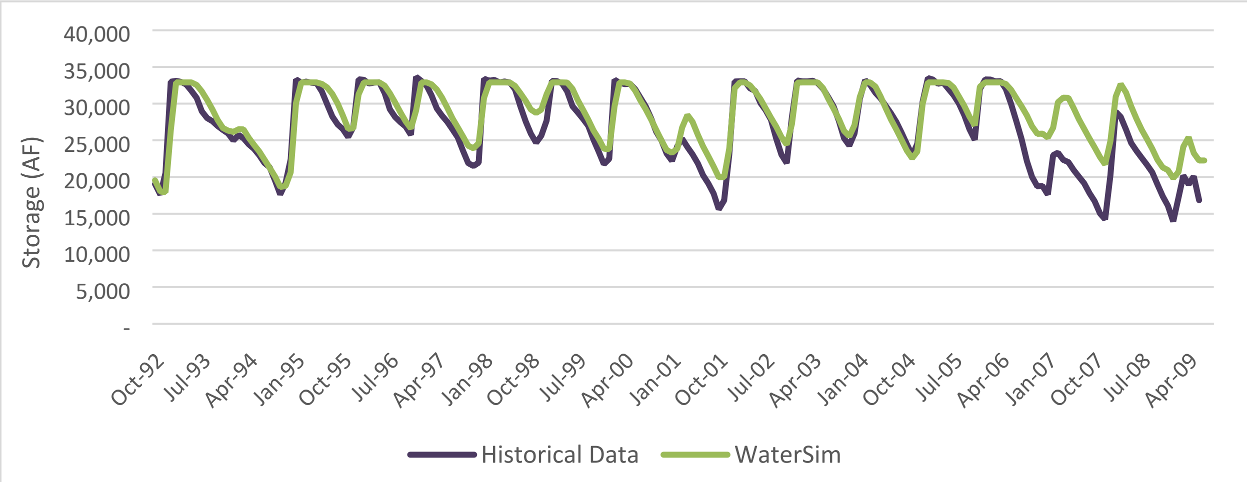


Table 9-2: Nicasio Storage

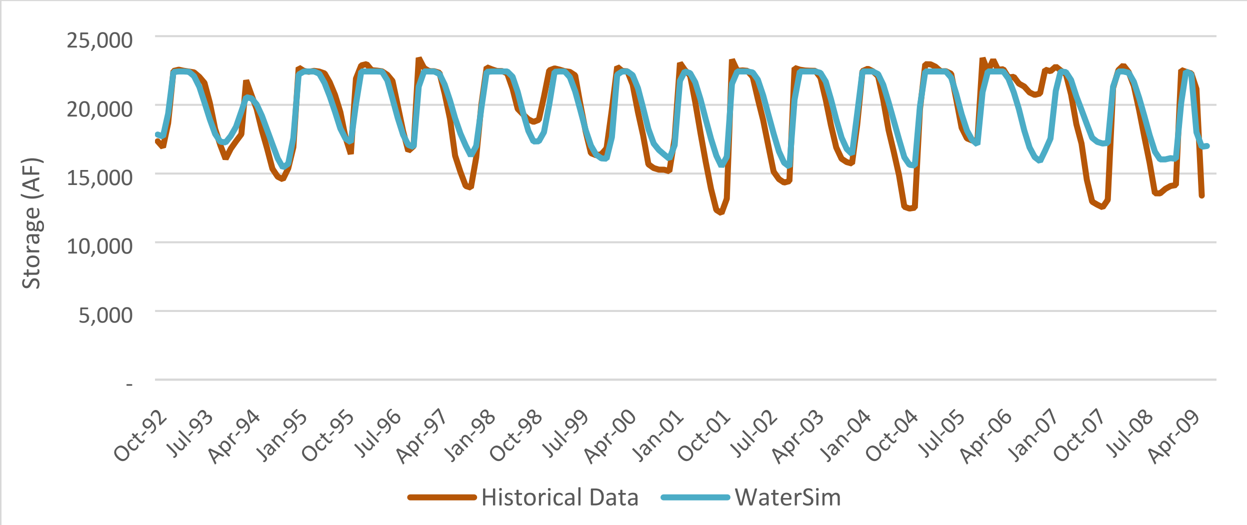


Figure 9-3: Alpine Storage

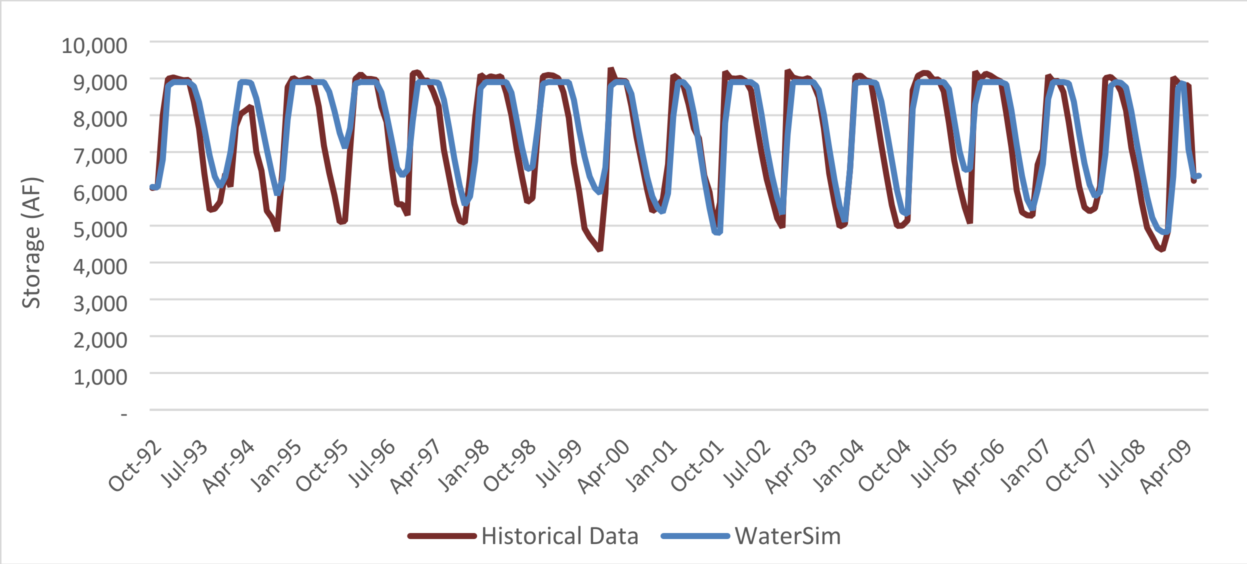


Figure 9-4: Bon Tempe Storage

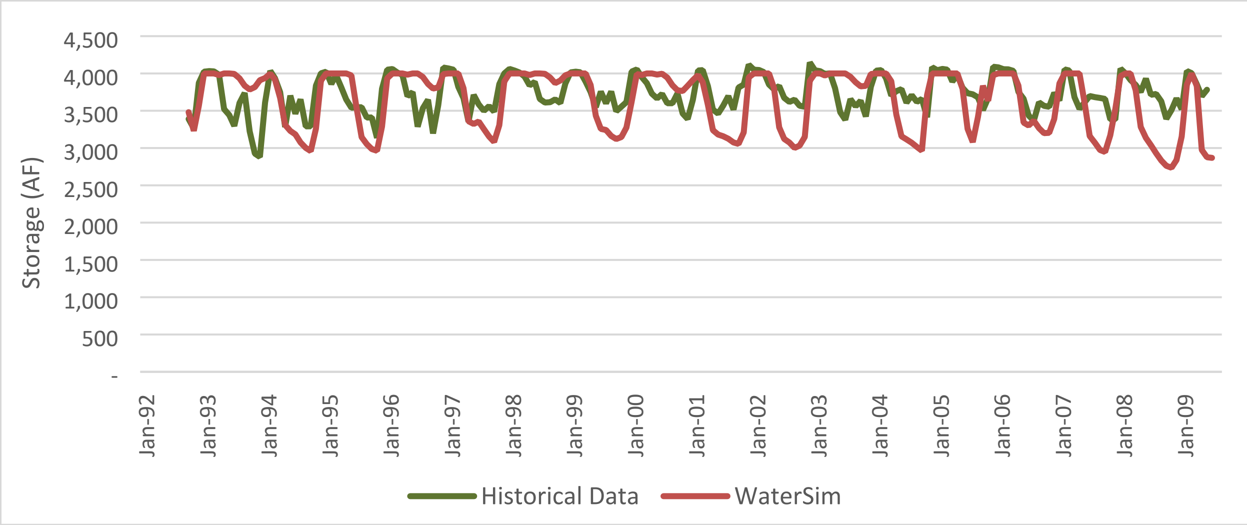


Figure 9-5: Soulajule Storage

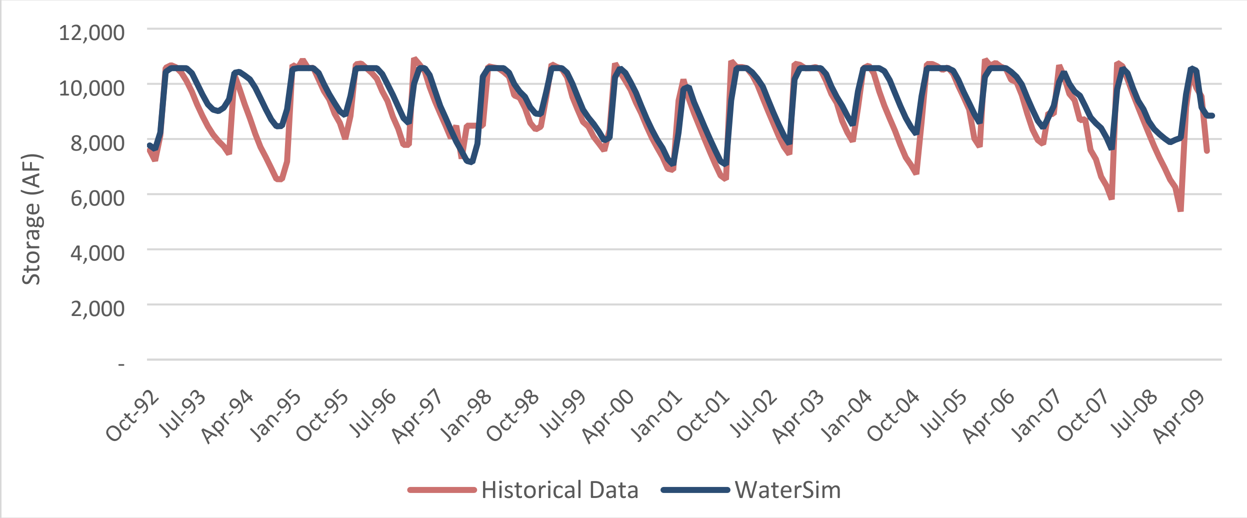
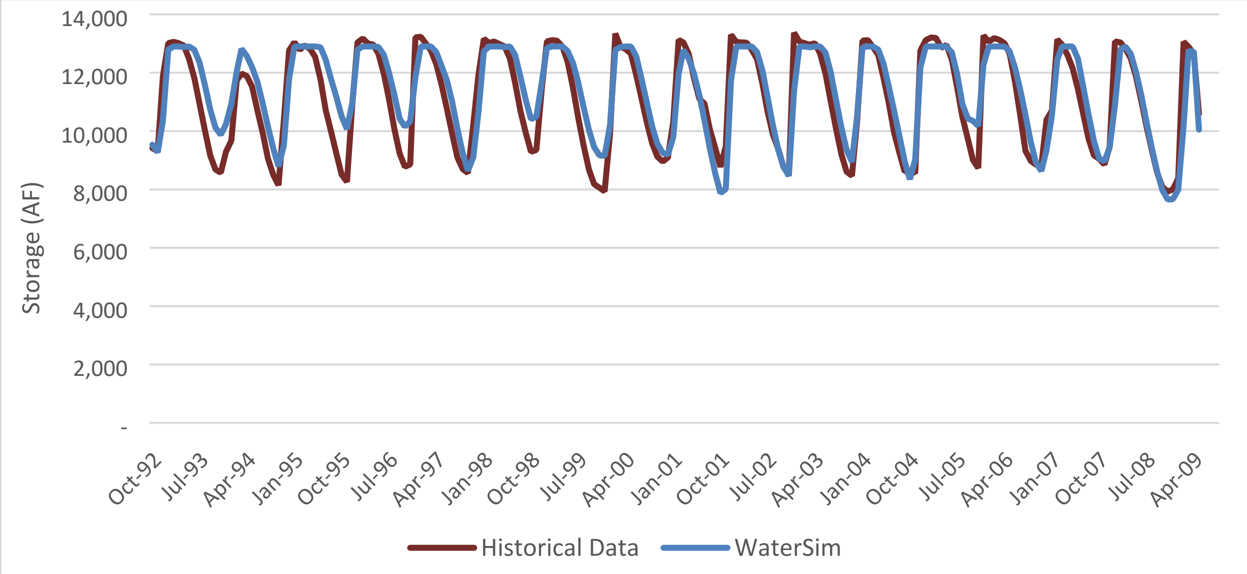


Figure 9-6: Alpine and Bon Tempe Combined Storage



9.2.2 Spills

As shown in Figures 9-7 through 9-13, modeled spills for the lakes appear to correspond more closely to historical data than the modeled storage. This is in part due to the greater magnitude of the spills of some lakes, which deviations between the model and historical data less visible graphically.

Figure 9-1: Kent Spills

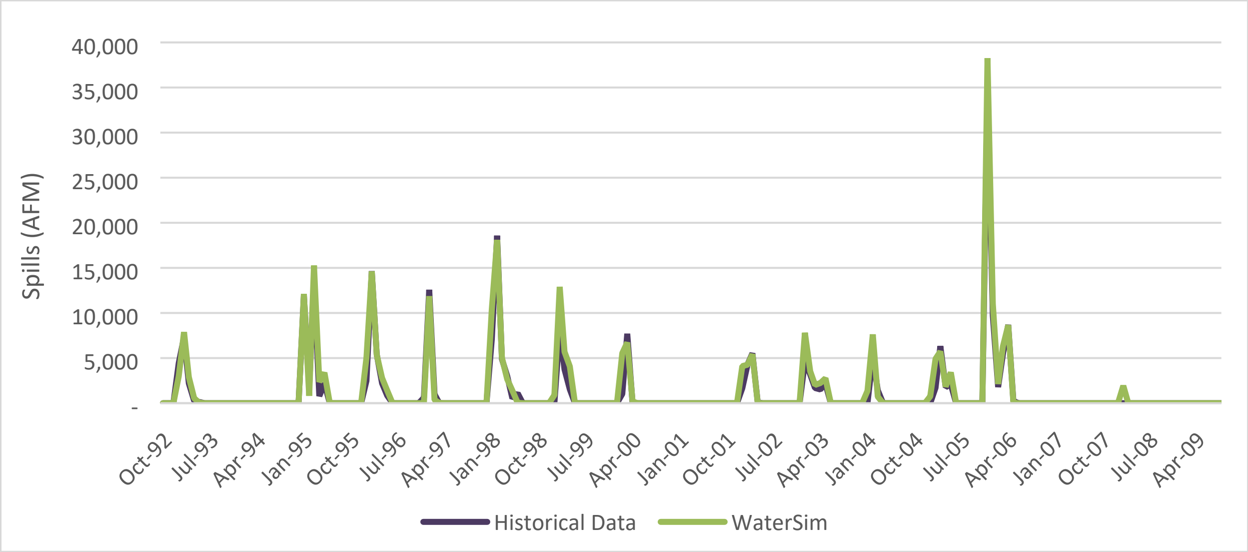


Figure 9-2: Nicasio Spills

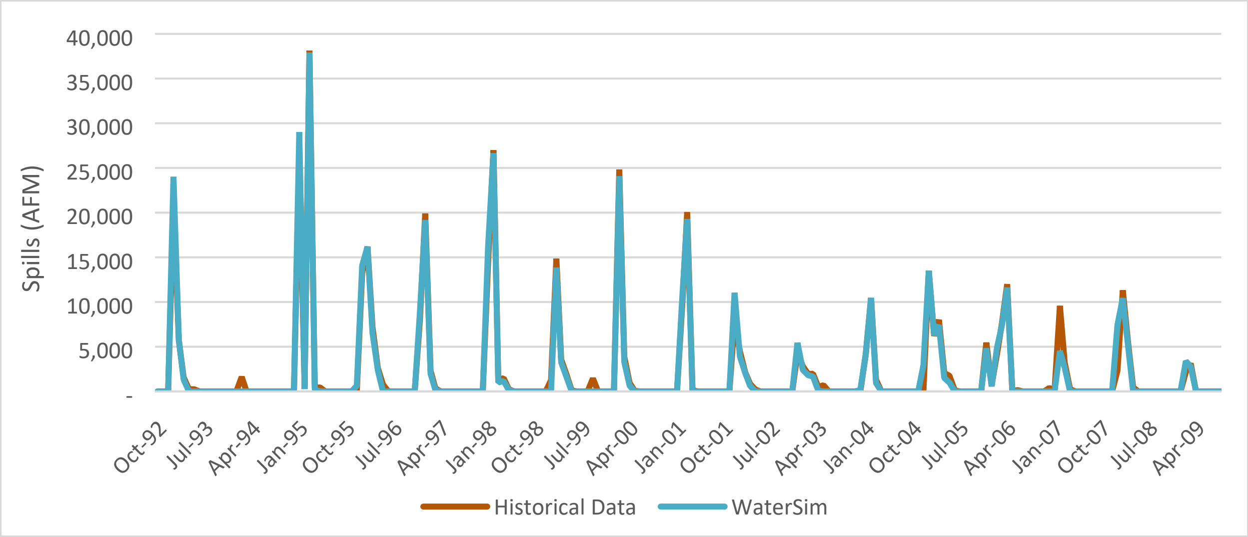


Figure 9-3: Alpine Spills

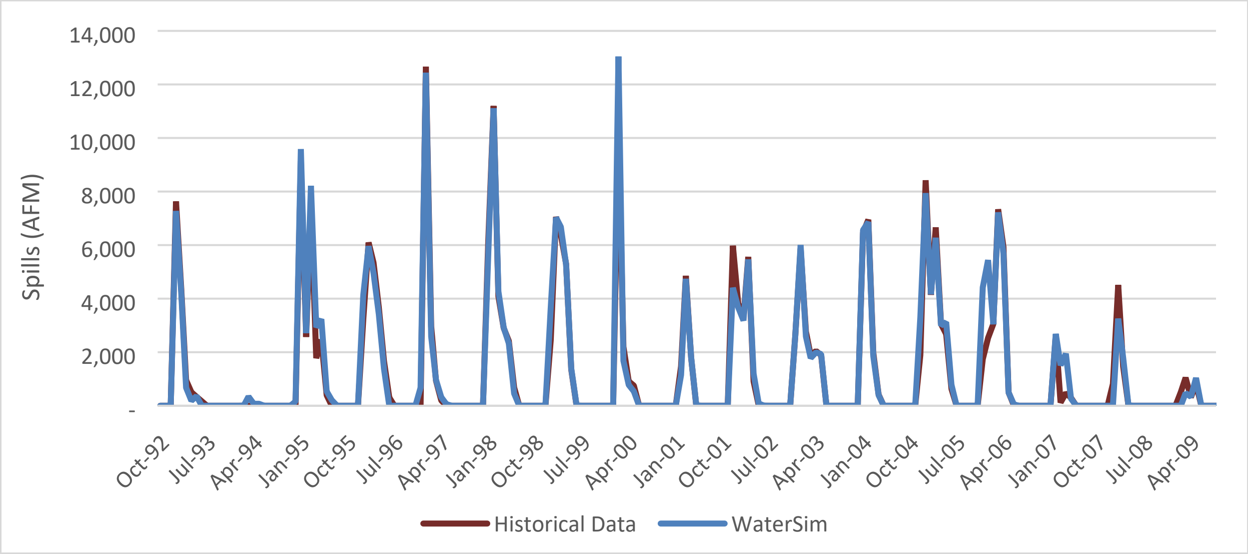


Figure 9-4: Bon Tempe Spills

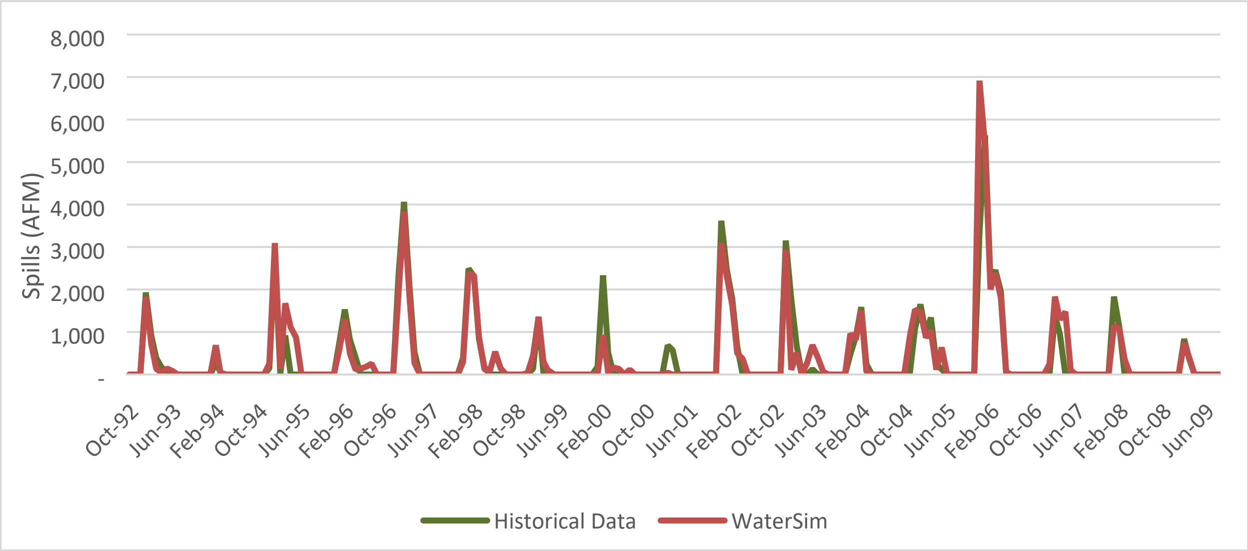


Figure 9-5: Lagunitas Spills

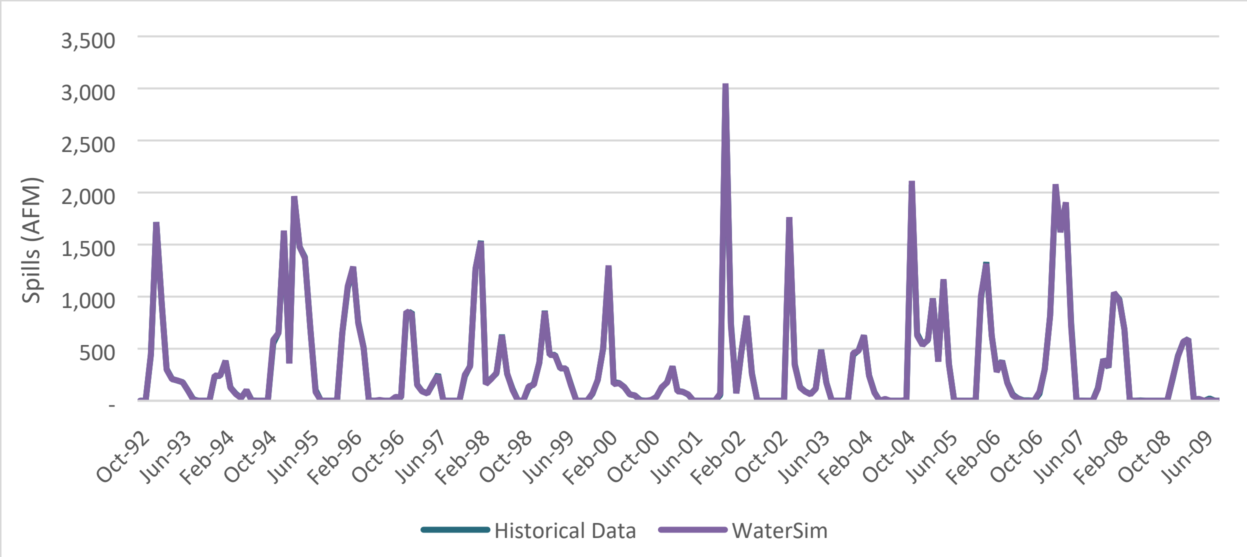


Figure 9-6: Phoenix Spills

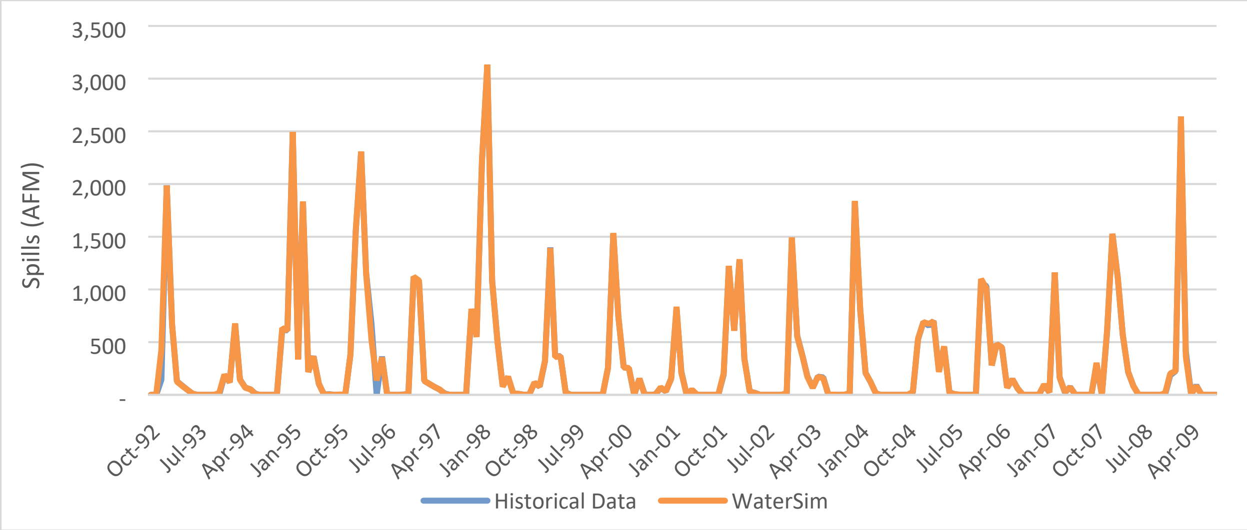
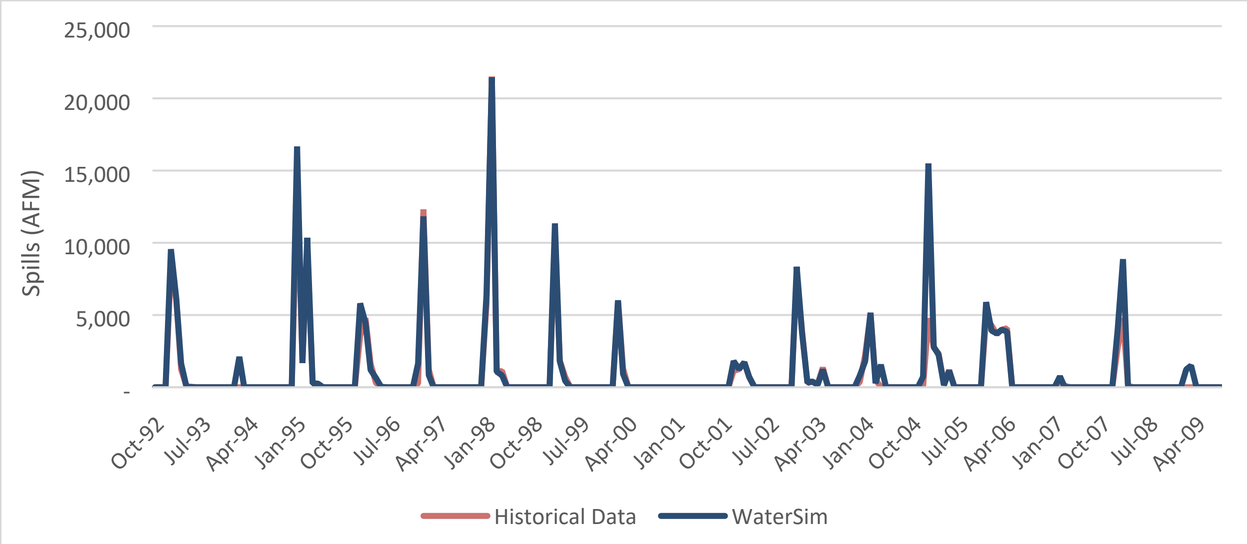


Figure 9-7: Soulajule Spills



9.2.3 Environmental Releases

Environmental Releases are only performed from Kent Lake and Soulajule Lake. The releases are meant to follow a mandatory minimum, though at operator and system discretion more can be released. This is apparent in Figures 9-14 and 9-15 below, where the simulated releases are generally lower than the system releases.

Figure 9-8: Kent Environmental Releases

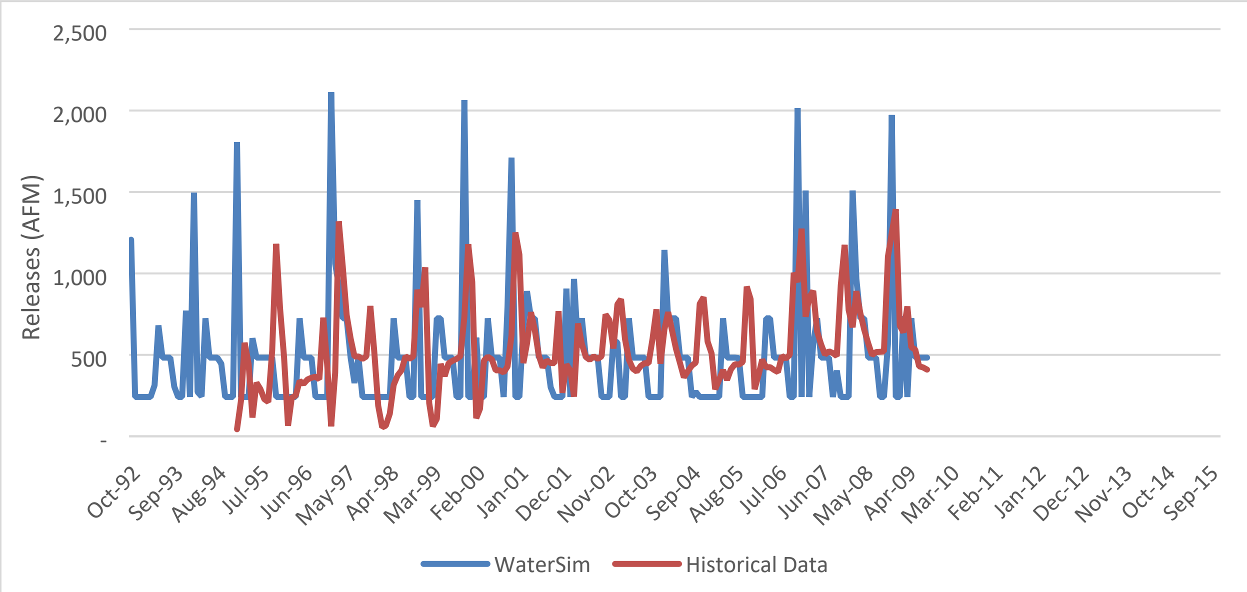
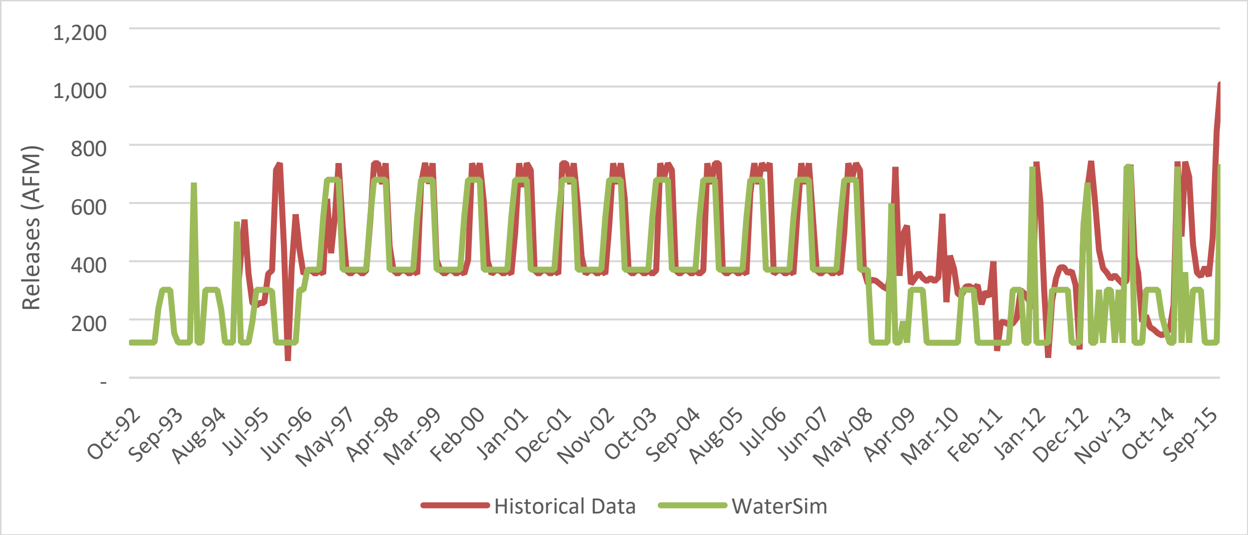


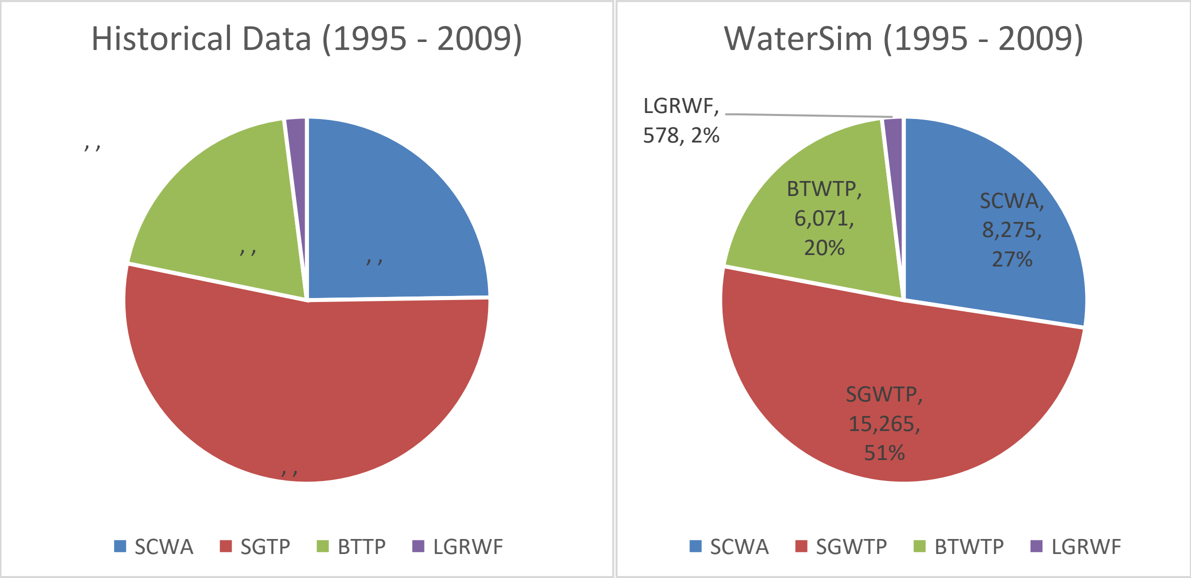
Figure 9-9: Soulajule Environmental Releases



9.2.4 Operational Flows

Due to the heavy influence of human decisions in operational flows, the comparison of monthly operational flows can have more significant deviations in validation compared to validation based on storage and spills. In the validation of operational flows, the seasonal trends were largely present. The operational flows ultimately dictate the water production at the three treatment plants. **Figure 9-10** shows the validation comparison of the contribution of each plant to total production. Minor differences in production can be accounted for due to real-world operations that were decided based on varying goals and criteria for which inputs are not available and cannot be re-created.

Figure 9-10: Annual Operational Flows by Source



9.2.5 Evaporation

Evaporation calculations are largely based on temperature and storage. As shown in Figures 9-17 through 9-23, this results in a high level of consistency between the data and the simulated values. In those cases where the data is significantly different, deviation may be due to a data error. MMWD informed RMC that the difference between the data and the modeled evaporation in the last several years of the validation period is most likely the result of data collection errors.

Figure 9-11: Alpine Evaporation

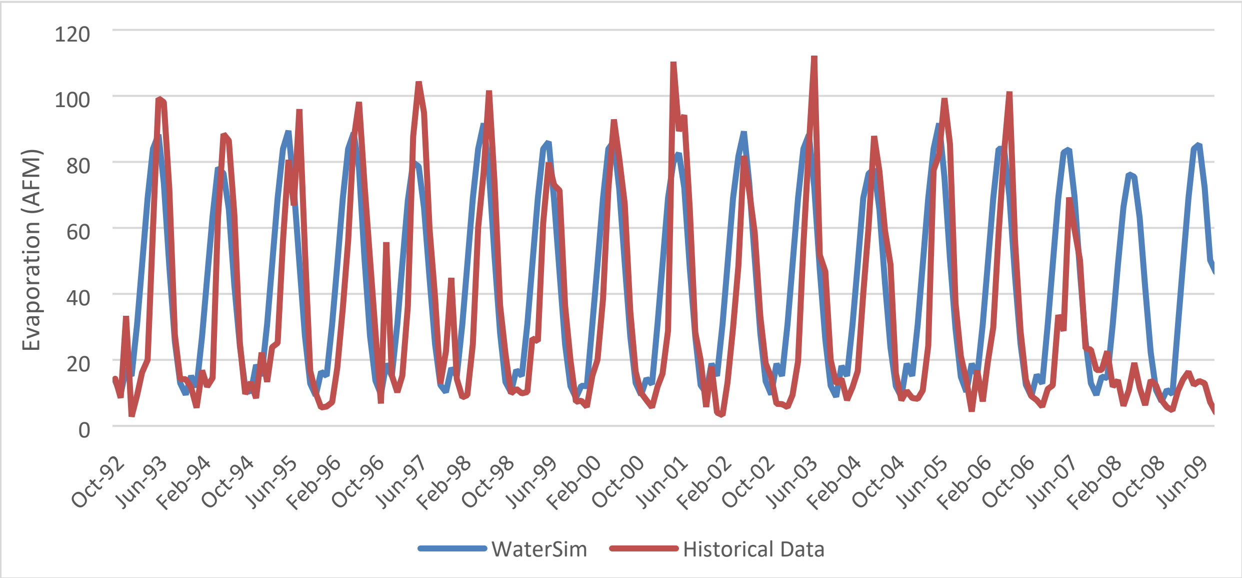


Figure 9-12: Bon Tempe Evaporation

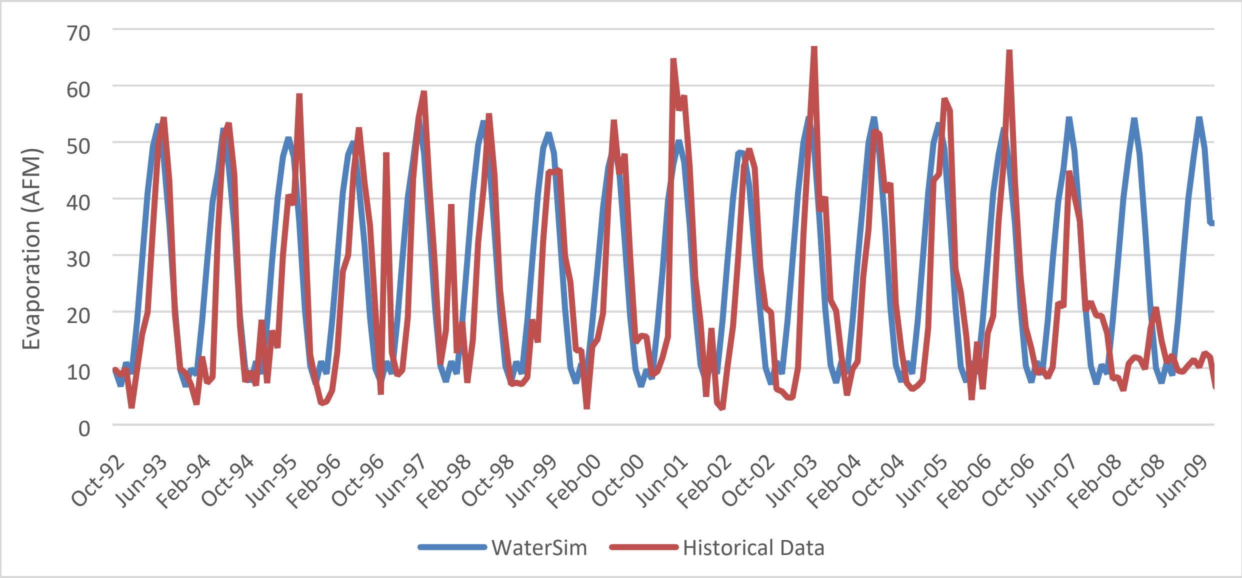


Figure 9-13: Kent Evaporation

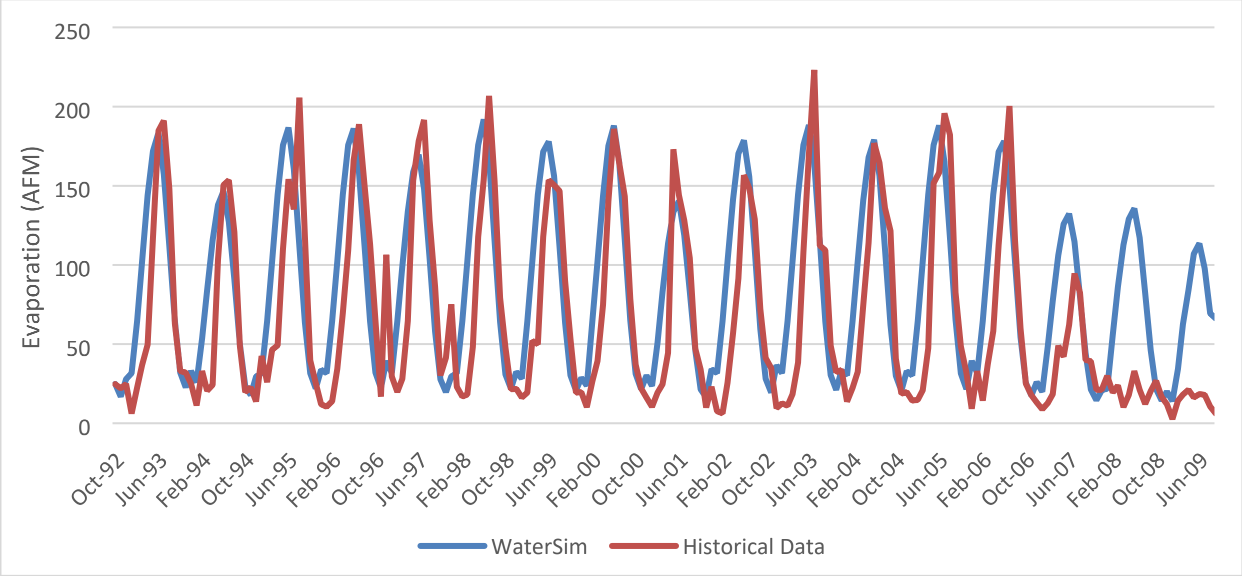


Figure 9-14: Lagunitas Evaporation

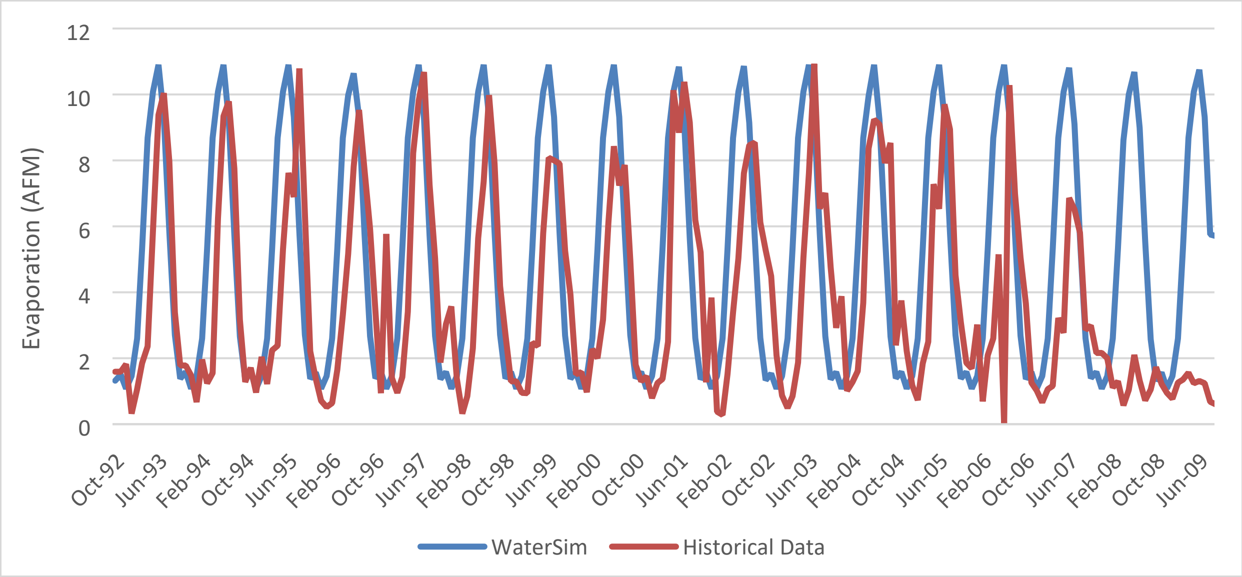


Figure 9-15: Soulajule Evaporation

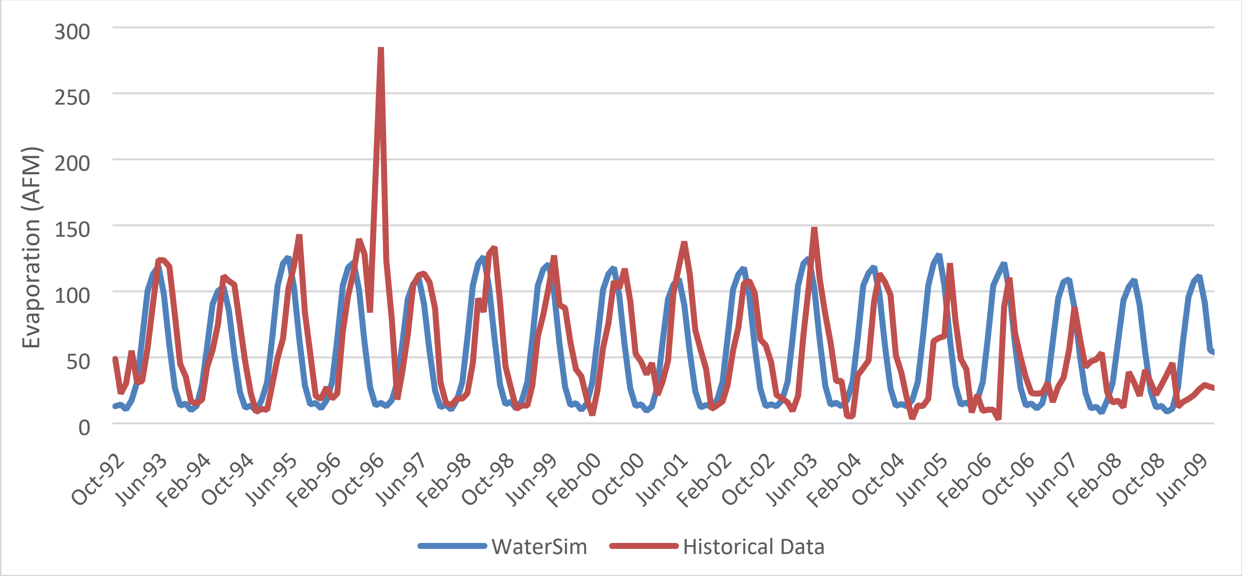


Figure 9-16: Nicasio Evaporation

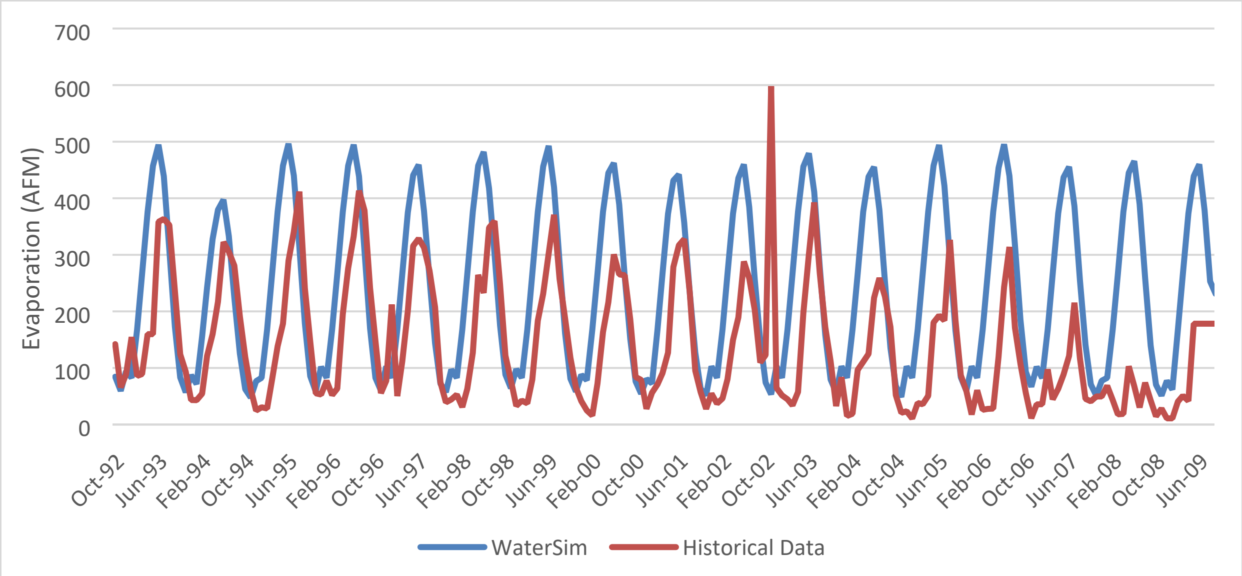
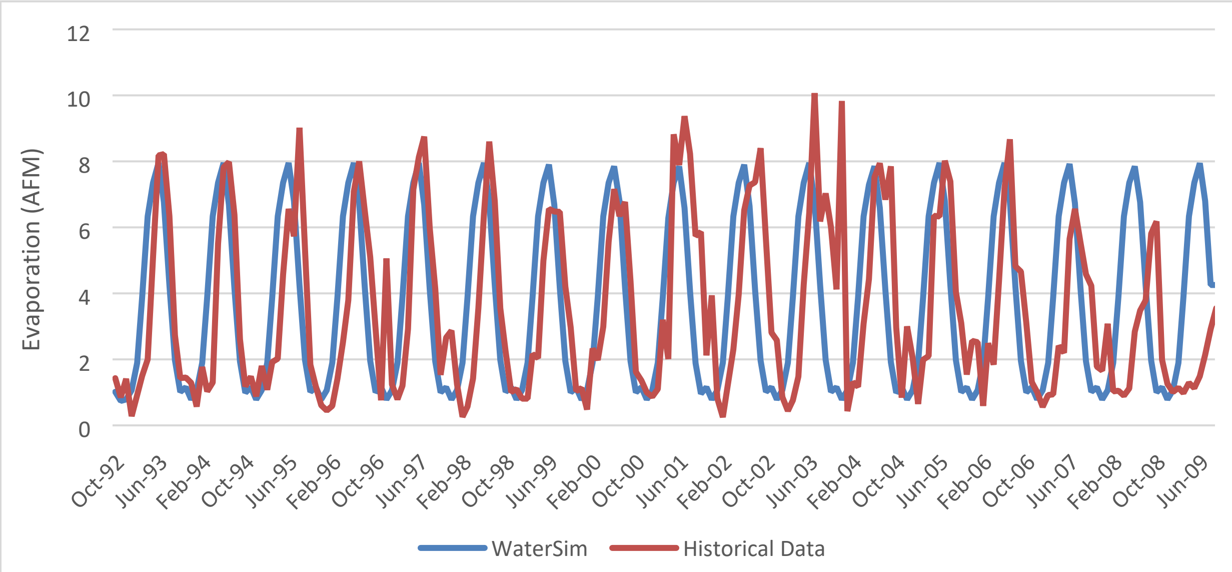


Figure 9-17: Phoenix Evaporation



10 Model Output File

The GoldSim software includes customizable charting and display functions that are used in Marin WaterSim for viewing results. In addition, Marin WaterSim also exports result into separate output files, for post-processing and analysis in MS-Excel spreadsheets.

GoldSim can export output files in spreadsheet files or as a text file. Following the completion of a run, Marin WaterSim exports the output files automatically to MS-Excel files. For multi-realization Monte Carlo simulations, Marin WaterSim also has the option of exporting text files using the .csv (comma separated value) format. Text file outputs are exported manual within the applicable Time Series Elements.

If the output file currently exists, dialogue box will open asking the user to confirm before overwriting the contents of the existing file. If the referenced file does not exist, GoldSim will automatically create one. The Output files are located in a relative path, meaning the export folder will be located in the same location as the GoldSim model file. The export files can be found at the following relative path:

.\Runs\Outputs_Do Not Modify\

11 References

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Appendix D

Marin WaterSim Model Operational Yield Analysis Technical Memorandum

Technical Memorandum

MMWD Water Resources Plan 2040

Subject:	**Marin WaterSim Model Operational Yield Analysis**
Prepared For:	Carl Gowan, MMWD
Prepared by:	Rachel Gross, RMC Simon Kobayashi, RMC
Reviewed by:	Enrique Lopezcalva, RMC Alyson Watson, RMC
Date:	September 23, 2016
Reference:	0041-010

The operational yield analysis was performed to estimate the level of demand that existing potable water supplies can securely provide, based on the hydrologic record. Operational yield is dependent on the assumptions used for local supply, Sonoma County Water Agency (SCWA) imports, and the amount of emergency storage in the district's local reservoir. This technical memorandum describes the assumptions and analysis used to determine the district's operational yield and provides a working definition used for the Water Resources Plan 2040.

1 Background and Objective

The operational yield represents maximum annual demand that can be met by the Marin Municipal Water District's (MMWD's) water supply system during the hydrologic record. The hydrologic record used in this analysis is the 115-year synthetic hydrology, as described in the Synthetic Hydrograph Technical Memorandum of the Water Resources Plan 2040 (WRP 2040). The operational yield was determined using the Marin WaterSim model developed to simulate MMWD's water supply system, as described in the Marin WaterSim Model Technical Memorandum of the WRP 2040. This analysis was limited to MMWD's local watershed supplies, meaning it excludes the water imported from the Sonoma County Water Agency (SCWA) and locally produced recycled water. An additional constraint of maintaining a minimum level of 25 % emergency storage was also imposed. For this operational yield analysis, an annual maximum deficit up to 290 acre-feet (AF) (1% of projected upper-range future demands of 29,000 acre-feet per year (AFY)), was allowed.

Eight additional scenarios were considered to determine the impact of imported water from the Sonoma County Water Agency (SCWA) and of the level of emergency storage on MMWD's ability to meet customer demand. For these scenarios Emergency Storage Level (ESL) was set to 0%, 25% and 50%; and imported water from SCWA was set to 0 AFY, 5,300 AFY (coinciding with the take-or-pay contract), and 10,000 AFY (the approximate existing physical limitation on delivery).

2 Operational Assumptions

The operational yield Marin WaterSim model runs did not consider the contribution of the Las Gallinas Treatment Plant (LGTP), as recycled water cannot be used as potable supply. The operations of the operational yield Marin WaterSim model simulations were similar to those in the Marin WaterSim validation model simulations (as described in the Marin WaterSim Model Technical Memorandum of the WRP 2040 (Appendix C)), where the model simulates the historical operational patterns used by

MMWD. However, given the lack of imported water, demand was assumed to be met only through production from MMWD's two treatment facilities, Bon Tempe Treatment Plant (BTTP) and San Geronimo Treatment Plant (SGTP). BTTP primarily draws from two of MMWD's lakes, Alpine Lake and Bon Tempe Lake, while SGTP draws mostly from Kent Lake, Nicasio Lake, and Soulajule Lake. As with all other simulations generated in WRP 2040, demands are split between the two plants based on the historical production division between the two plants. Any remaining unsatisfied demand after this division is attempted to be met by SGTP.

Under normal hydrologic conditions, available SGTP supply is determined based on the historical monthly split between Nicasio Lake and Kent Lake. When the stored supply in Kent Lake falls below a threshold of 15,000 AF, the fraction of water drawn from each lake is driven by remaining usable storage, such that the lake with more storage is drawn down first. Kent Lake is considered to be the limiting supply source since Nicasio Lake storage can be augmented by transfers from Soulajule Lake when its storage gets low. These assumptions were developed by RMC in coordination with MMWD staff, as the operational yield Marin WaterSim model tests MMWD's current supply system more strenuously than has been observed in the past. No historical operational protocols currently exist for pushing the system to its limit.

MMWD is considering several Resiliency Options that would increase the operational yield. The modeling of these options, including their effect on operational yield, is described in the Marin WaterSim Model Technical Memorandum.

3 Results

The results of this analysis show that MMWD's local supply system has an operational yield of 29,020 AFY if 25% of usable storage is reserved for emergency supply and imported water is excluded from the analysis. These results do not suggest that imported water should not be used but rather suggest the maximum demand able to be met by the existing reservoir system under historical hydrologic conditions. Table 1 shows the results of each of the nine variations on the operational yield analysis. As expected, increasing the amount of imported water and decreasing the Emergency Storage Limit (ESL) will increase the system's operational yield. Conversely, decreasing imported water and increasing the ESL will decrease the system's operational yield. Maintaining an ESL of 50% is not recommended for MMWD, as this high level of emergency storage would make it difficult for the District to meet demands, even at the base case projected level of 24,171 AFY. Conversely, maintaining no ESL could leave MMWD vulnerable to supply shortages in the event of catastrophic supply interruptions due to chronic drought conditions, or events such as earthquakes generating extended outages.

Table 1: Operational Yield Analysis Results

		SCWA Supply Limit (AFY)		
		0	5,300	10,000
Emergency Storage Limit (ESL)	50%	**20,445**	**25,110**	**27,810**
	25%	**29,020**	**34,280**	**37,075**
	0%	**31,830**	**37,870**	**41,925**

Based on this analysis, it is recommended that MMWD adopt the following working definition of operational yield:

The maximum annual demand that can be met by MMWD's local water supply throughout the hydrologic period of record while maintaining a 25% storage reserve in MMWD's reservoir system.

Based on this definition and historical hydrology, MMWD's operational yield is 29,020 AFY.

Appendix E

Resiliency Scenarios/Futures Technical Memorandum

Technical Memorandum

MMWD Water Resources Plan 2040

Subject:	**Reliability Threats**
Prepared For:	Carl Gowan, MMWD
Prepared by:	Rachel Gross, RMC
	Enrique Lopezcalva, RMC
Reviewed by:	Alyson Watson, RMC
Date:	September 23, 2016
Reference:	0041-010

1 Background and Objective

Critical to the Water Resources Plan 2040 is analysis of the impact that different hydrologic and system interruption events could have in the Marin Municipal Water District's (MMWD) reliability to provide potable water to its customers. To define potential projects and actions to increase the resiliency of MMWD's system, the vulnerability of different type of events needs to be characterized, with reliability at the center of the analysis. In order to conduct this vulnerability assessment, multiple events were defined as likely to occur in MMWD's service area and the MMWD system was simulated under those events.

Nomenclature

The nomenclature used for the analysis and planning of the Water Resources Plan 2040 is outlined in **Table 1-1**.

Table 1-1: Nomenclature Used for WRP 2040

Term	Meaning	Example
Events	Events or conditions that may happen impacting supply and demand balance	Intensity and length of drought, earthquakes, climate change, etc.
Reliability Threats	A probable future or condition that includes at least one event	Year 2040 under a 6 year and 9 year drought, climate change, existing system with a 30 day interruption of San Geronimo Treatment Plant, etc.
Options	Individual projects, programs, arrangements to increase supply, increase reliability, or manage demand	Indirect Potable Reuse, Direct Potable Reuse, increased storage, increase capacity of conveyance, increased water purchases, conservation measures, etc.
Alternatives	Combination of options	Combine increased conveyance with increased conservation, combine increased reuse with increased storage, etc.

Term	Meaning	Example
Scenarios	Combination of a given alternative, with an uncertainty state, to evaluate that alternative under the conditions associated with the uncertainty state (also applicable to base case). This is consistent with the GoldSim use of the Scenario.	Reuse and storage alternative with increased length of droughts; increased conveyance and conservation with climate change, etc.

The reliability threats described in this TM were developed to test how MMWD's water supply system would react under various potential hydrologic and system interruption events. Once potential reliability threats were defined, they were incorporated into the GoldSim model of MMWD's system using projected demand in 2040 to evaluate how the system would react to each particular reliability threat. The reliability threat were tested to see if they would produce supply deficits with a projected 2040 demand of 24,171 AFY and with 25% emergency storage in MMWD's reservoirs.

2 Reliability Threats

2.1 Drought

2.1.1 Single Critical Dry Year

Description

This event reflects the conditions during the most critically dry calendar year on record, 2013. Rainfall in 2013 was 24% of the average rainfall.

MMWD Response and Mitigation Actions

The model shows no shortages when MMWD experiences a single critical dry year with projected 2040 demand levels. MMWD would have enough storage available to meet demand, even with one year of critically low inflow. The agency could continue to operate as usual, with the regular division between supplying customers from San Geronimo Treatment Plant (SGTP), Bon Tempe Treatment Plant (BTTP), and imported water from Sonoma County Water Agency (SCWA).

2.1.2 Extended Drought

Description

This event reflects the conditions during the most extreme five-year drought on record. The driest five calendar years on record in Marin County occurred between 1928 through 1932, in which the region received approximately 62% percent of its average rainfall.

MMWD Response and Mitigation Actions

The model shows no shortages if MMWD were to experience extended drought reflective of historical conditions with projected 2040 demand levels. MMWD would have enough supply available to meet demand, even with five years of low inflow similar to the historical period 1987 to 1991. The agency could continue to operate as usual, with the regular division between supplying customers from SGTP, BTTP, and imported water from SCWA.

2.2 Climate Change

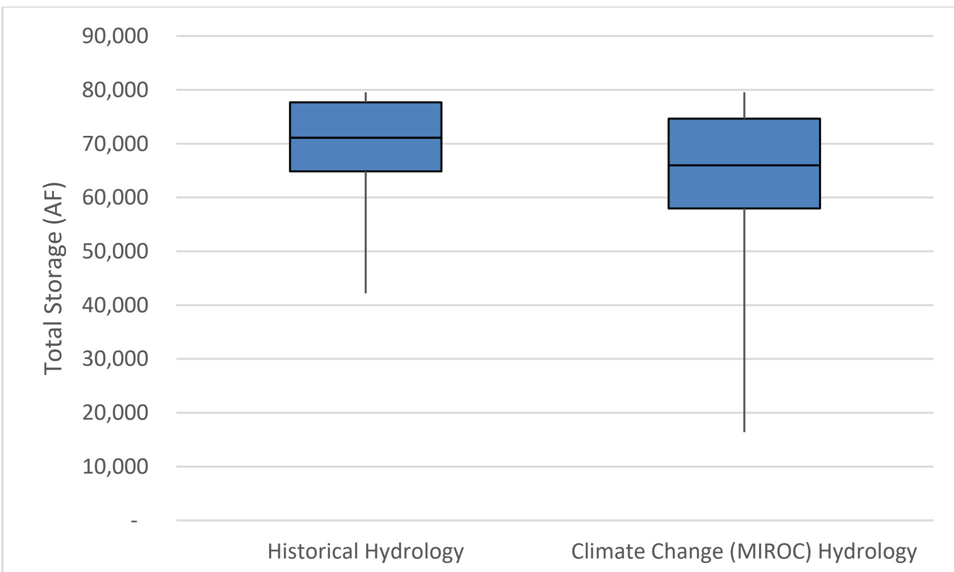
Description

The Climate Change reliability threat simulates future water supply and demand conditions based on perturbed hydrology and demands under climate change conditions. USGS provided modeled data for precipitation and inflow for 2010 through 2099 for each of MMWD's lakes under four climate change models: CCSM4_rcp85, CNRM_rcp85, GFDL_A2, and MIROC_ESM_rcp85. The 89 years of climate change hydrology was modeled under anticipated 2040 demand to capture a broad range of potential effects of climate change.

Impact on MMWD Operations

There are no predicted shortages with projected demand through 2040 under climate change conditions. MWMD could continue to operate with the regular division between SGTP, BTTP, and SCWA, making use of storage in Soulajule in some instances and accessing generally lower levels in the main lakes. Overall storage levels are expected to decrease under climate change conditions. **Figure 2-1** shows that total storage in MMWD's current system may reach as low a level as 16,000 AF in the most extreme case, compared to a low level of 40,000 AF under historical hydrology. **Figure 2-1** also shows that median storage is likely to decrease under climate change hydrology.

Figure 2-1: Total Storage Under Historical Hydrology and Climate Change Hydrology



2.3 Fires

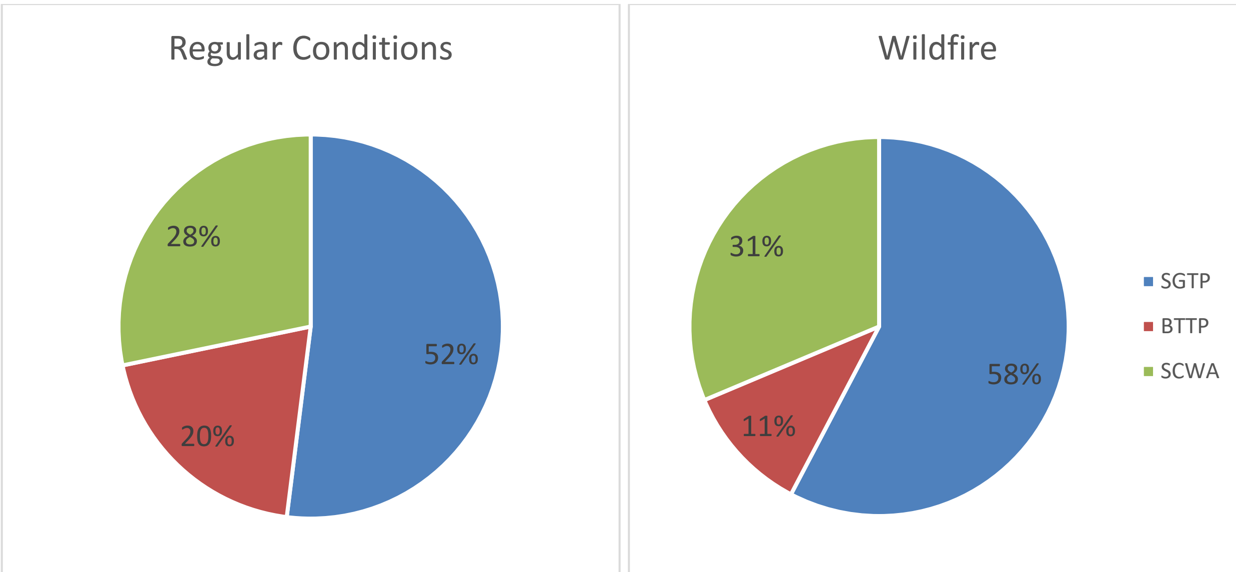
Description

Wildfires are an anticipated threat to the wooded areas in the Lagunitas Creek watershed. A severe wildfire in the area could affect the water quality in Kent, Alpine, Bon Tempe, Lagunitas, and Phoenix Lakes. Wildfire can degrade the water quality of reservoirs by drastically increasing erosion in the watershed and increase the turbidity of the water. This decline in water quality could impact the efficiency of MMWD's treatment plants. Thus, this reliability threat was modeled by reducing BTTP's throughput to half of its historical average and switching the supply source of SGTP from Kent to Nicasio, which would likely not be affected by wildfire. The period of impact for this reliability threat is three months.

Impact on MMWD Operations

There are no predicted shortages under reduced treatment plant capacity caused by wildfires. However, SCWA imports up to the current capacity of 10,000 AFY and water drawn from Nicasio would both increase to make up for demand not supplied by Kent or through BTTP. **Figure 2-2** shows the increase in SCWA supplies and production from SGTP (drawn from Nicasio) that would be required to make up for the decrease in production from BTTP.

Figure 2-2: Wildfire's Impact on MMWD Operations



2.4 Earthquakes

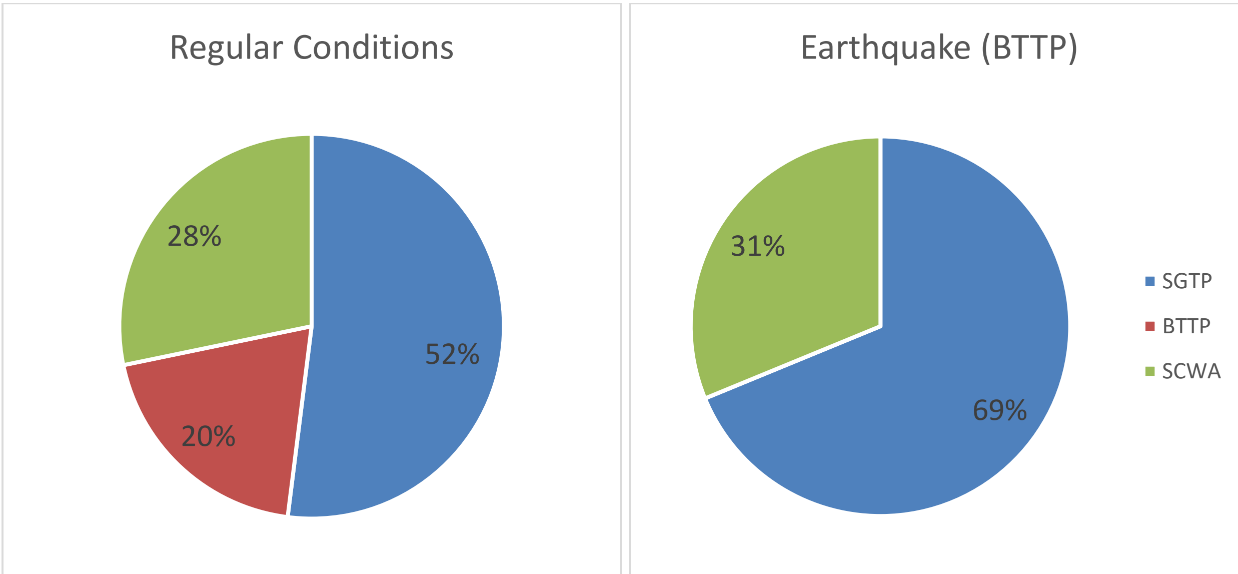
Description

Two faults, the San Andreas and the Hayward/Rogers Creek, run through Marin County. The Association of Bay Area Governments Resilience Program states that there is a “52% chance of a major (6.7 or greater magnitude) earthquake occurring in one of these faults between now and 2036” (USGS, 2013). An earthquake in Marin County could temporarily affect the ability of MMWD to serve its customers by impacting facilities at BTTP, SGTP, or the Ignacio pump station, through which SCWA deliveries reach MMWD customers. The period of impact for this reliability threat is one to three months.

Impact on MMWD Operations – Bon Tempe TP

There are no predicted shortages if BTTP were to be disabled for a month due to damage from an earthquake. As shown in **Figure 2-3**, production from SGTP could be increased to make up for the missing production from BTTP. Deliveries from SCWA would also need to slightly increase.

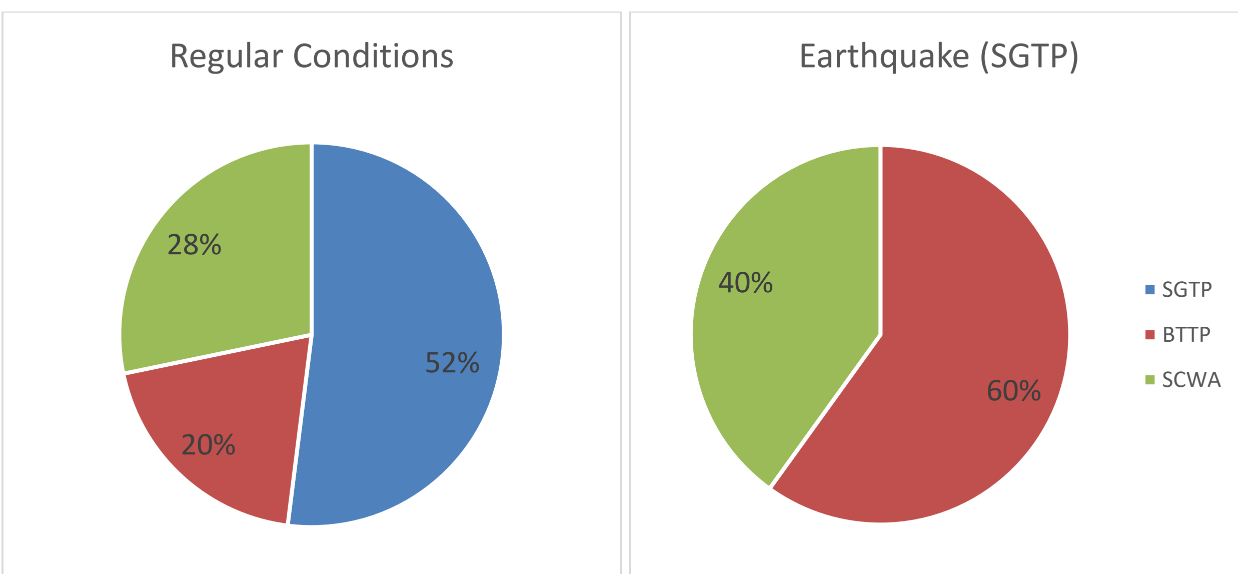
Figure 2-3: Earthquake at BTTP's Impact on MMWD Operations



Impact on MMWD Operations – San Geronimo TP

There are no predicted shortages if SGTP were to be out of service for a period of one to three months due to damage from an earthquake. MMWD could compensate for the missing production from SGTP by greatly increasing imports from SCWA up to capacity and increasing production from BTTP to up to 1,870 AF/mon. as shown in **Figure 2-4** shows how MMWD's supply sources would change during months when SGTP is out of service.

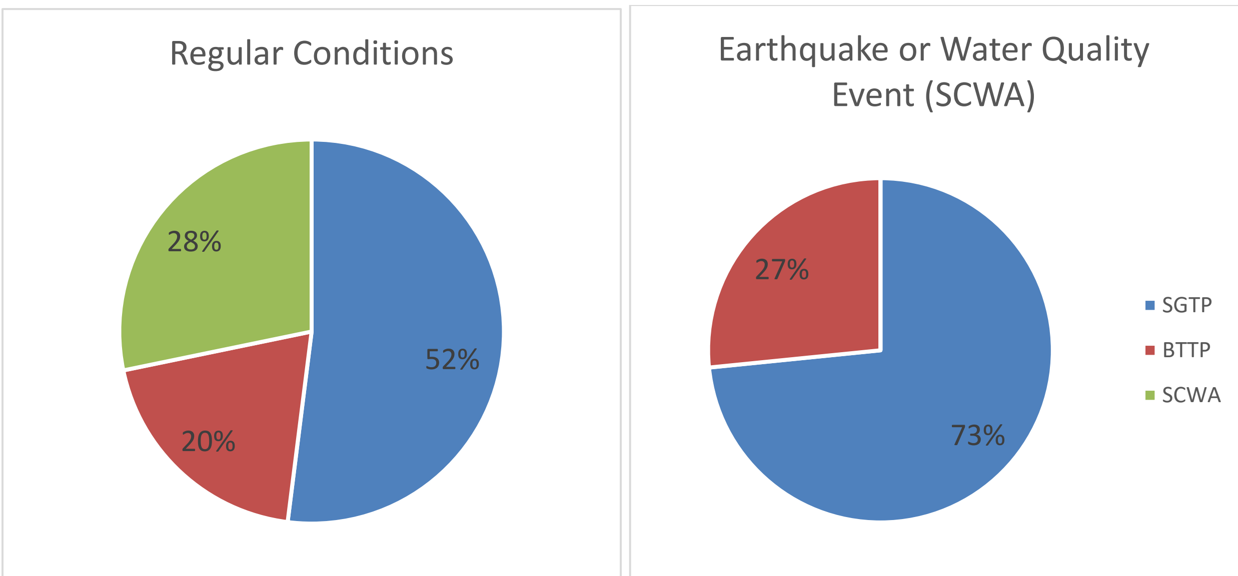
Figure 2-4: Earthquake at SGTP's Impact on MMWD Operations



Impact on MMWD Operations – Ignacio PS and / or Conveyance Infrastructure

There are no predicted shortages if the Ignacio Pump Station and/or conveyance infrastructure from SCWA were out of service for a month due to damage from an earthquake. As shown in **Figure 2-5**, production from SGTP could entirely make up for the missing SCWA water until the infrastructure could be repaired.

Figure 2-5: Earthquake at SCWA Facilities' Impact on MMWD Operations



2.5 Water Quality-Related Events

Description

Local and critical water supplies have been affected by water quality issues in the past and have been unusable by MMWD for several months. Water from SCWA has had low alkalinity issues, and Nicasio Lake cannot be used periodically due to high levels of turbidity in the water, unless mixed with source water from Kent Lake. Kent and Alpine Lakes have been impacted by MID, a compound with an earthy odor and taste that occurs when algae and bacteria build up in dammed reservoirs. The period of impact for a generic SCWA water quality issues is one year and the period of impact for a generic event affecting Nicasio, Kent, and Alpine water quality issues is six months.

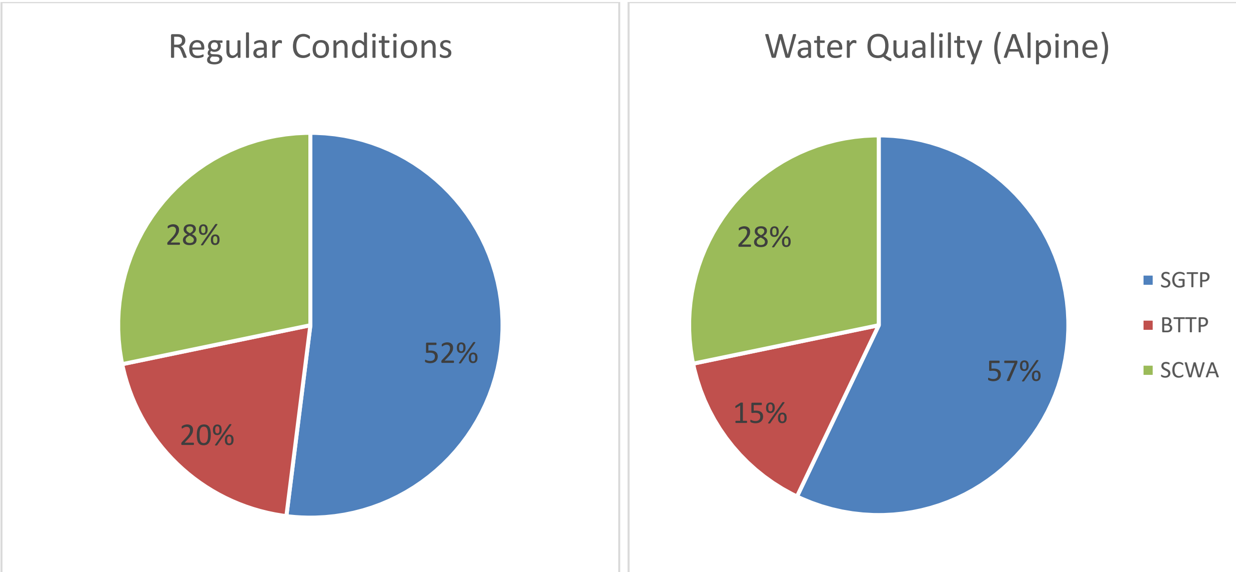
Impact on MMWD Operations – Imported Supplies

If SCWA supplies were to be impacted by a water quality-related event, MMWD operations would be impacted to the same extent if the Ignacio Pump Station or SCWA conveyance infrastructure were to be disabled by an earthquake. Under these conditions, MMWD would not have deficits and the supply sources would be divided as seen in **Figure 2-5**.

Impact on MMWD Operations – Nicasio, Kent, and Alpine

There are no predicted shortages if MMWD were unable to use Nicasio, Kent or Alpine for a period of 6 months. If Kent or Nicasio were to be impacted by a water quality event, enough water from the remaining lake could be drawn to maintain regular levels of production in SGTP, with additional back up storage from Soulajule when Nicasio is not impacted. If Alpine were to be impacted by a water quality event, production from BTTP would decrease and more water would have to be produced from SGTP to make up for the missing Alpine water, as shown in **Figure 2-6**.

Figure 2-6: Water Quality Event at Alpine's Impact on MMWD's Operations



2.6 Landslides

Description

Marin County, like much of the Bay Area and California, is vulnerable to landslides. Landslides can be triggered by large amounts of rainfall or earthquakes and are also more likely to occur in steep-sloped areas. Thus, the Lagunitas watershed is susceptible to landslides as the area is mountainous, at risk of earthquakes, and receives large amounts of rainfall in relatively intense storms. Kent, Alpine, Bon Tempe, Lagunitas, and Phoenix lakes could all be impacted if a landslide were to occur into the lake, significantly increasing the turbidity in the lake to the point where water could not be treated. Landslides could also impact the pumping and conveyance infrastructure needed to utilize these lakes. The period of impact analyzed for this reliability threat is six months.

Impact on MMWD Operations

No shortages are predicted if landslides were to impact Kent, Alpine, Bon Tempe, Lagunitas, or Phoenix lakes. A landslide into Kent would produce a similar impact as a water quality impact to Kent, and would not change the operation of MMWD's treatment plants and imported water sources. A landslide into Alpine would produce a similar impact as a water quality event in Alpine, so MMWD's change in operations would be similar to that shown in Figure 6. A landslide into Bon Tempe would essentially prohibit the use of BTTP, as water must be pumped from Alpine through Bon Tempe to reach the treatment plant. This would affect MMWD's operations in the same way that an earthquake impacting BTTP would, as shown in Figure 3. A landslide impacting Lagunitas or Phoenix lakes would not affect MMWD's operations, as these two small lakes are rarely used for water supply.

2.7 PG&E Outage

Description

If a power outage were to occur at SGTP, the ability to produce and deliver water from this plant could be impacted for up to one month. The outage could occur through damage to PG&E facilities from events described in this TM like an earthquake or a landslide, or through some other problem in the power system.

Impact on MMWD Operations

The impact of a power outage at SGTP would affect MMWD's operations in a similar manner as an earthquake impacting SGTP. There may be supply shortages, but the probability of such a shortage is low and the shortage magnitude would be minor. A shortage is more likely to occur in a dry year when the reservoir levels are low and in the summer months when demand is high. If SGTP could not produce water, most of the missing supply could be balanced with an increase in supply from BTTP and imported water from SCWA as shown in **Figure 2-4**.

2.8 Severe Drought

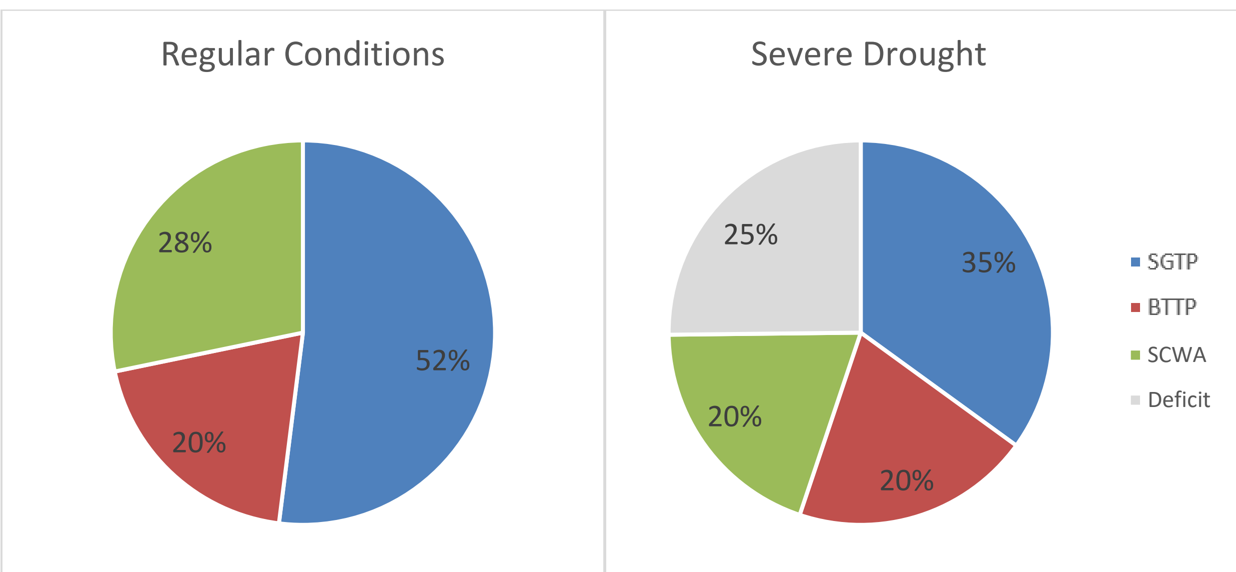
Description

As described in the Hydrology TM included in the Water Resources Plan 2040 as Appendix C, the "Severe Drought" is a synthetically created hydrology based on repeating water year (WY) 1924 hydrology for a period of up to nine years. While this drought is more severe in magnitude and duration than any droughts seen in recorded history or predicted with climate change, droughts of this length and similar magnitude have been observed in the past prior to the measured period as indicated by paleo-hydrology in other areas in California, as described in the Hydrology TM. Imported water from SCWA is assumed to be capped at 5,300 AFY, as SCWA would be unlikely to supply more water than this amount in a drought of this magnitude, which would likely impact the Russian River along with the Marin County area. Simulating this drought shows how MMWD's system would react in a prolonged period with very little inflow into its local reservoir system.

Impact on MMWD Operations

Assuming that MMWD could only receive 5,300 AFY of water from SCWA during this Severe Drought and would maintain 25% emergency storage, extreme deficits would start in the fifth year of the nine-year drought and could be as high of a deficit as 7,600 AFY. This deficit represents almost one-third of total anticipated annual demand in 2040. Over the course of the drought, approximately 25% of demand would go unmet, while production at BTTP and SGTP would decrease due to low inflows, as shown in **Figure 2-7**.

Figure 2-7: Supply Sources and Deficits under Severe Drought Conditions



Since the magnitude of deficits are so severe under these conditions, several scenarios were modeled to test the system's sensitivity to varying amounts of SCWA imports, emergency storage levels, and demand level. **Table 2-1** shows the results of this scenario testing, including the year of the drought in which the first deficit occurs, the magnitude of that first deficit, the worst deficit if the drought last nine years, and the worst deficit if the drought lasts six years. While the oldest hydrologic records in Marin County date back to 1879, paleo-hydrology records derived from tree ring analysis of the Sacramento and San Joaquin watersheds date back to 900 (Meko, 2014). These records, as well as the Palmer Drought Index, have been used to determine the probability of droughts lasting six and nine years (Cook, 2004). The probability of a six-year drought is approximately 3% to 4% (3 to 4 occurrences in a 100-year period) while a nine year drought probability is less than 1%. More information about the use of paleo-hydrology records can be found in the Hydrology TM. **Table 2-1** below shows the assumptions for each Severe Drought scenario.

Table 2-1: Severe Drought Scenarios

Scenario	Demand	SCWA Imports	Emergency Storage	Year of First Deficit	First Deficit (AFY)	Worst Deficit (9 YR)	Worst Deficit (6 YR)
0	24,171	5,300	50%	3	3,772	11,060	10,935
1	24,171	5,300	25%	5	1,701	6,883	6,850
2	24,171	0	25%	4	8,897	11,787	11,787
3	24,171	0	10%	5	6,213	10,169	10,193
4	20,545	0	10%	6	2,382	6,250	6,298

These scenarios show that decreasing the emergency storage from 25% to 10% could eliminate one year of deficits. The results also show that if SCWA imports were unavailable (which may occur in a drought of this magnitude), deficits could start in the fourth year of drought and reach as high as 11,800 AFY. Additionally, decreasing demands by 15% significantly reduces the magnitude of shortages, indicating that conservation measures could be effective in these conditions.

3 Conclusion

The only reliability threats that the model indicates to cause supply shortages are an outage of SGTP caused by either an earthquake or a PG&E power outage, or an "Severe Drought" worse than any dry period in recorded history but present in the paleo-hydrology records. Although other reliability threats may alter MMWD's operations, generally enough water can be pulled from a source other than the one impacted to make up for the missing supply. Since the "Severe Drought" was the only condition seen to produce significant deficits, resiliency options and alternatives will be tested against this drought to determine their effectiveness

4 References

USGS via Association of Bay Area Governments Resilience Program. 2013. *Marin County Earthquake Hazard*. http://resilience.abag.ca.gov/earthquakes/marin/

David M. Meko, Connie A. Woodhouse, and Ramzi Touchan, 2014. *Sacramento and San Joaquin Four River Index unimpaired runoff (900-2012).*

Cook, E.R., Woodhouse, C.A., Eakin, C.M., Meko, D.M., and Stahle, D.W, 2004. *North American Drought Atlas PDSI Reconstructions, Gridpoint 36 (0-2003).*

Appendix F

Resiliency Options Technical Memorandum

Technical Memorandum

MMWD Water Resources Plan 2040

Subject:	**Resiliency Options**
Prepared For:	Carl Gowan, MMWD
	Katie Cole, RMC Ryan Doyle, RMC Rachel Gross, RMC
Prepared by:	Simon Kobayashi, RMC
	Enrique Lopezcalva, RMC
Reviewed by:	Alyson Watson, RMC
Date:	September 23, 2016
Reference:	0041-010

1 Background and Objective

A wide variety of resiliency options were developed to explore how MMWD could increase its resiliency and meet demands in times of potential supply shortages caused by variable hydrology or system disruption. A total of 40 resiliency options were developed and grouped into eight categories based on the type of option. The supply categories include Water Use Efficiency (WE), Reuse (RU), Expanded SCWA Conveyance (SC), Expanded Storage (ES), Water Purchases (WP), Desalination (DS), and Emerging Options (EO). The list of resiliency options was presented to the MMWD Drought Resiliency Task Force on August 19, 2016 and subsequently modified and supplemented with feedback from the Task Force.

Each option was developed at a conceptual level including a description of the option, required facilities, cost, yield, reliability, implementation considerations, and conceptual maps or schematics. This information is presented in a fact sheet for each option and should be used for high level planning only. The technical information should not be considered as a feasibility study or schematic design. Cost estimates should be treated as Class 5 (-20% +100% in the Association for the Advancement of Cost Engineering, AACE classification). The fact sheets for each option are included in this technical memorandum.

2 Resiliency Options Methodology

Some of the resiliency options were conceptualized by RMC, but many have been built on options transmitted from MMWD's and other agencies' previous supply studies. As such, a large body of knowledge already exists about many of the resiliency option ideas. RMC extracted information from these sources to populate the fact sheets, and updated costs and yields to reflect current or expected conditions. Data sources for each option are referenced in the cost backup sheet for that option. For options that were not based on previous studies, information was developed in collaboration with MMWD. Two workshops were held on July 5th and on July 27th in which Michael Ban, Carl Gowan, and Lucy Croy from MMWD reviewed the resiliency options and provided input for suggested revisions.

After the resiliency options were developed, they were scored based on criteria described in the MMWD Decision Process and Criteria to Rank Resiliency Options Technical Memorandum, provided as Appendix G to the Water Resources Plan 2040. The average year and dry year yield, reliability, and annual cost per acre-foot derived from the resiliency options fact sheets were some of the most important factors considered in the option scoring. The results for this evaluation are described in the Resiliency Option Evaluation Technical Memorandum, provided as Appendix H of the Water Resources Plan 2040.

3 Resiliency Options

The following pages include the fact sheets for each resiliency option.

Resiliency Option: Water Use Efficiency - Enhanced Conservation (WE01)

1. Description

MMWD has committed to implementing Conservation Program A. This resiliency option would increase the level of conservation by implementing additional conservation measures and increasing the penetration rate of those measures. Option 1 involves implementing the measures under Conservation Programs B and C. These measures include:

1) Public Info & School Education - SMWSP
2) Indoor and Outdoor Surveys (CII)
3) Replace CII Inefficient Equipment
4) Efficient Toilet Replacement Project - CII
5) Urinal Rebates - CII
6) Plumber Initiated UHET and HEU Retrofit Program
7) HE Faucet Aerator/Showerhead Giveaway - CII
8) Direct Install UHET, Showerheads, Faucet Aerators - SF/MF
9) Submeters Incentives
10) Turf Removal - MF, CII

CII = Commercial, Industrial, Institutional

Option 2 includes increasing the penetration rate of select measures up to 2% of accounts. Option 3 includes increasing the penetration rate of the remaining measures. While all three options for enhanced conservation are included below, it was assumed that Marin would enhance conservation up to the 1,000 AFY in savings in Option 3.

2. Facilities Required

There are no facilities required for this supply option. However, implementing additional conservation measures will require financial investments in staff time, public outreach, and conservation measure implementation. Further, increased conservation would result in reduced revenue.

3. Costs

Average Annual Costs*

	Option 1	Option 2	Option 3**
Admin Costs	$115,000	$490,000	$580,000
Other Costs (Rebates, fixtures, etc.)	$460,000	$1,900,000	$2,300,000
TOTAL UTILITY COSTS	$575,000	$2,390,000	$2,880,000
Yield (AFY)	265	670	1,000
Annual Cost per Acre-Foot	$270	$1,080	$990

*Costs reflect those over and above the investment required for implementing Program A and represent Marin's portion of the total costs.

** Total customer costs for Option 3 above Program A are $2.6M, which is equivalent to $860/AF.

4. Yield and Reliability

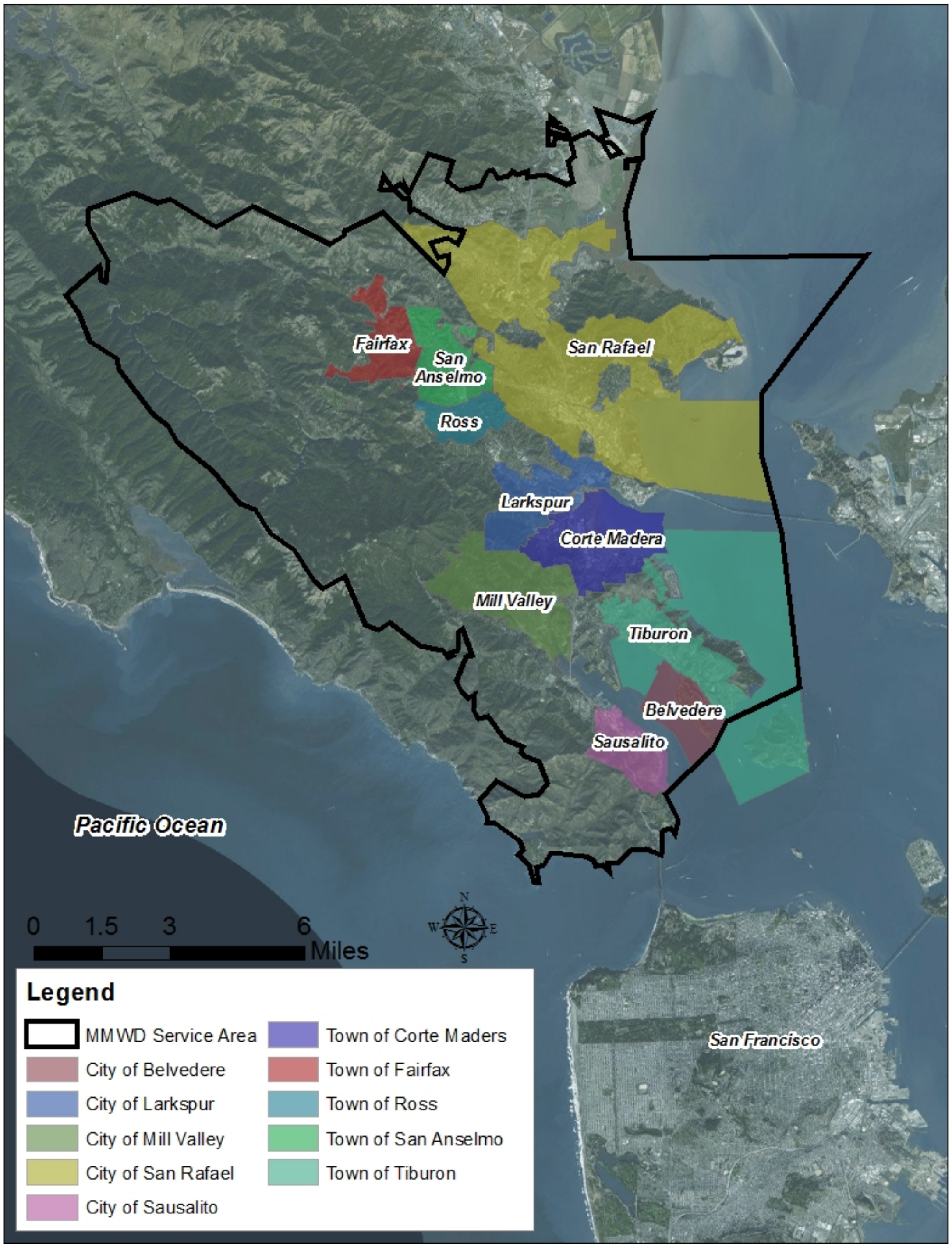
Source: Potable Water
Average Year Yield (AFY): 1,000
Dry Year Yield (AFY): 1,000
Seasonality: None

Potential Reliability Concerns: Reduction levels may fluctuate given level of customer involvement

5. Implementation Considerations

As MMWD customers become more efficient in their water use, demand hardens and it becomes more difficult to further reduce demand. In addition, conservation, while effective at reducing demand, is not effective at mitigating catastrophic events. It is estimated that this option could be implemented in 1 year.

6. Conceptual Map/Schematic



Resiliency Option: Water Use Efficiency - Residential Rainwater & Graywater Use (WE02)

1. Description

This option involves implementing onsite reuse for residential customers and includes rainwater and graywater capture and reuse. The SFPUC recently completed a potable offset investigation study to determine the potential residential potable offset associated with implementing various onsite reuse alternatives, including rainwater and graywater harvesting. This study found that the SFPUC could offset roughly 7,500 AFY (6.73 mgd) by 2040. Using this study and LADWPs Stormwater Capture Master Plan as a basis, it was determined that Marin could offset 60 AFY if 50% of single family homes implemented reuse techniques (25% rainwater and 25% gray water). After comparing rainwater and graywater rebates from San Diego Water Authority, the SFPUC, Santa Clara Valley Water Disitrict, and the City of Santa Rosathe average rainwater rebate is $50 and the average graywater rebate is $150. For costing purposes, these rebate averages were assumed; however, costs will vary depending on the level of rebate ultimately chosen by the district. It was also assumed that the captured rainwater and graywater would require no treatment and be applied to outdoor landscaping. Yield is consistent with conclusions in a 2016 report published by the National Academies Press titled *Using Greywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits;* this report found that rainwater provides little benefit on the arid west coast, but that graywater has the potential for greater potable demand reduction.

2. Facilities Required

Graywater: Piping and appurtenances, connections, and subsurface drip irrigation
Rainwater: 55 gallon outdoor storage tank

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Graywater system	ea	3,350			$ 2,000
Rainwater system	ea	3,350			$ 1,000

* Size/Number assumes 25% penetration rate of 2040 single family accounts for graywater and rainwater systems (50% combined penetration rate), consistent with LADWPs Stormwater Capture Master Plan. Facility costs are per unit and from the SFPUC Potable Reuse Investigation Study.

Probable Capital Cost	**$**	**10,050,000**
Marin's Share of Capital Cost (\$50 Rainwater & \$150 Graywater Rebate)*	**$**	**686,750**
Annualized Capital Cost (3% over 30 yrs)	$	35,000
Annual O&M	$	-
Total Annual Cost	**$**	**35,000**
Yield (AFY)		60
Annual Cost per Acre-Foot	**$**	**600**

* This cost represents Marin's portion of the capital cost. The share of the capital cost borne by the customer is $9.3M, which is equivalent to $8,000/AF.

4. Yield and Reliability

Source: Rainwater and Graywater

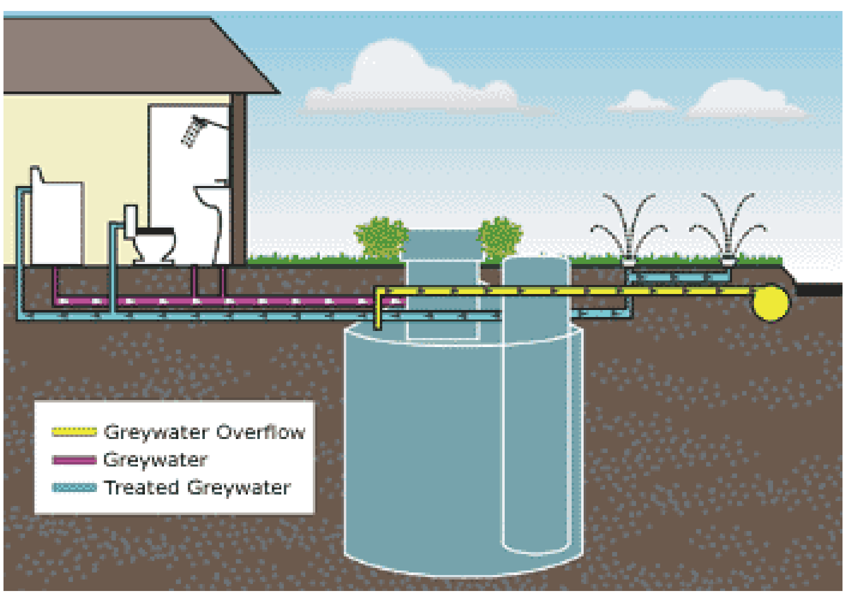
Average Year Yield (AFY): 60
Dry Year Yield (AFY): 50
Seasonality: Greater rainwater harvesting yield during wet weather
Potential Reliability Concerns: Rainwater harvesting requires precipitation and its limited storage capacity makes it susceptible to dry spells. Graywater provides a more reliable alternative as it is not dependent on precipitation.

5. Implementation Considerations

Implementing rain collection and graywater systems would increase system resiliency while also providing benefits to individual homeowners. Due to the cost of these systems, the District would likely need to implement some kind of rebate or other subsidy, where the customer pays a portion of the cost. Grant opportunities may also be available for implementation. It is estimated that this option could be implemented in 1 year.

6. Conceptual Map/Schematic

Source: gradybarrels.com



Source: grenum.com

MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Reuse - DPR SASM (RU01)

1. Description

This supply option involves constructing additional treatment facilities at the Sewerage Agency of Southern Marin's (SASM) wastewater treatment plant to further purify recycled water and deliver for direct consumption via the potable water distribution system to areas around the SASM facility. With dry-weather flows of 2.2 mgd, it is assumed the project could divert 2 mgd and produce 1.44 mgd of product water (72% recovery, 28% brine reject). It is assumed that brine can be discharged into the existing outfall. This option corresponds to DPR-1 Onsite from the 2014 SASM Recycled Water Feasibility Study. Advanced treated water supply would be conveyed to a storage tank (12 hours of storage) prior to being introduced to the water distribution system. It should be noted that this type of potable reuse is not currently permitted in California.

2. Facilities Required

Full Advanced Treatment (FAT) facility
Water Tanks
Conveyance Piping
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
FAT Facility	mgd	2.0	output mgd	1.44	$ 13,000,000
Water Tank	MG	0.7	tanks	3	$ 2,156,250
Conveyance pipeline	diameter - in	12	LF	4,800	$ 777,600
Pump	hp	210	gpm	1,000	$ 1,650,600

SASM treatment costs assumed to be the same for DPR, SWA, and IPR options

Raw Construction Cost	$	17,580,000
Mobilization, Contractor's Profit, & Construction Contingency	$	13,190,000
Base Construction Cost	*$*	*30,770,000*
Implementation and Environmental Mitigation	$	8,070,000
Probable Capital Cost	**$**	**38,800,000**
Annualized Capital Cost (3% over 30 yrs)	$	1,980,000
Annual O&M (treatment, power, pipeline maintenance)	$	1,710,000
Total Annual Cost	**$**	**3,690,000**
Yield (AFY)		1,600
Annual Cost per Acre-Foot	**$**	**2,300**

4. Yield and Reliability

Source: Treated wastewater
Average Year Yield (AFY): 1,610
Dry Year Yield (AFY): 1,610
Seasonality: None.
Potential Reliability Concerns: Minimal. Supply is drought-resistant, but seismic activity could affect the treatment plant.

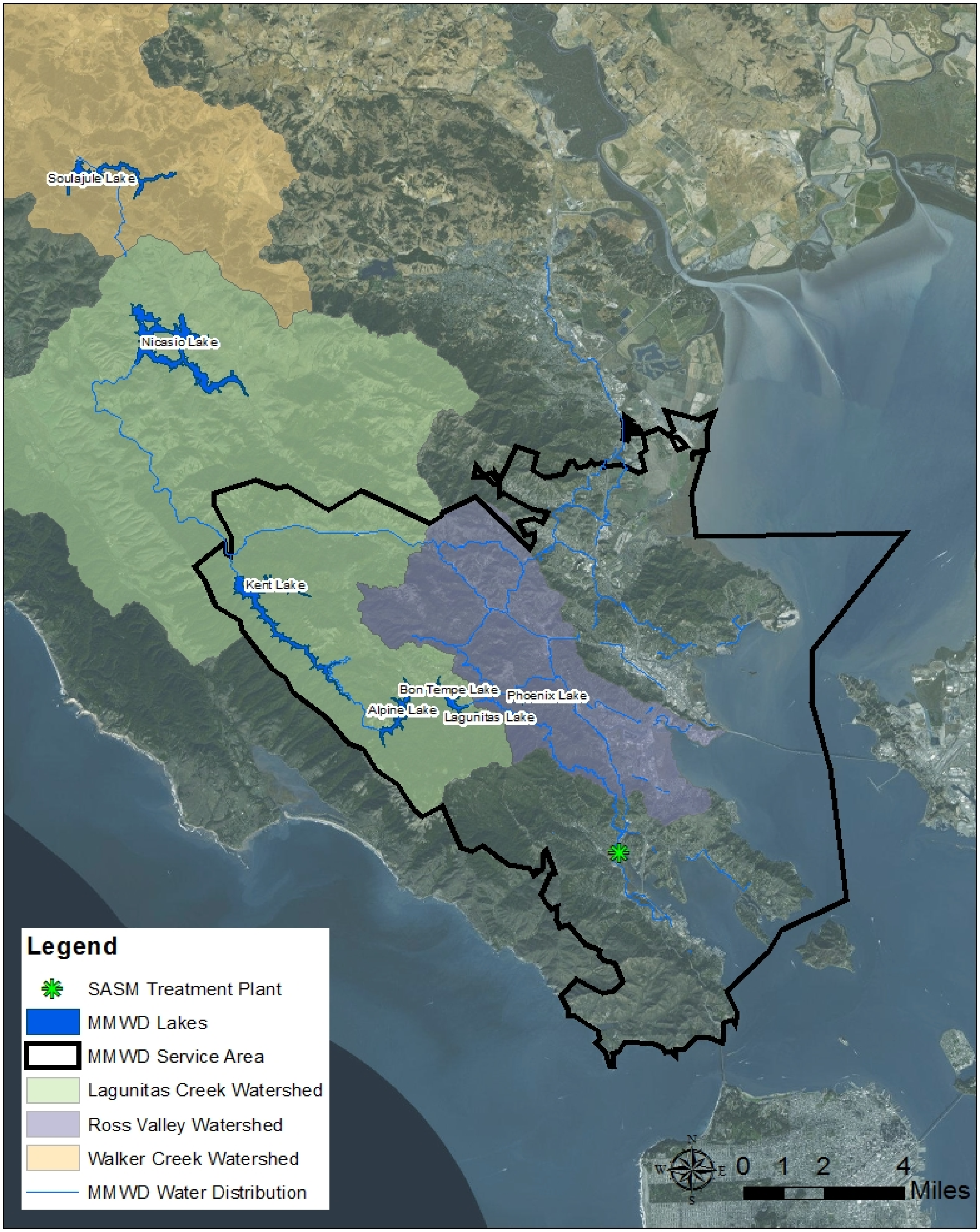
MARIN MUNICIPAL WATER DISTRICT

RMC water and environment

5. Implementation Considerations

Where and how DPR product water gets introduced into MMWD facilities will depend upon regulations and District demands, needs, and constraints. Currently, DPR facility permitting could theoretically be done on a case-by-case basis until regulations are set (feasibility study results expected by December 2016; regulations likely within 5 years); however, no DPR installations have been permitted in California. Because this is "pipe to pipe" DPR (e.g., not upstream of a water treatment plant), it is anticipated to be extremely challenging, if not infeasible, from both permitting and public acceptance perspectives. New training for operators of the plant will be required and significant permits may be needed. It is estimated that this option could be implemented in 8 years.

6. Conceptual Map/Schematic


Soulajule Lake
Nicasio Lake
Kent Lake
Bon Tempe Lake
Phoenix Lake
Alpine Lake
Lagunitas Lake
Legend
SASM Treatment Plant
MMWD Lakes
MMWD Service Area
Lagunitas Creek Watershed
Ross Valley Watershed
Walker Creek Watershed
MMWD Water Distribution
0 1 2 4
Miles

Resiliency Option: Reuse - DPR CMSA (RU02)

1. Description

This supply option involves constructing additional treatment facilities at the Central Marin Sanitation Agency (CMSA) wastewater treatment plant to further purify recycled water and deliver into MMWD's potable water distribution system for direct consumption in areas near the CMSA facility. The plant would take a maximum day demand (MDD) of 2.8 MGD with direct potable water output averaging 2 MGD (72% recovery, 28% brine reject). The facility could be expanded to intake 5 MGD, as dry weather flows average around 5.6 MGD. It is assumed that brine can be discharged into the existing outfall. This option corresponds to Alternative 4B from 2016 CMSA Recycled Water Master Plan. It should be noted that this type of potable reuse is not currently permitted in California.

2. Facilities Required

Full Advanced Treatment (FAT) Facility
Water Tanks
Conveyance Piping
Pump Station

3. Sizing and Cost

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
FAT Facility	mgd	2.8	output mgd	2.02	$ 18,108,800
Water Tank	MG	1	tanks	3	$ 3,000,000
Conveyance pipeline	diameter - in	18	LF	5,500	$ 1,375,000
Pump	hp	170	gpm	1,400	$ 1,336,200

CMSA treatment costs assumed to be the same for DPR, SWA, and IPR options

Raw Construction Cost	$ 23,820,000
Construction and Estimating Contingency	$ 9,528,000
Base Construction Cost	*$ 33,350,000*
Implementation and Environmental Mitigation	$ 10,435,000
Probable Capital Cost	**$ 43,800,000**
Annualized Capital Cost	$ 2,235,000
Annual O&M (treatment, power, pipeline maintenance)	$ 3,020,000
Total Annual Cost	**$ 5,255,000**
Yield	2,200
Cost per Acre-Foot	**$ 2,400**

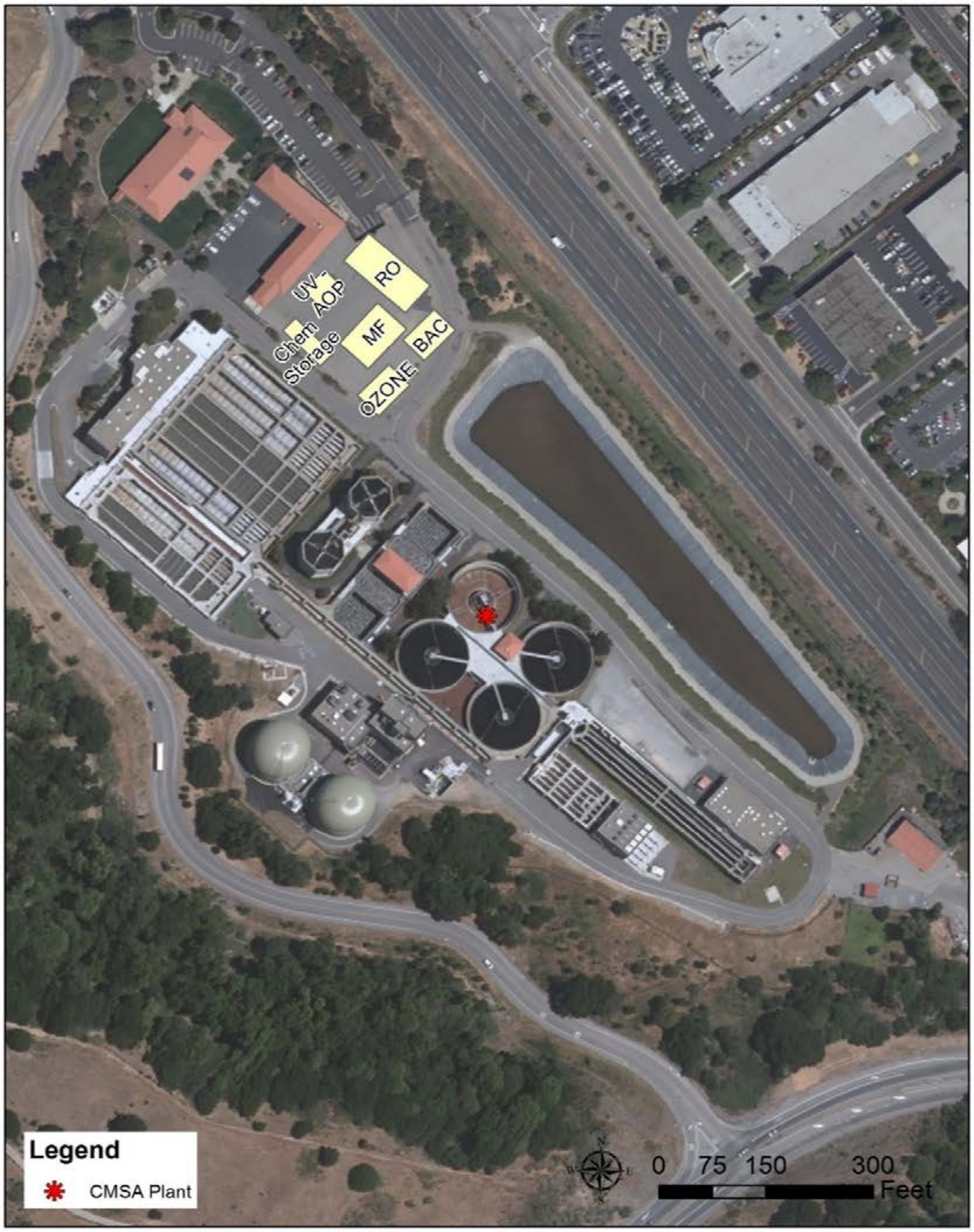
4. Yield and Reliability

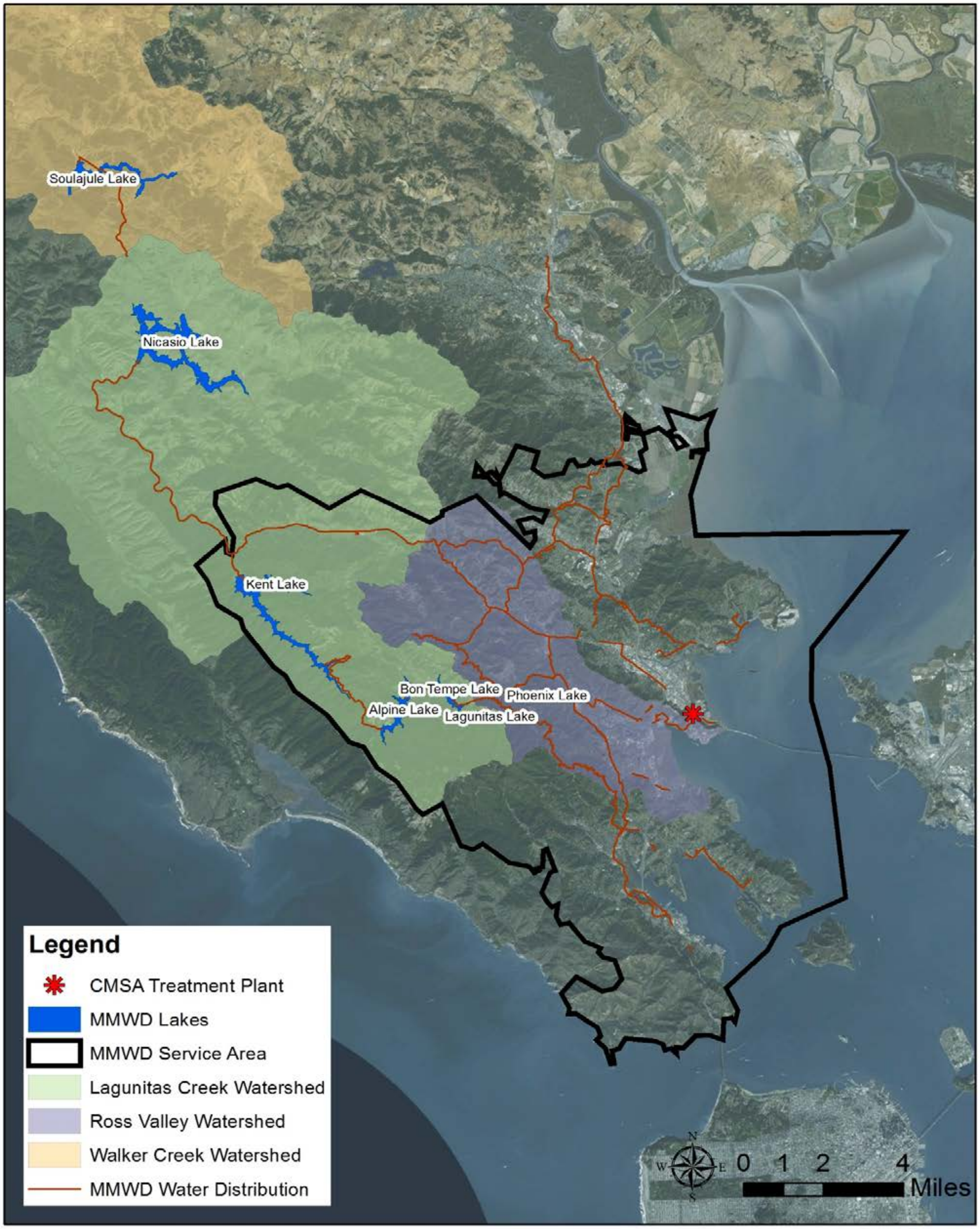
Source: Treated wastewater
Average Year Yield (AFY): 2,240
Dry Year Yield (AFY): 2,240
Seasonality: None
Potential Reliability Concerns: Minimal. Supply is drought-resistant, but seismic activity could affect the treatment plant.

5. Implementation Considerations

Where and how DPR product water gets introduced into MMWD facilities will depend upon regulations and District demands, needs, and constraints. Currently, DPR facility permitting could theoretically be done on a case-by-case basis until regulations are set (feasibility study results expected by December 2016; regulations likely within 5 years); however, no DPR installations have been permitted in California. Because this is "pipe to pipe" DPR (e.g., not upstream of a water treatment plant), it is anticipated to be extremely challenging, if not infeasible, from both permitting and public acceptance perspectives. New training for operators of the plant will be required and significant permits may be needed. It is estimated that this option could be implemented in 8 years.

6. Conceptual Map/Schematic




Soulajule Lake
Nicasio Lake
Kent Lake
Bon Tempe Lake
Phoenix Lake
Alpine Lake
Lagunitas Lake
Legend
CMSA Treatment Plant
MMWD Lakes
MMWD Service Area
Lagunitas Creek Watershed
Ross Valley Watershed
Walker Creek Watershed
MMWD Water Distribution
N
W
E
S
0 1 2 4
Miles

Resiliency Option: Reuse - DPR Las Gallinas (RU03)

1. Description

This supply option involves upgrading the existing Las Gallinas recycled water treatment plant to further purify recycled water and deliver into the MMWD potable water distribution system for direct consumption in areas near the Las Gallinas facility. The project would connect to the distribution system (if permittable) to deliver DPR water MMWD customers. The water source is treated wastewater that would otherwise be discharged and will not interfere with supplying recycled water for non-potable uses. The facility is assumed to produce 0.79 MGD on 1.1 MGD influent (72% recovery, 28% brine reject). It is assumed that brine can be discharged into the existing outfall. It should be noted that this type of potable reuse is not currently permitted in California.

2. Facilities Required

Full Advanced Treatment (FAT) Facility
Water Tanks
Conveyance Piping
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
FAT Facility	mgd	1.1	output mgd	0.79	$ 9,000,000
Water Tank	MG	0.4	tanks	3	$ 1,191,964
Conveyance pipeline	diameter - in	12	LF	22,500	$ 4,860,000
Pump	hp	130	gpm	1,400	$ 973,000

Las Gallinas treatment costs assumed to be the same for DPR, SWA, and IPR options

Raw Construction Cost	$	16,020,000
Mobilization, Contractor's Profit, & Construction Contingency	$	8,760,000
Base Construction Cost	*$*	*24,780,000*
Implementation and Environmental Mitigation	$	12,760,000
Probable Capital Cost	**$**	**37,500,000**
Annualized Capital Cost (3% over 30 yrs)	$	1,913,000
Annual O&M (treatment, power, pipeline maintenance)	$	2,120,000
Total Annual Cost	**$**	**4,033,000**
Yield (AFY)		900
Annual Cost per Acre-Foot	**$**	**4,500**

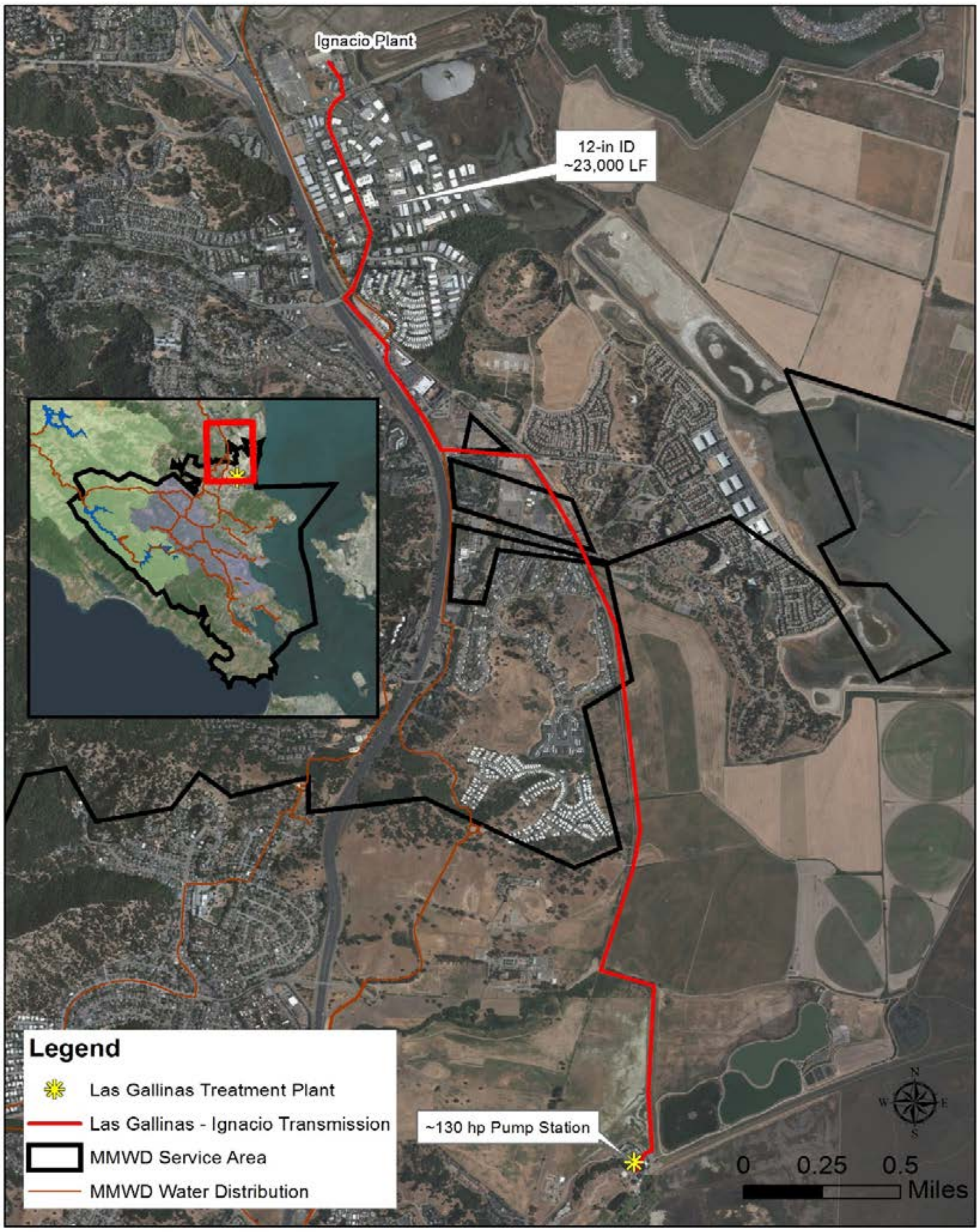
4. Yield and Reliability

Source: Treated wastewater
Average Year Yield (AFY): 890
Dry Year Yield (AFY): 890
Seasonality: None
Potential Reliability Concerns: Minimal. Supply is drought-resistant, but seismic activity could affect the treatment plant.

5. Implementation Considerations

Where and how DPR product water gets introduced into MMWD facilities will depend upon regulations and District demands, needs, and constraints. Currently, DPR facility permitting could theoretically be done on a case-by-case basis until regulations are set (feasibility study results expected by December 2016; regulations likely within 5 years); however, no DPR installations have been permitted in California. Because this is "pipe to pipe" DPR (e.g., not upstream of a water treatment plant), it is anticipated to be extremely challenging, if not infeasible, from both permitting and public acceptance perspectives. New training for operators of the plant will be required and significant permits may be needed. It is estimated that this option could be implemented in 8 years.

6. Conceptual Map/Schematic



Resiliency Option: Reuse - DPR Through Lakes SASM (RU04)

1. Description

This supply option involves constructing additional treatment facilities at SASM's wastewater treatment plant to further purify recycled water prior to conveyance to Bon Tempe Lake for subsequent treatment and delivery within MMWDs service area (surface water augmentation - SWA). With dry-weather flows of 2.2 mgd, it is assumed that the project could divert 2 mgd and produce 1.44 mgd of product water (72% recovery, 28% brine reject). It is assumed that brine can be discharged into the existing outfall. Option also includes constructing a pipeline to Bon Tempe Lake. It should be noted that, while this option includes mixing advance-treated recycled water in a surface water body upstream of a water treatment plant, it is anticipated that the relatively low detention time in Bon Tempe Lake will require additional treatment compared with a traditional surface water augmentation project. These types of projects are currently being permitted on a case-by-case basis in California.

2. Facilities Required

Full Advanced Treatment (FAT) Facility
Pipeline from SASM to Bon Tempe
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
FAT Facility	mgd	2	mgd outflow	1.44	$ 13,000,000
Piping to lake	diameter - in	12	lf	55,000	$ 11,880,000
Pump	hp	440	gpm	1,000	$ 2,124,000

SASM treatment costs assumed to be the same for DPR, SWA, and IPR options

Raw Construction Cost	$	27,000,000
Mobilization, Contractor's Profit, & Construction Contingency	$	14,770,000
Base Construction Cost	*$*	*41,770,000*
Implementation and Environmental Mitigation	$	21,520,000
Probable Capital Cost	**$**	**63,300,000**
Annualized Capital Cost (3% over 30 yrs)	$	3,230,000
Annual O&M (treatment, power, pipeline maintenance)	$	1,690,000
Total Annual Cost	**$**	**4,920,000**
Yield (AFY)		1,600
Annual Cost per Acre-Foot	**$**	**3,100**

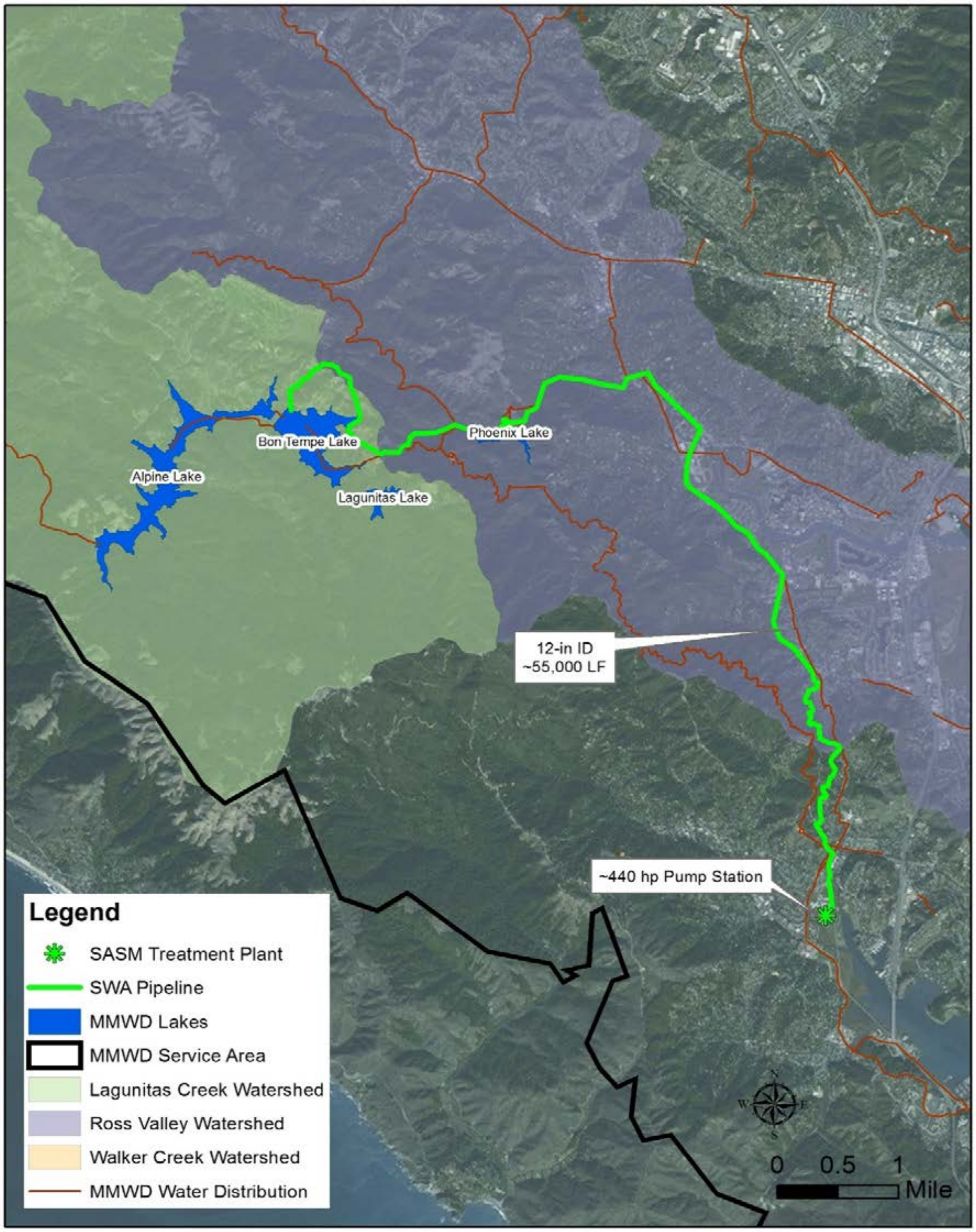
4. Yield and Reliability

Source: Treated wastewater
Average Year Yield (AFY): 1,610
Dry Year Yield (AFY): 1,610
Seasonality: None
Potential Reliability Concerns: Sufficient minimum lake storage (to ensure response time). Suspend operations when lake is spilling. Seismic activity.

5. Implementation Considerations

Project permitting (regulations to be finalized by December 2016), CEQA, and other regulatory compliance. Public acceptance will be key to project success/viability. New training for operators of the plant will be required. Increased monitoring of the lake to ensure dilution concentrations are maintained. It is estimated that this option could be implemented in 5 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Reuse - DPR Through Lakes CMSA (RU05)

1. Description

This supply option involved constructing additional treatment facilities at CMSA's wastewater treatment plant to further purify recycled water prior to conveyance to Bon Tempe Lake for subsequent treatment and delivery to MMWDs service area (surface water augmentation - SWA). The plant would take a Maximum Day Demand of 2.8 MGD with direct potable water output averaging 2.02 MGD (72% recovery, 28% brine reject). Pipeline to Bon Tempe Lake for required residence time. It should be noted that, while this option includes mixing advance-treated recycled water in a surface water body upstream of a water treatment plant, it is anticipated that the relatively low detention time in Bon Tempe Lake will make this a direct potable reuse project, not an indirect potable reuse project. These types of projects are currently being permitted on a case-by-case basis in California.

2. Facilities Required

Full Advanced Treatment (FAT) Facility
Pipeline to Bon Tempe Lake
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
FAT Facility	mgd	2.80	mgd outflow	2.00	$ 18,108,800
Piping to lake	diameter - in	12	lf	43,000	$ 9,288,000
Pump	hp	670	gpm	1,400	$ 2,780,000

CMSA treatment costs assumed to be the same for DPR, SWA, and IPR options

Raw Construction Cost	$	30,180,000
Mobilization, Contractor's Profit, & Construction Contingency	$	16,500,000
Base Construction Cost	*$*	*46,680,000*
Implementation and Environmental Mitigation	$	24,040,000
Probable Capital Cost	**$**	**70,700,000**
Annualized Capital Cost (3% over 30 yrs)	$	3,607,000
Annual O&M (treatment, power, pipeline maintenance)	$	2,130,000
Total Annual Cost	**$**	**5,737,000**
Yield (AFY)		2,200
Annual Cost per Acre-Foot	**$**	**2,600**

4. Yield and Reliability

Source: Treated wastewater
Average Year Yield (AFY): 2,240
Dry Year Yield (AFY): 2,240
Seasonality: None
Potential Reliability Concerns: Sufficient minimum lake storage (to ensure response time). Suspend operation when lake is spilling. Seismic activity.

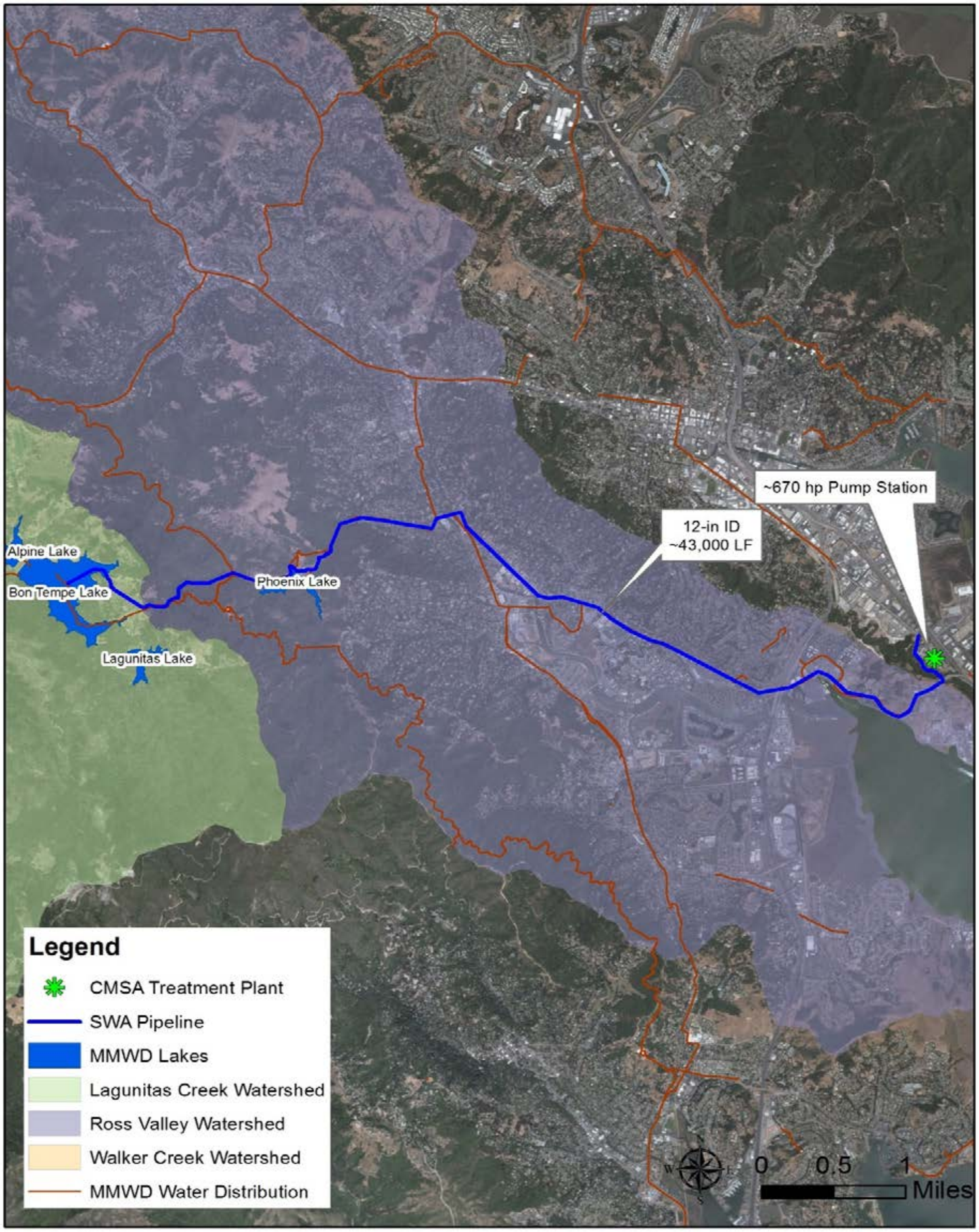
Marin Municipal Water District

RMC water and environment

5. Implementation Considerations

Project permitting (regulations to be finalized by December 2016), CEQA, and other regulatory compliance. Public acceptance will be key to project success/viability. New training for operators of the plant will be required. Increased monitoring of the lake being augmented to ensure dilution concentrations are maintained. It is estimated that this option could be implemented in 5 years.

6. Conceptual Map/Schematic



Resiliency Option: Reuse - DPR Through Lakes Las Gallinas (RU06)

1. Description

This option involves constructing additional treatment facilities at the Las Gallinas plant to further purify recycled water prior to conveyance to Nicasio Lake and subsequent treatment and delivery to MMWDs service area (surface water augmentation - SWA). The plant would take a Maximum Day Demand of 1.1 MGD with water output averaging 0.79 MGD (72% recovery, 28% brine reject). Pipeline to Nicasio for required residence time. It should be noted that, while this option includes mixing advance-treated recycled water in a surface water body upstream of a water treatment plant, it is anticipated that the relatively low detention time in Nicasio Lake will make this a direct potable reuse project, not an indirect potable reuse project. These types of projects are currently being permitted on a case-by-case basis in California.

2. Facilities Required

Full Advanced Treatment (FAT) Facility
Pipeline to Nicasio Lake
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
FAT Facility	mgd	1.1	mgd outflow	0.79	$ 9,000,000
Piping to lake	diameter - in	12	lf	77,500	$ 16,740,000
Pump	hp	360	gpm	600	$ 1,936,000

Las Gallinas treatment costs assumed to be the same for DPR, SWA, and IPR options

Raw Construction Cost	$	27,680,000
Mobilization, Contractor's Profit, & Construction Contingency	$	15,140,000
Base Construction Cost	*$*	*42,820,000*
Implementation and Environmental Mitigation	$	22,400,000
Probable Capital Cost	**$**	**64,900,000**
Annualized Capital Cost (3% over 30 yrs)	$	3,311,000
Annual O&M (treatment, power, pipeline maintenance)	$	1,920,000
Total Annual Cost	**$**	**5,231,000**
Yield (AFY)		900
Annual Cost per Acre-Foot	**$**	**5,800**

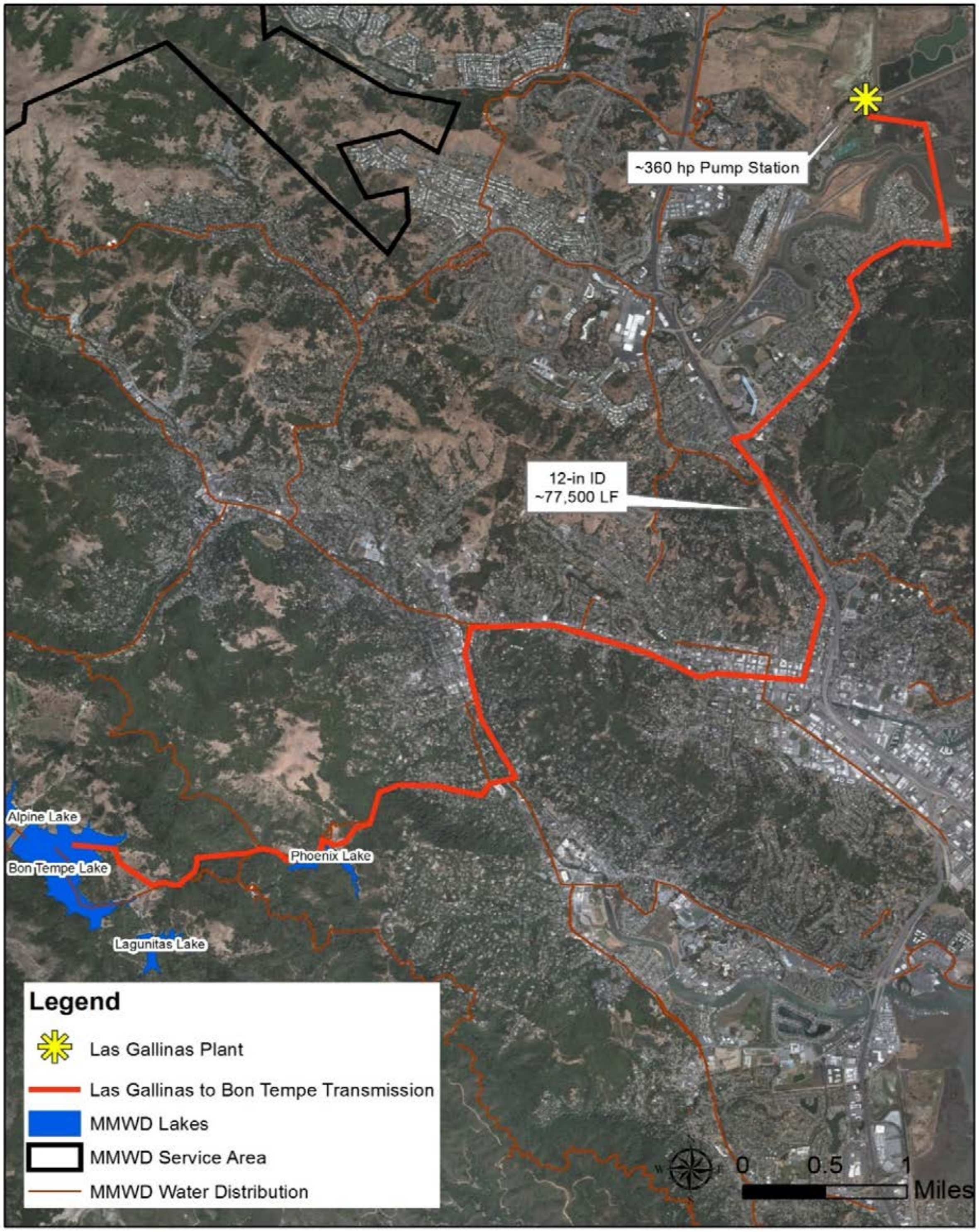
4. Yield and Reliability

Source: Treated wastewater
Average Year Yield (AFY): 890
Dry Year Yield (AFY): 890
Seasonality: None
Potential Reliability Concerns: Sufficient minimum lake storage (to ensure response time). Suspend operation when lake is spilling. Seismic activity.

5. Implementation Considerations

Project permitting (regulations to be finalized by December 2016), CEQA, and other regulatory compliance. Public acceptance will be key to project success/viability. New training for operators of the plant will be required. Increased monitoring of the lake to ensure dilution concentrations are maintained. It is estimated that this option could be implemented in 5 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Reuse - IPR SASM (RU07)

1. Description

This supply option includes constructing additional treatment facilities at SASM's wastewater treatment plant to further purify recycled water prior to conveyance to Kent Lake and subsequent storage, treatment, and delivery to MMWDs service area. With dry-weather flows of 2.2 mgd, it is assumed that 2 mgd will be diverted to produce 1.44 mgd of product water (72% recovery, 28% brine reject). Due to the large volume to flow through Kent Lake, this is expected to be viewed from a regulatory perspective as a typical surface water augmentation project.

2. Facilities Required

Full Advanced Treatment (FAT) Facility
Pipeline from SASM to Kent Lake
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
FAT Facility	mgd	2.00	mgd outflow	1.44	$ 13,000,000
Piping to lake	diameter - in	12	lf	85,000	$ 18,360,000
Pump	hp	530	gpm	1,000	$ 2,393,000

SASM treatment costs assumed to be the same for DPR, SWA, and IPR options

Raw Construction Cost	$ 33,750,000
Mobilization, Contractor's Profit, & Construction Contingency	$ 18,470,000
Base Construction Cost	*$ 52,220,000*
Implementation and Environmental Mitigation	$ 26,630,000
Probable Capital Cost	**$ 78,850,000**
Annualized Capital Cost (3% over 30 yrs)	$ 4,023,000
Annual O&M (treatment, power, pipeline maintenance)	$ 1,700,000
Total Annual Cost	**$ 5,723,000**
Yield (AFY)	1,600
Annual Cost per Acre-Foot	**$ 3,600**

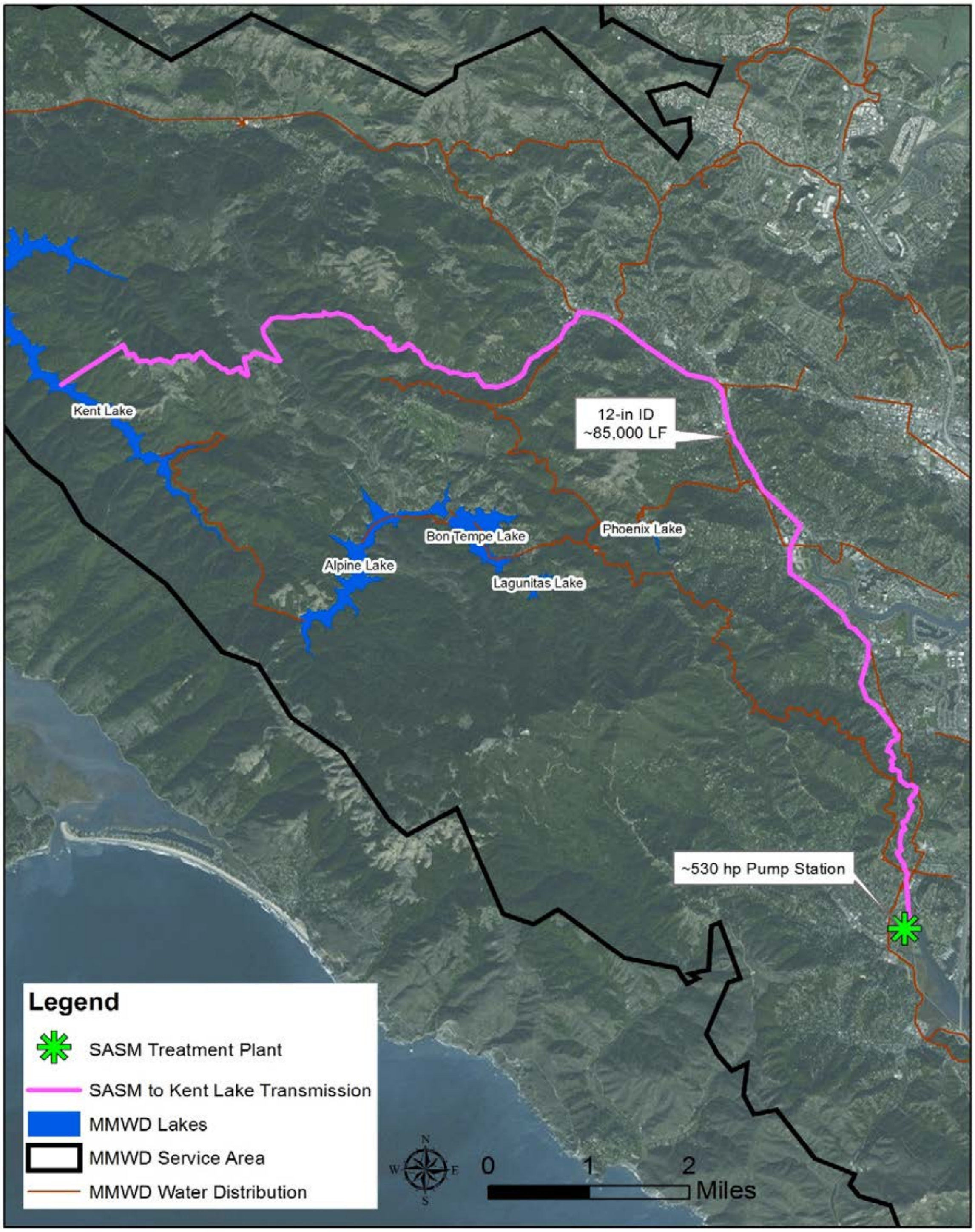
4. Yield and Reliability

Source:	Treated wastewater
Average Year Yield (AFY):	1,610
Dry Year Yield (AFY):	1,610
Seasonality:	None
Potential Reliability Concerns:	Sufficient minimum lake storage (to ensure dilution) and water quality issues. Modeling shows that there would be sufficient retention time in Kent Lake 99.9% of the time. Operations may need to be suspended for one month in the winter after a severe drought to ensure compliance with 6 month residence time regulations. Seismic activity.

5. Implementation Considerations

Implementation requires consideration of surface water augmentation project permitting (regulations to be finalized by December 2016), CEQA documentation, and other regulatory compliance. Public acceptance will be key to project success/viability and new training for operators of the plant will be required. Increased monitoring of the lake to ensure dilution concentrations are maintained. It is estimated that this option could be implemented in 5 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Reuse - IPR CMSA (RU08)

1. Description

This supply option involves constructing additional treatment facilities at CMSA's wastewater treatment plant to further purify recycled water and prior to conveyance to Kent Lake and subsequent storage, treatment, and delivery to MMWDs service area. The plant would take a maximum day demand (MDD) of 2.8 MGD with direct potable water output averaging 202 MGD (recovery 72%, Brine 28%). Due to the large volume to flow rate ration of Kent Lake, this is expected to be viewed from a regulatory perspective as a surface water augmentation project.

2. Facilities Required

Full Advanced Treatment (FAT) Facility
Pipeline to Kent Lake
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
FAT Facility	mgd	2.80	mgd outflow	2.02	$ 18,108,800
Piping to lake	diameter - in	12	lf	72,000	$ 15,552,000
Pump	hp	1160	gpm	1,400	$ 3,951,000

CMSA treatment costs assumed to be the same for DPR, SWA, and IPR options

Raw Construction Cost	$	37,610,000
Mobilization, Contractor's Profit, & Construction Contingency	$	20,580,000
Base Construction Cost	*$*	*58,190,000*
Implementation and Environmental Mitigation	$	29,680,000
Probable Capital Cost	**$**	**87,870,000**
Annualized Capital Cost (3% over 30 yrs)	$	4,483,000
Annual O&M (treatment, power, pipeline maintenance)	$	2,510,000
Total Annual Cost	**$**	**6,993,000**
Yield (AFY)		2,300
Annual Cost per Acre-Foot	**$**	**3,000**

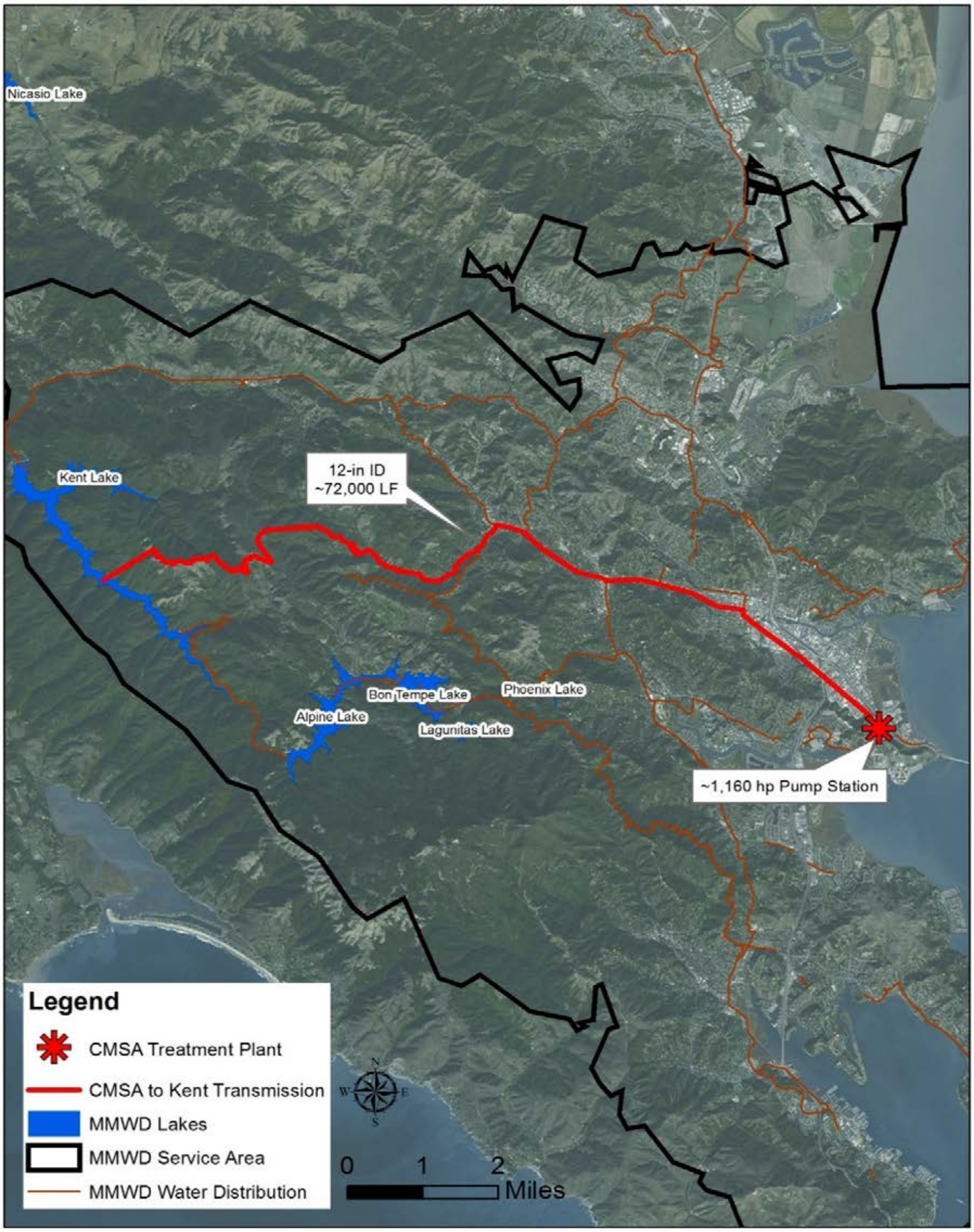
4. Yield and Reliability

Source:	Treated wastewater
Average Year Yield (AFY):	2,260
Dry Year Yield (AFY):	2,260
Seasonality:	None
Potential Reliability Concerns:	Sufficient minimum lake storage (to ensure dilution) and water quality issues. Modeling shows that there would be sufficient retention time in Kent Lake 99.9% of the time. Operation may need to be suspended for one month in the winter after a severe drought to ensure compliance with 6 month residence time regulations. Seismic activity.

5. Implementation Considerations

Implementation requires consideration of surface water augmentation project permitting (regulations to be finalized by December 2016), CEQA documentation, and other regulatory compliance. Public acceptance will be key to project success/viability and new training for operators of the plant will be required. Increased monitoring of the lake to ensure dilution concentrations are maintained. It is estimated that this option could be implemented in 5 years.

6. Conceptual Map/Schematic



Resiliency Option: Reuse - IPR Las Gallinas (RU9)

1. Description

This supply option involves upgrading the existing Las Gallinas recycled water treatment plant to further purify recycled water prior to conveyance to Nicasio Lake and subsequent storage, treatment, and delivery to the MMWD system. Water source is treated wastewater that would otherwise be discharged and will not interfere with current recycled water deliveries. Due to the large volume to flow rate ration of Nicasio Lake, this is expected to be viewed from a regulatory perspective as a surface water augmentation project. This option depends on confirming, with modeling, the travel time required for the treated water in the lake.

2. Facilities Required

Full Advanced Treatment (FAT) Facility
Pipeline
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
FAT Facility	mgd	1.1	output mgd	0.79	$ 9,000,000
Conveyance pipeline	diameter - in	10	LF	78,000	$ 14,040,000
Pump	hp	440	gpm	800	$ 2,124,000

Las Gallinas treatment costs assumed to be the same for DPR, SWA, and IPR options

Raw Construction Cost	$ 25,160,000
Mobilization, Contractor's Profit, & Construction Contingency	$ 13,760,000
Base Construction Cost	*$ 38,920,000*
Implementation and Environmental Mitigation	$ 20,100,000
Probable Capital Cost	**$ 59,020,000**
Annualized Capital Cost (3% over 30 yrs)	$ 3,011,000
Annual O&M (treatment, power, pipeline maintenance)	$ 1,980,000
Total Annual Cost	**$ 4,991,000**
Yield (AFY)	900
Annual Cost per Acre-Foot	**$ 5,500**

4. Yield and Reliability

Source: Treated wastewater
Average Year Yield (AFY): 890
Dry Year Yield (AFY): 890
Seasonality: None
Potential Reliability Concerns: Sufficient minimum lake storage (to ensure dilution) and water quality issues. Suspend operation when lake is spilling. Seismic activity.

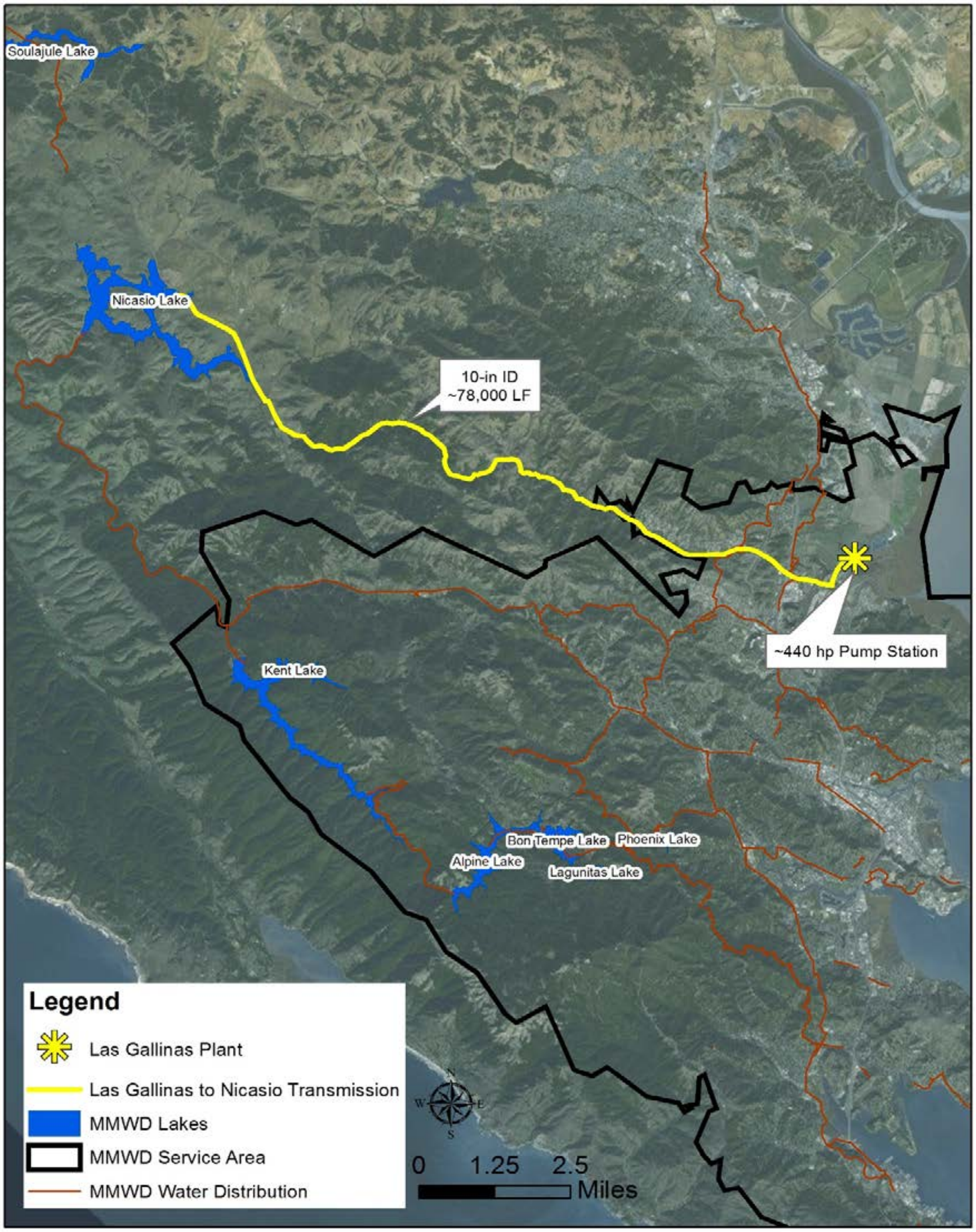
MARIN MUNICIPAL WATER DISTRICT

RMC water and environment

5. Implementation Considerations

Implementation requires consideration of surface water augmentation project permitting (regulations to be finalized by December 2016), CEQA documentation, and other regulatory compliance. Public acceptance will be key to project success/viability and new training for operators of the plant will be required. Increased monitoring of the lake to ensure dilution concentrations are maintained. It is estimated that this option could be implemented in 5 years.

6. Conceptual Map/Schematic



Resiliency Option: Reuse - RW SASM (RU10)

1. Description

Candidates for recycled water use include parks and schools near the SASM's wastewater treatment plant (WWTP). The preferred alternative in the 2014 SASM Recycled Water Feasibility Study ("Irrigation South") was chosen. This option would expand the existing tertiary treatment (including filtration and disinfection) at the SASM WWTP. The option would serve customers near the existing SASM WWTP and include a new pipeline alignment routed south along Camino Alto to the Tamalpais High School and playing fields. Total annual demand for these new recycled water customers is 66 AF of recycled water, with a maximum day demand of 0.31 mgd. The treatment system is sized to meet maximum day demand. It is currently the most cost effective approach; estimates for the other alternatives range from $4M to $6M.

2. Facilities Required

Pipeline
Pump Station
Expanded Tertiary Treatment

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Pipeline	diameter - in	6	lf	3,380	$ 852,000
Pump Station	hp	75	gpm	600	$ 1,403,000
Tertiary Treatment	mgd	0.39	output mgd	0.31	

Raw Construction Cost	$ 2,330,000
Mobilization, Contractor's Profit, & Construction Contingency	$ 590,000
Base Construction Cost	*$ 2,920,000*
Implementation and Environmental Mitigation	$ 150,000
Probable Capital Cost	**$ 3,100,000**
Annualized Capital Cost (3% over 30 yrs)	$ 158,000
Annual O&M	$ 142,000
Total Annual Cost	**$ 300,000**
Yield (AFY)	100
Annual Cost per Acre-Foot	**$ 3,000**

4. Yield and Reliability

Source: Treated wastewater
Average Year Yield (AFY): 66
Dry Year Yield (AFY): 66
Seasonality: Irrigation demands are higher during the summer months.
Potential Reliability Concerns: Minimal. Seismic activity could affect the treatment plant.

5. Implementation Considerations

Implementing the recommended alternative would require obtaining firm commitments from potential customers to use recycled water and permits and clearances from applicable regulatory agencies (RWQCB, DPH, etc.). It is estimated that this option could be implemented in 4 years.

6. Conceptual Map/Schematic

RECOMMENDED PROJECT - PROPOSED PIPELINE ROUTING

Source: Carollo, 2014. SASM/MMWD Recycled Water Feasibility Study

MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Reuse - RW CMSA (RU11)

1. Description

This supply option includes expanding the CMSA's wastewater treatment facility to include microfiltration. Water treated with microfiltration would be delivered to San Quentin Prison, which was identified as the preferred alternative in the CMSA 2016 Recycled Water Feasibility Study, to be used for dual plumbing in prison blocks, landscape irrigation, and boiler make-up water. Total annual demand for these customers is 154 AF of recycled water, with a maximum day demand of 0.20 mgd. The treatment system is sized to meet maximum day demand. Other potential options range from $5.3M to $ 15.8M and include suppling recycled water to Larkspur Landing, portions of Larkspur, Corte Madera, Greenbrae, and Kenfield.

2. Facilities Required

Pipeline
Storage
Pump Station
Microfiltration

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Pipeline	diameter - in	6	lf	3,800	$ 2,912,000
Storage	gal	75,600			
Pump Station	hp	50	gpm	290	$ 3,873,800
Microfiltration	mgd	0.25	output mgd	0.2	

Raw Construction Cost	$	6,786,000
Construction and Estimating Contingency	$	872,500
Base Construction Cost	*$*	*7,660,000*
Implementation and Environmental Mitigation	$	962,500
Probable Capital Cost	**$**	**8,600,000**
Annualized Capital Cost (3% over 30 yrs)	$	439,000
Annual O&M	$	117,000
Total Annual Cost	**$**	**556,000**
Yield		200
Cost per Acre-Foot	**$**	**2,800**

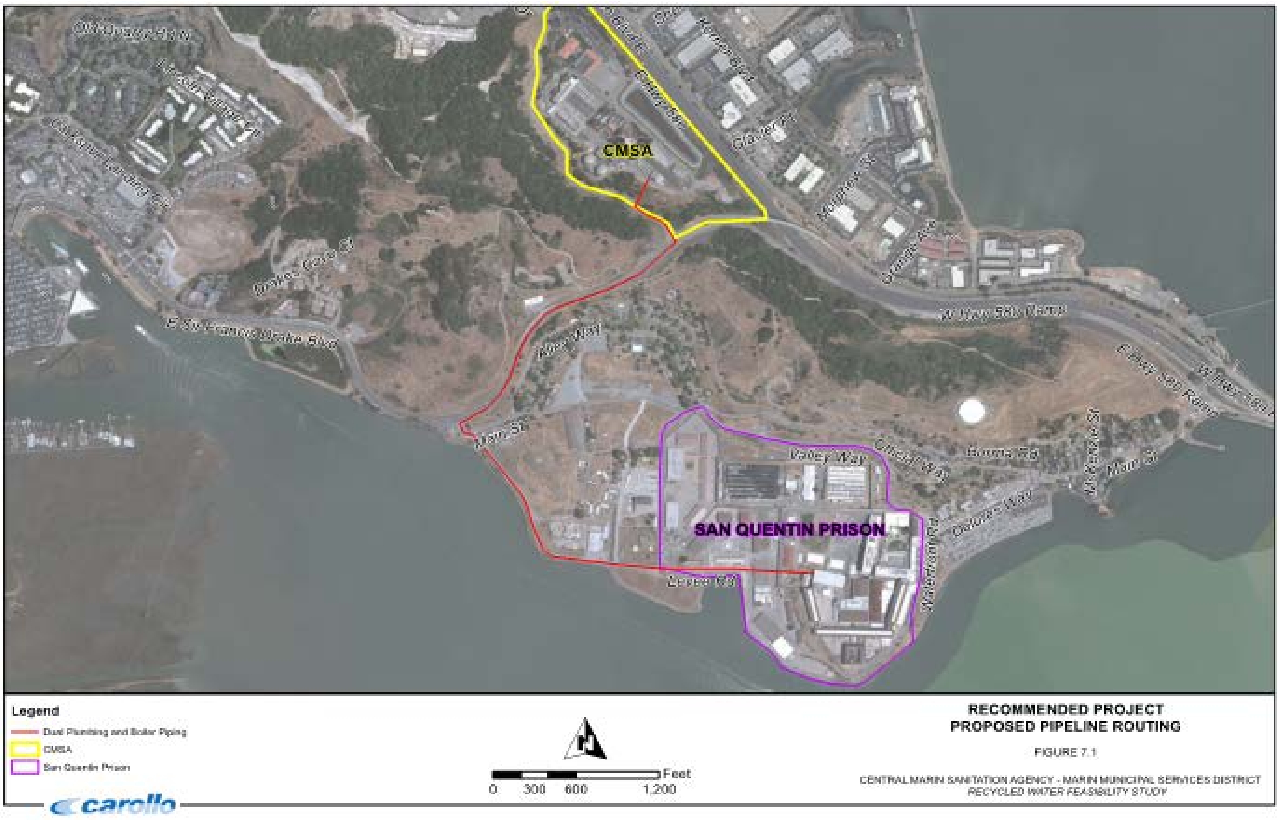
4. Yield and Reliability

Source: Treated wastewater
Average Year Yield (AFY): 154
Dry Year Yield (AFY): 154
Seasonality: Irrigation demands are higher during the summer months.
Potential Reliability Concerns: Seismic activity.

5. Implementation Considerations

Implementing the recommended alternative would require obtaining firm commitments from potential customers to use recycled water and permits and clearances from applicable regulatory agencies (RWQCB, DPH, etc.). It would also require development of a Salt/Nutrient Management Plan or approval from RWQCB that a plan is not needed to protect groundwater in this area. It is estimated that this option could be implemented in 5 years.

6. Conceptual Map/Schematic



Source: Carollo, 2016. CMSA/MMWD Recycled Water Feasibility Study

MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Reuse - RW RBSD (RU12)

1. Description

Richardson Bay Sanitary District (RBSD) taps the treated effluent outfall line of SASM and then further treats the wastewater using polishing ponds and mixed media filtration for use in Tiburon. This project corresponds to alternative I-6 North in the SASM 2014 Recycled Water Feasibility Study. This supply option includes increasing the amount of water treated by RBSD and serving that additional water to Tiburon to further offset potable use for landscape irrigation and commercial sites. This option requires new tertiary treatment, including filtration and disinfection, at the RBSD Trestle Glen WRF. The total annual demand from customers is 29 AFY and the treatment system was sized for the maximum day demand of 0.08 mgd. The North alternative was chosen over the South ($1.9M) because it has a lower unit cost.

2. Facilities Required

Pump Station
Pipeline
Tertiary Treatment

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Pump Station	hp	10	gpm	100	$ 104,100
Pipeline	diameter - in	6	lf	10,500	$ 1,673,900
Tertiary Treatment	mgd	0.10	output mgd	0.08	

Raw Construction Cost	$ 1,778,000
Mobilization, Contractor's Profit, & Construction Contingency	$ 1,000,000
Base Construction Cost	*$ 2,770,000*
Implementation and Environmental Mitigation	$ 720,000
Probable Capital Cost	**$ 3,500,000**
Annualized Capital Cost (3% over 30 yrs)	$ 179,000
Annual O&M	$ 10,000
Total Annual Cost	**$ 189,000**
Yield (AFY)	30
Annual Cost per Acre-Foot	**$ 6,300**

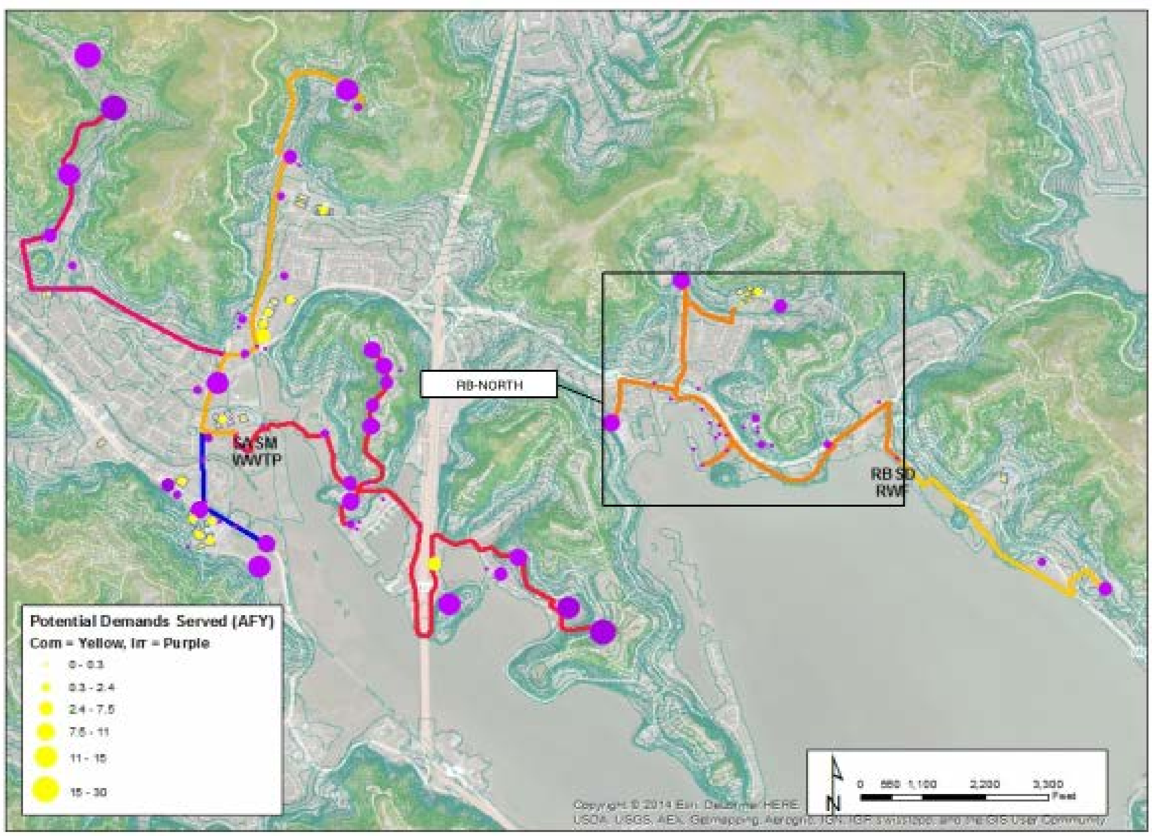
4. Yield and Reliability

Source: Treated wastewater
Average Year Yield (AFY): 29
Dry Year Yield (AFY): 29
Seasonality: Irrigation demands are higher during the summer months.
Potential Reliability Concerns: Seismic activity.

5. Implementation Considerations

Implementing the recommended alternative would require obtaining firm commitments from potential customers to use recycled water and permits and clearances from applicable regulatory agencies (RWQCB, DPH, etc.). It would also require development of a Salt/Nutrient Management Plan, or approval from RWQCB that a plan is not needed to protect groundwater in this area. It is estimated that this option could be implemented in 4 years.

6. Conceptual Map/Schematic



ALTERNATIVE I-6 RB-NORTH
PROPOSED PIPELINE ROUTING

Source: Carollo, 2014. SASM/MMWD Recycled Water Feasibility Study

Resiliency Option: Reuse - Regional IPR (RU13)

1. Description

The three major regional wastewater treatment plants within Marin County (SASM, CMSA, and Las Gallinas) present an opportunity to treat and reuse the influent that would create a sustainable, local, and reliable source of supply. This option looks to convey SASM and Las Gallinas flow to CMSA, where all three plants would further purify recycled water prior to conveyance to Kent Lake for subsequent storage, treatment, and delivery to the MMWD system.

2. Facilities Required

(3) Pipelines
(4) Pump Stations
Full Advanced Treatment (FAT) Facility

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
SASM to CMSA Pipe	diameter - in	12	LF	33,500	$ 8,040,000
Las Gall. to CMSA Pipe	diameter - in	12	LF	43,000	$ 10,320,000
CMSA to Kent Pipe	diameter - in	30	LF	71,280	$ 42,768,000
SASM Pump	hp	100	gpm	800	$ 877,000
Las Gallinas Pump	hp	100	gpm	764	$ 877,000
CMSA #1 Pump	hp	830	gpm	6,111	$ 3,398,000
CMSA #2 Pump	hp	4,280	gpm	6,111	$ 9,710,000
FAT Facility	mgd	8.8	output mgd	7	$ 84,665,000

Raw Construction Cost	$ 154,540,000
Mobilization, Contractor's Profit, & Construction Contingency	$ 84,540,000
Base Construction Cost	*$ 239,080,000*
Implementation and Environmental Mitigation	$ 120,180,000
Probable Capital Cost	**$ 359,260,000**
Annualized Capital Cost (3% over 30 yrs)	$ 18,329,000
Annual O&M (treatment, power, pipeline maintenance)	$ 7,920,000
Total Annual Cost	**$ 26,249,000**
Yield (AFY)	7,900
Annual Cost per Acre-Foot	**$ 3,300**

4. Yield and Reliability

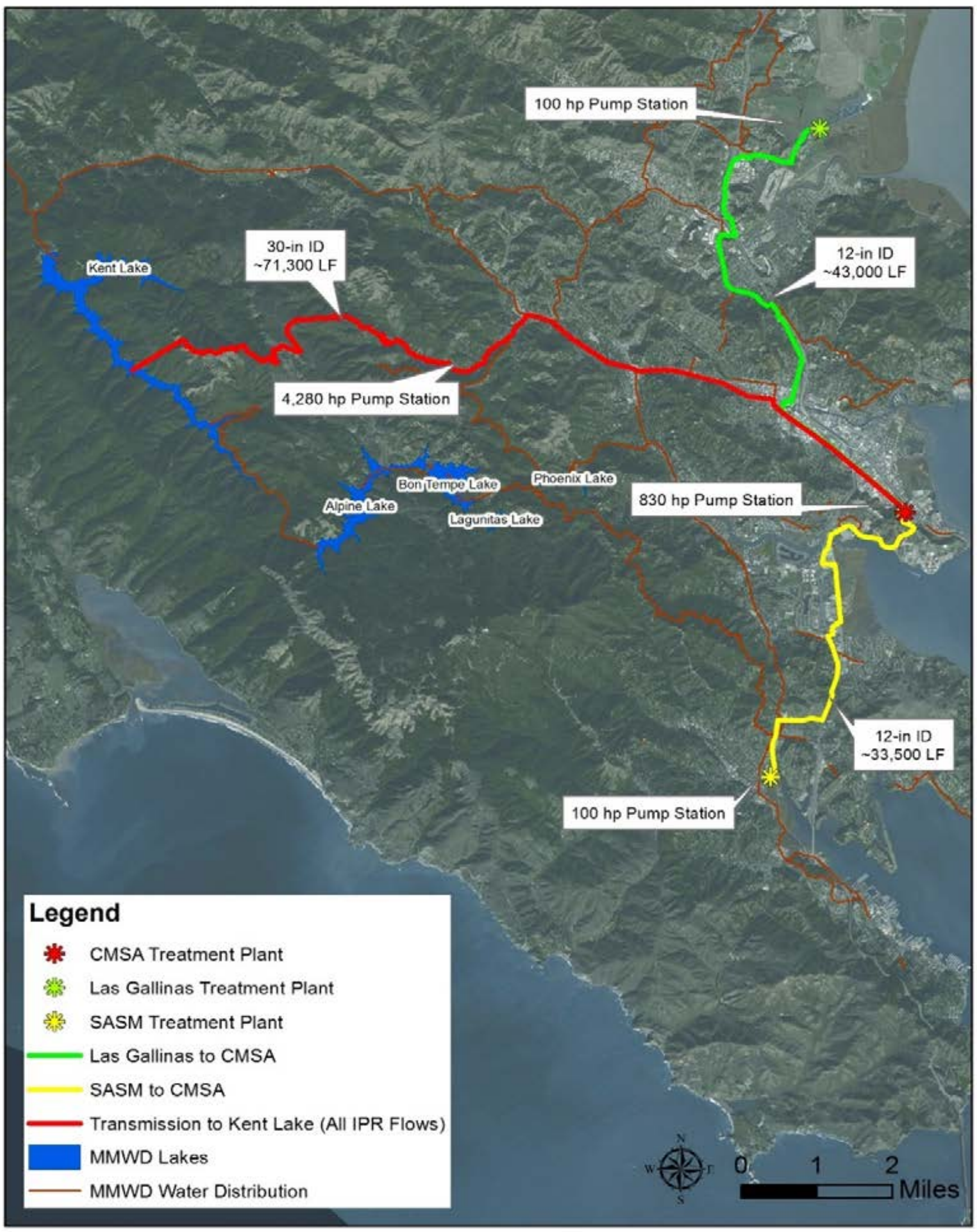
Source: Treated wastewater
Average Year Yield (AFY): 7,885
Dry Year Yield (AFY): 7,885
Seasonality: None

Potential Reliability Concerns: Sufficient minimum lake storage (to ensure dilution) and water quality issues. Modeling shows that there would be sufficient retention time in Kent Lake 99.5% of the time. Operation may need to be suspended for one or two months in the winter after a severe drought to ensure compliance with 6 month residence time regulations. Seismic activity.

5. Implementation Considerations

Implementation requires consideration of surface water augmentation project permitting (regulations to be finalized by December 2016), CEQA documentation, and other regulatory compliance. Public acceptance will be key to project success/viability and new training for operators of the plant will be required. Increased monitoring of the lake to ensure dilution concentrations are maintained. It is estimated that this option could be implemented in 5 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Expand Conveyance - SCWA Kastania Pump Station (SC01)

1. Description

Currently, there is an 18 mgd "choke point" in the pipeline from Sonoma County Water Agency (SCWA); 10 mgd of this capacity is for MMWD and the remaining 8 mgd is for North Marin Water District (NMWD). To increase the capacity of the water transfer infrastructure, this supply option would upgrade Kastania Pump Station to serve additional water from the North Marin Aqueduct. The pump station upgrade would include new variable speed pumps.

2. Facilities Required

New Variable Speed (VS) Pumps at Kastania Pump Station
Potentially new / additional cans, Electrical, SCADA

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
New VS Pumps	hp	800	gpm	3,720	$ 2,000,000

Raw Construction Cost	$	2,000,000
Mobilization, Contractor's Profit, & Construction Contingency	$	1,190,000
Base Construction Cost	*$*	*3,090,000*
Implementation and Environmental Mitigation	$	1,840,000
Probable Capital Cost	**$**	**4,930,000**
Annualized Capital Cost (3% over 30 yrs)	$	252,000
Annual O&M (inc. wheeling)	$	158,000
Annual Cost of Water	$	4,300,000
Total Annual Cost	**$**	**4,710,000**
Yield (AFY)		4,300
Annual Cost per Acre-Foot	**$**	**1,100**

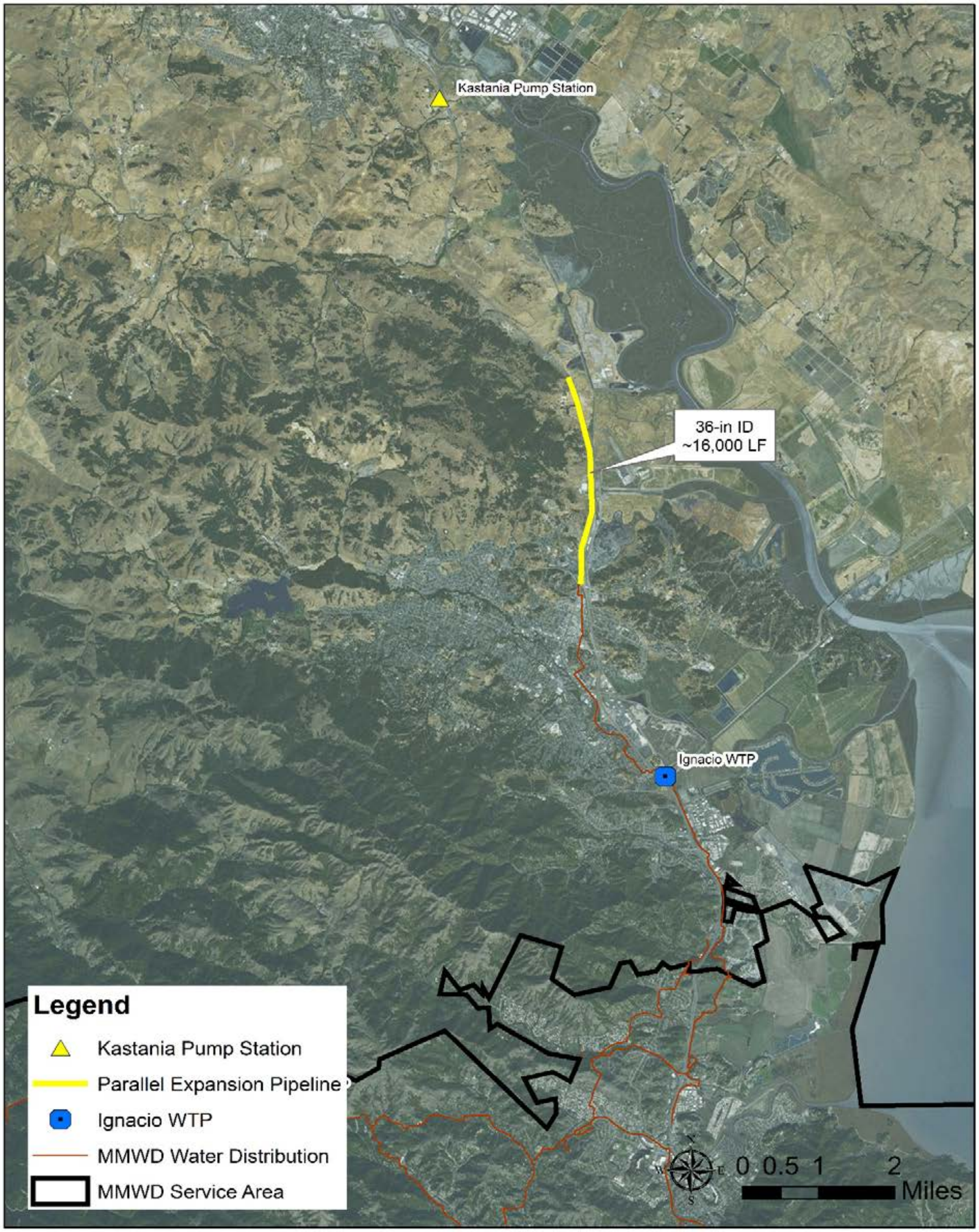
4. Yield and Reliability

Source:	Sonoma County Water Agency	
Average Year Yield (AFY):	4,300	
Dry Year Yield (AFY):	0 to 4,300	(Additional above current 10 TAFY limit)
Seasonality:	Likely dictated by operation of the regional system.	
Potential Reliability Concerns:	Likely reduced deliveries during droughts.	

5. Implementation Considerations

Requires coordination with other agencies served by SCWA, including NMWD. Minor construction-related regulatory and permitting barriers. It is estimated that this option could be implemented in 2 years.

6. Conceptual Map/Schematic



Resiliency Option: Expand Conveyance - SCWA Pipeline (SC02)

1. Description

Currently, there is an 18 mgd "choke point" in the pipeline from Sonoma County Water Agency (SCWA); 10 mgd of this capacity is for MMWD and the remaining 8 mgd is for North Marin Water District (NMWD). To increase the capacity in this area of the pipeline, this supply option would include construction of a parallel pipeline between the Redwood Landfill and San Marin Avenue to increase transfer capacity from SCWA.

2. Facilities Required

Conveyance Pipeline

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Pipeline	Diameter - in	36	lf	16,000	$ 10,368,000

Raw Construction Cost	$ 10,370,000
Mobilization, Contractor's Profit, & Construction Contingency	$ 5,690,000
Base Construction Cost	*$ 16,040,000*
Implementation and Environmental Mitigation	$ 8,124,000
Probable Capital Cost	**$ 24,164,000**
Annualized Capital Cost (3% over 30 yrs)	$ 1,233,000
Annual O&M (inc. wheeling)	$ 96,000
Annual Cost of Water	$ 4,300,000
Total Annual Cost	**$ 5,629,000**
Yield (AFY)	4,300
Annual Cost per Acre-Foot	**$ 1,300**

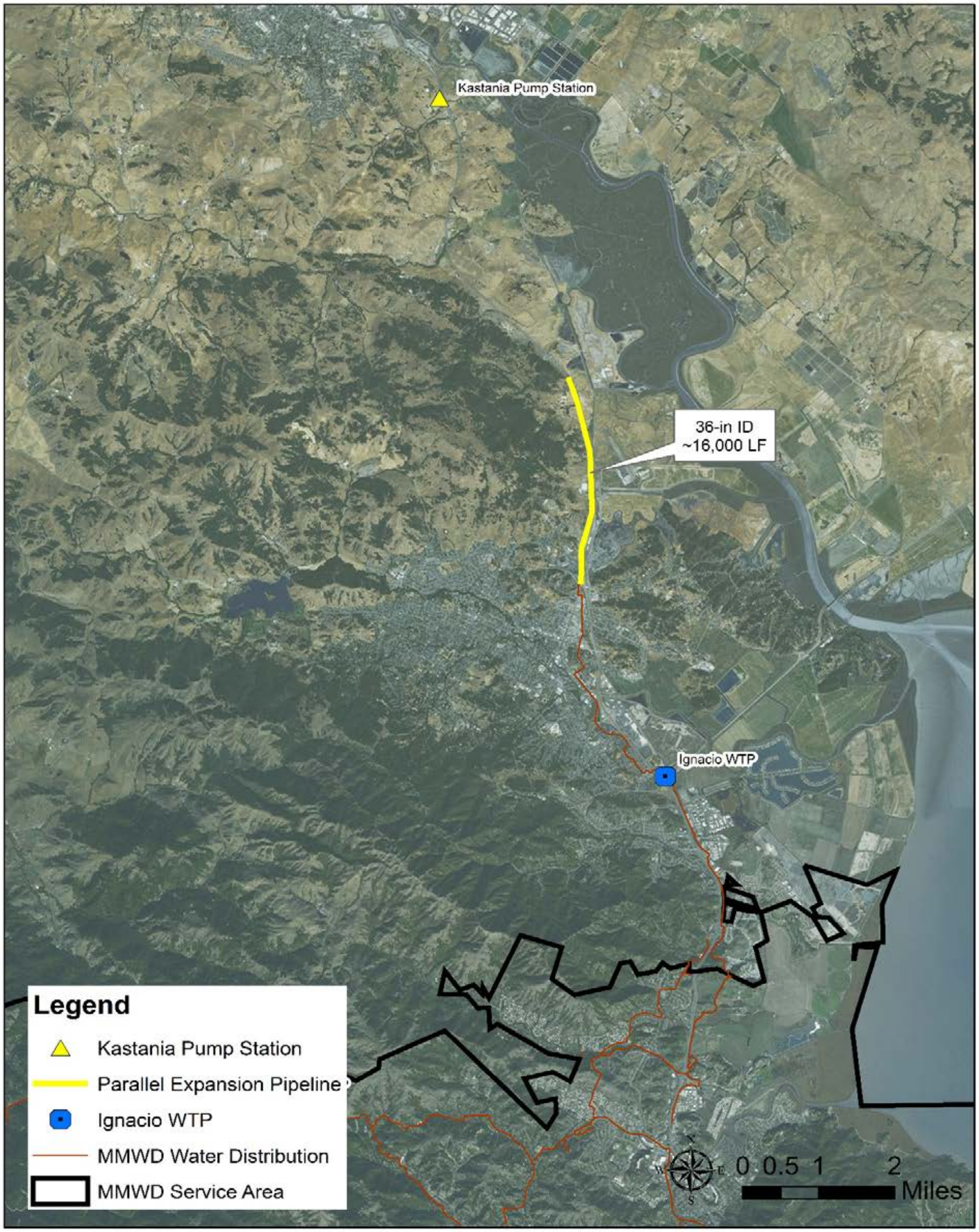
4. Yield and Reliability

Source: Sonoma County Water Agency
Average Year Yield (AFY): 4,300
Dry Year Yield (AFY): 0 to 4,300 (Additional above current 10 TAFY limit)
Seasonality: Likely dictated by operation of the regional system.
Potential Reliability Concerns: Likely reduced deliveries during droughts.

5. Implementation Considerations

Requires coordination with other agencies served by SCWA, including NMWD. Minor construction-related regulatory and permitting barriers. It is estimated that this option could be implemented in 4 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Expand Conveyance - SCWA (SC03)

1. Description

Currently, there is an 18 mgd "choke point" in the pipeline from Sonoma County Water Agency (SCWA); 10 mgd of this capacity is for MMWD and the remaining 8 mgd is for North Marin Water District (NMWD). To increase the capacity in this area of the pipeline, this supply option would upgrade Kastania Pump Station to serve water from the North Marin Aqueduct in conjunction with the Narrows expansion project. This would include construction of a parallel pipeline between the Redwood Landfill and San Marin Avenue to increase transfer capacity from SCWA. New variable speed pumps may be required, depending on future demands from NMWD. For costing purposes, these variable speed pumps were included.

2. Facilities Required

New Variable Speed (VS) Pumps at Kastania Pump Station
Potentially new / additional cans, Electrical, SCADA
Conveyance Pipeline

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
New VS Pumps	hp	800	gpm	3,720	$ 2,000,000
Pipeline	Diameter - in	36	lf	16,000	$ 10,368,000

Raw Construction Cost	$	12,370,000
Mobilization, Contractor's Profit, & Construction Contingency	$	6,770,000
Base Construction Cost	*$*	*19,140,000*
Implementation and Environmental Mitigation	$	9,860,000
Probable Capital Cost	**$**	**29,000,000**
Annualized Capital Cost (3% over 30 yrs)	$	1,480,000
Annual O&M (inc. wheeling)	$	168,000
Annual Cost of Water	$	4,300,000
Total Annual Cost	**$**	**5,948,000**
Yield (AFY)		4,300
Annual Cost per Acre-Foot	**$**	**1,400**

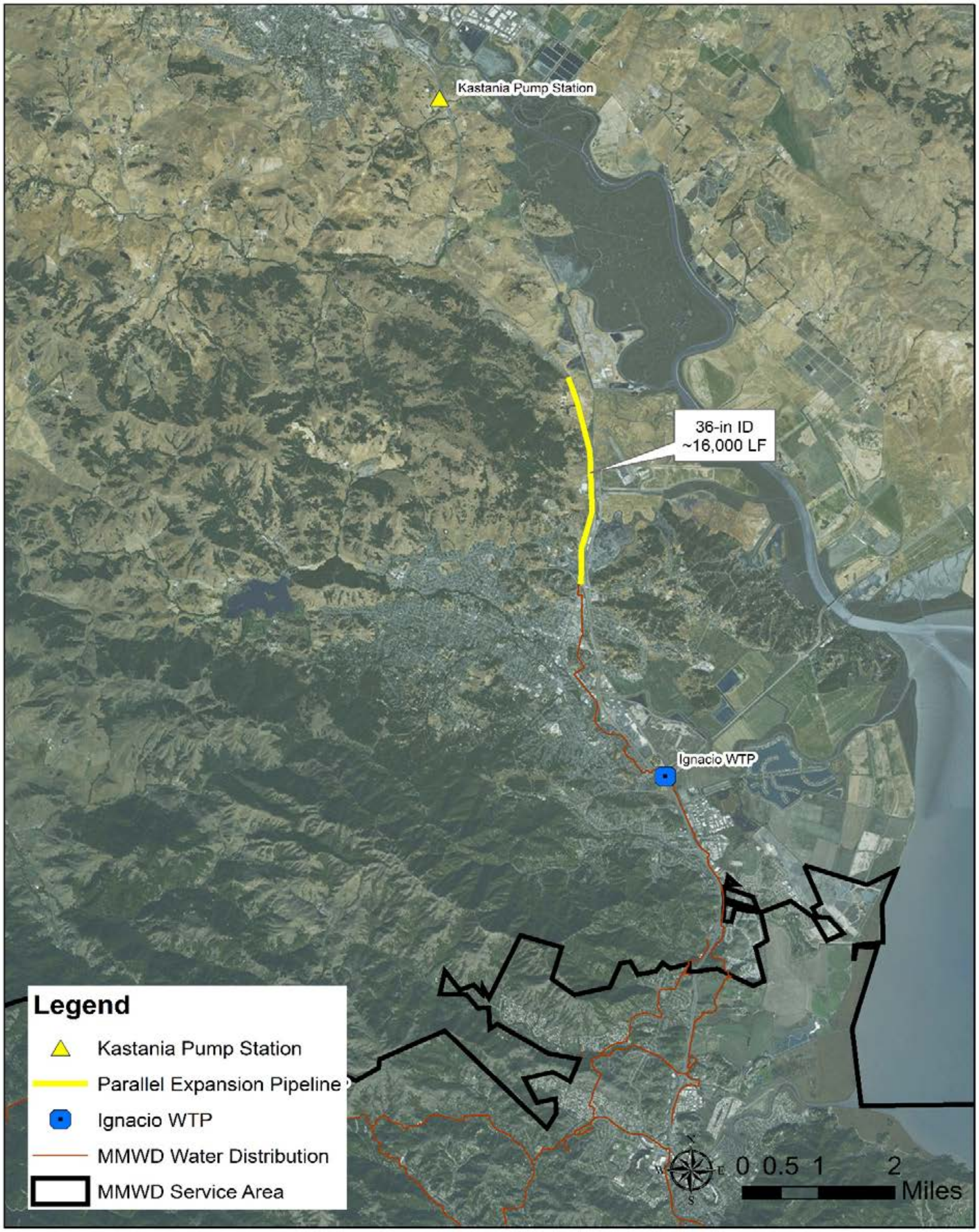
4. Yield and Reliability

Source:	Sonoma County Water Agency
Average Year Yield (AFY):	4,300
Dry Year Yield (AFY):	0 to 4,300 (Additional above current 10 TAFY limit)
Seasonality:	Likely dictated by operation of the regional system.
Potential Reliability Concerns:	Likely reduced deliveries during droughts.

5. Implementation Considerations

Requires coordination with other agencies served by SCWA, including NMWD. Minor construction-related regulatory and permitting barriers. It is estimated that this option could be implemented in 4 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Storage - Reservoir Excavation/Dredging (ES01)

1. Description

This supply option involves excavating Nicasio Lake to increase available storage. This option assumes that 1.6 million cubic yards of sediment must be removed from Nicasio Lake to increase capacity by 1,000 AF. A 100% yield return was assumed for initial costing to determine if the option is cost effective to justify further investigation.

2. Facilities Required

None

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Process Cost
Dredging	CY	1.6 million			$ 25,600,000
Tipping	CY	1.6 million			$ 72,000,000

Raw Construction Cost	$	25,600,000
Mobilization, Contractor's Profit, & Construction Contingency	$	14,006,000
Base Construction Cost	*$*	*39,610,000*
Implementation and Environmental Mitigation	$	19,810,000
Environmental Mitigation Measures Costs	$	590,000
Probable Capital Cost	**$**	**132,000,000**
Annualized Capital Cost (3% over 10 yrs)	$	15,474,000
Annual O&M	$	-
Total Annual Cost	**$**	**15,474,000**
Yield (AFY)		1,000
Annual Cost per Acre-Foot	**$**	**15,500**

4. Yield and Reliability

Source: Nicasio Lake
Average Year Yield (AFY): 1,000
Dry Year Yield (AFY): 1,000
Seasonality: Increases storage capacity, which provides greatest benefit in normal to wet years, may increase carryover storage in dry years
Potential Reliability Concerns: Loss of capacity due to ongoing sediment loading (like the rest of the lake)

5. Implementation Considerations

Environmental and fishing interests may oppose the dredging due to potential negative impacts associated with dredging large amounts of sediment, including mobilizing contaminants that have settled in the sediment. Regulatory compliance and approval for the dredging must be secured. Disposal of dredge material may be an issue depending on sediment composition. It is estimated that this option could be implemented in 5 years.

6. Conceptual Map/Schematic

Source: Salix "Expert desilting or dredging of ponds, lakes, and reservoirs" (http://www.salixrw.com/techniques/lake-desilting/)

MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Storage - Pump Station Improvements at Nicasio (ES02)

1. Description

This option involves pump station improvements to reduce lake elevation constraints on pumping, thereby increasing the amount of usable storage. When Nicasio Lake drops below half elevation, the Tocaloma Booster Pump Station experiences cavitation and the four pumps must be replaced. This option would replace the existing pump station with a deep barrel pump station, with the additional depth of the pump station barrels/impellers being approximately equal to the additional available storage within the lake. The additional depth provides net suction head at the pump station and increases the amount of usable storage in Nicasio Lake by 2,300 AF. This option does not provide a new water supply, thus the yield is 0 AFY. This option potentially reduces the cost of obtaining the 2,300 AF at the bottom of Nicasio Lake and the value of the option will be determined in a modeling analysis.

2. Facilities Required

New Booster Pump Station at Tocaloma Booster Pump Station site

3. Sizing and Cost

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Pump station	hp	2,500	gpm	14,800	$ 7,660,000
Upgrade to Electrical					$ 500,000

Raw Construction Cost	**$**	**8,160,000**
Mobilization, Contractor's Profit, & Construction Contingency	$	4,460,000
Base Construction Cost	***$***	***12,620,000***
Implementation and Environmental Mitigation	$	6,436,200
Probable Capital Cost	**$**	**19,100,000**
Annualized Capital Cost (3% over 30 yrs)	$	974,000
Annual O&M	$	382,000
Total Annual Cost	**$**	**1,356,000**
Yield (AFY)		-
Annual Cost per Acre-Foot	**N/A**	

4. Yield and Reliability

Source: Nicasio Lake

Average Year Yield (AFY): 0

Dry Year Yield (AFY): 0

Note: This option does not create new supply, it allows MMWD to more easily access 2,300 AF.

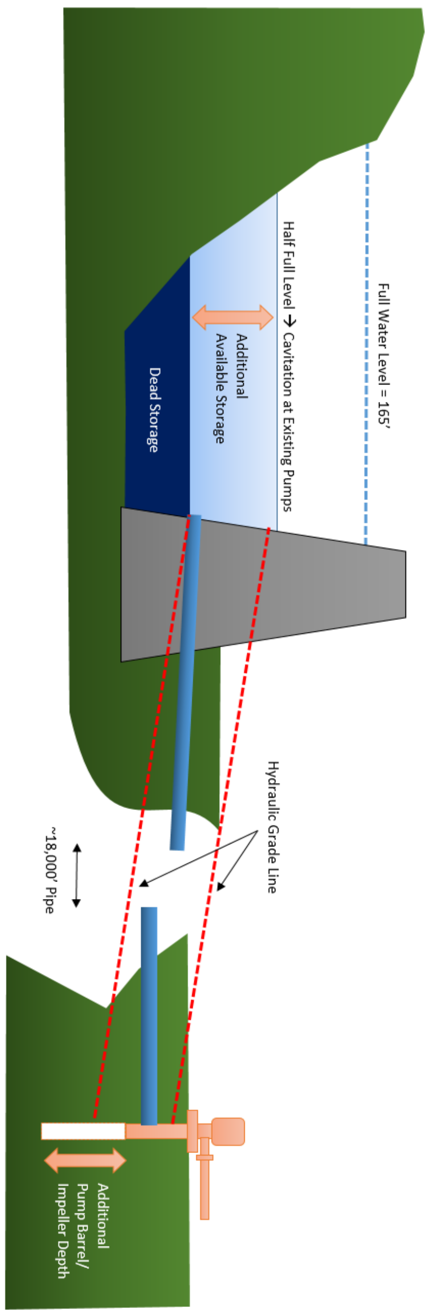
Seasonality: None

Potential Reliability Concerns: Potential water quality issues.

5. Implementation Considerations

Dry year yield may be limited during prolonged drought conditions. Project assumes adequate hydraulic capacity in the suction line between the lake and the pump station. Deep barrel pumps are relatively expensive to construct, and construction feasibility and methodologies will be subject to geotechnical considerations. It is assumed that the current pump station site has sufficient space to allow construction of a new station adjacent to the existing pump station, allowing construction without impacting operation of the existing facilities. System modeling shows that Nicasio rarely, if ever, must be drained to 2,300 AF during both historical and projected hydrologic conditions; thus this option may not be necessary or cost effective. It is estimated that this option could be implemented in 3 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Storage - Raise Soulajule Dam (ES03)

1. Description

The storage capacity of Soulajule Lake is roughly 10,000 AF, whereas annual potential average inflow is about 14,000 AFY. Studies indicate that Soulajule Lake storage could be increased from 10,000 to 30,000 AF to capture more of this flow by raising the dam height at Soulajule Lake by about 48 feet. Increasing Soulajule's dam height is the only feasible surface storage expansion option within MMWD's region due to environmental and water right issues at other lake sites. In addition to raising the dam, this option includes installation of permanent pumping infrastructure at the dam to help meet District potable water demands.

2. Facilities Required

Increased earthen dam

Permanent power drop for pump station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Earthen Dam	AF	20,000	ft	48	$ 40,000,000
Power Drop					$ 2,000,000

Raw Construction Cost	$ 42,000,000
Mobilization, Contractor's Profit, & Construction Contingency	$ 22,970,000
Base Construction Cost	*$ 64,970,000*
Implementation and Environmental Mitigation	$ 33,460,000
Probable Capital Cost	**$ 98,400,000**
Annualized Capital Cost (3% over 30 yrs)	$ 5,020,000
Annual O&M	$ 3,320,000
Total Annual Cost	**$ 8,340,000**
Yield (AFY)	4,000
Annual Cost per Acre-Foot	**$ 2,100**

4. Yield and Reliability

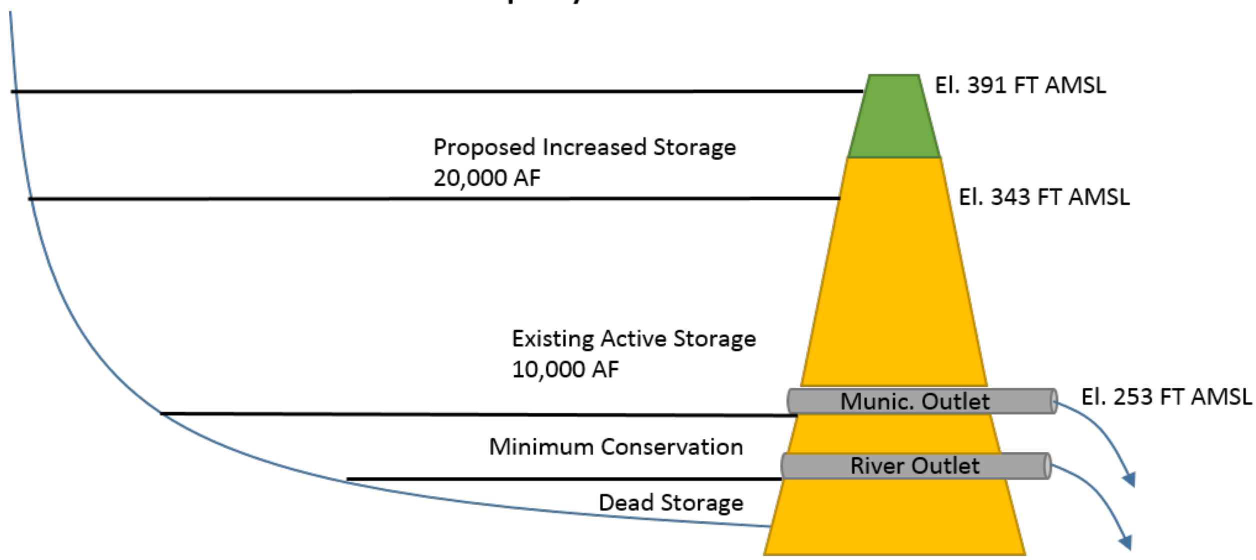
Source:	Soulajule Lake
Average Year Yield (AFY):	zero to 4,000
Dry Year Yield (AFY):	zero to 4,000
Seasonality:	Additional storage in all year types
Potential Reliability Concerns:	As a surface water supply, this project's yield will be vulnerable to drought and climate change.

5. Implementation Considerations

There may be significant public concern associated with raising the dam at Soulajule Lake, including from fishery and environmental groups. Furthermore, there would likely be environmental impacts that would require mitigation. This option would require a review of MMWD's water rights and environmental flow requirements. It is estimated that this option could be implemented in 10 years.

6. Conceptual Map/Schematic

Soulajule Reservoir Capacity Increase



Resiliency Option: Storage - Ross Valley (ES04)

1. Description

This option involves pumping groundwater from the Ross Valley area with a distributed system of 25 low yield wells, each with a pumping rate of 10 gallons per minute. Groundwater produced from these wells would be piped to a small central treatment facility and then piped into MMWD's distribution system for use. The treatment facility would be a 0.36 mgd facility and include reverse osmosis (RO) treatment. For costing purposes, it was assumed that each well would require a lateral pipeline to a central pipeline that would carry the pumped groundwater to a central treatment plant. The central treatment plant would be located near the existing potable line along Sir Francis Drake Boulevard. Treated water would be tied into this existing distribution pipeline for distribution in MMWD's service area.

2. Facilities Required

Extraction Wells
Laterals from wells to central pipeline
Central treatment facility
Pipeline and tie-in to MMWD distribution system

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Project Element
Extraction Wells	gpm	10	wells	25	$ 1,210,000
Laterals	in	4	ea	25	$ 1,000,000
Treatment Facility	mgd	0.36	ea	1	$ 2,702,000
Pipeline and Tie-Ins	in	12	LF	5,000	$ 1,200,000

Raw Construction Cost	$	6,210,000
Mobilization, Contractor's Profit, & Construction Contingency	$	3,400,000
Base Construction Cost	*$*	*9,610,000*
Implementation and Environmental Mitigation	$	4,906,100
Probable Capital Cost	**$**	**14,520,000**
Annualized Capital Cost (3% over 30 yrs)	$	741,000
Annual O&M	$	290,000
Total Annual Cost	**$**	**1,031,000**
Yield (AFY)		400
Annual Cost per Acre-Foot	**$**	**2,600**

4. Yield and Reliability

Source:	Groundwater
Average Year Yield (AFY):	400
Dry Year Yield (AFY):	400
Seasonality:	Possible year round use, likely higher yields during wet months
Potential Reliability Concerns:	Groundwater contamination (to be addressed with RO). Seismic activity.

5. Implementation Considerations

CEQA and other regulatory compliance must be addressed.   While quality may be an issue as arsenic and nitrate have been detected above their respective MCLs in groundwater withdrawn from the Ross Valley; using RO for treatment would address these issues. Product water would require conditioning to better match existing District supplies. This option would require permits and easements from the County to construct wells on County property, or land acquisition would be required, which could signficantly increase unit costs. Land acquisition is necessary in order to secure overlying rights to access groundwater. It is estimated that this option could be implemented in 5 years.

6. Conceptual Map/Schematic

Alluvial Groundwater Basins and Subbasins within the San Francisco Bay Hydrologic Region

Source: Department of Water Resources, CWP 2013

MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Storage - Upper Lagunitas Watershed (ES05)

1. Description

This supply option involves pumping groundwater from the Upper Lagunitas Watershed for use within MMWD boundaries. The pumped groundwater is assumed to be infiltration from reservoirs in the area and other local watersheds. A 2004 groundwater report on this option concluded that implementing this option could yield 1,300 AFY of pumped groundwater to be returned to the reservoir. This would result in a net supply benefit of less than 1,300 AFY, due to: 1) increased hydrostatic pressure resulting from returning groundwater to the reservoir causing increased seepage rates to groundwater; and 2) reduced downstream flows resulting from lowering of the groundwater table increasing reservoir release requirements to maintain downstream flows. The actual net supply yield from this project would be less than 1,300 AFY, and additional work would be required to precisely estimate net yield. For the purposes of this study, it is assumed that at equilibrium, between 0% and 25% of pumped groundwater would be able to be used as additional net supply. Groundwater pumped from the watershed would be returned to the reservoirs, and thus would not require treatment. Since the exact location of the wells has yet to be determined, an allowance for roughly one mile of piping was assumed in this cost estimate.

2. Facilities Required

Groundwater Wells

Pipeline to Reservoirs

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Project Element
Groundwater Wells	gpm	10	wells	80	$ 3,870,000
Power Drop					$ 2,000,000
Pipeline to Reservoirs	in	12	LF	5,000	$ 1,200,000

Raw Construction Cost	**$ 7,070,000**
Mobilization, Contractor's Profit, & Construction Contingency	$ 3,860,000
Base Construction Cost	***$ 10,930,000***
Implementation and Environmental Mitigation	$ 5,580,000
Probable Capital Cost	**$ 16,510,000**
Annualized Capital Cost (3% over 30 yrs)	$ 842,000
Annual O&M	$ 327,900
Total Annual Cost	**$ 1,170,000**
Yield (AFY)	300
Annual Cost per Acre-Foot	**$ 3,900**

4. Yield and Reliability

Source: Infiltration from Bon Tempe, Alpine, and Kent reservoirs

Average Year Yield (AFY): 300

Dry Year Yield (AFY): 300

Seasonality: Possible year round use, likely higher yields during wet months

Potential Reliability Concerns: Groundwater sources in the area have been considered unreliable, with water quality concerns and inconsistent yields

5. Implementation Considerations

Quality may be an issue as arsenic and nitrate have been detected above their respective MCLs in groundwater withdrawn from the Lagunitas Valley Groundwater Basin. Increased groundwater withdrawals could impact streamflows, which must be maintained for environmental purposes. Drawing groundwater from the area may also increase water drawn from the reservoirs into the groundwater. The installation of multiple wells on Mt. Tamalpais could increase the risk of landslides. Additional study would be required to confirm supply availability, and to site and size necessary wells. It is estimated that this option could be implemented in 5 years.

6. Conceptual Map/Schematic

Source: marinwatersheds.org

MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Storage - Petaluma Valley Conjunctive Use (ES06)

1. Description

Petaluma Valley has sufficient sedimentary deposits that groundwater has accumulated and provides a limited source of supply. From 2011-2015, the City of Petaluma averaged 330 AFY of groundwater pumping from the basin. This options assumes that MMWD would purchase an additional 330 AFY in normal/wet years (2 of 3 years) from SCWA and inject the water into the groundwater basin via an injection well to produce 600 AF (roughly 90% of 660 AFY). Assumed operations are injection of 660 AF over 2 years (normal/wet years) and extraction of 600 AF in the third year (dry year). In the third year, Petaluma would forgo 600 AFY of SCWA supply, which would be delivered to MMWD via existing infrastructure. Additional study would be required to confirm basin suitability for injection/extraction capacities and to size the project.

2. Facilities Required

Injection Well
Pipeline to Injection Well

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Injection Well	mgd	1	ea	1	$ 1,700,000
Pipeline to Injection Well	in	12	lf	6,000	$ 1,440,000
Cost of Water			AF	660	$ 333,000

Raw Construction Cost	$	3,140,000
Mobilization, Contractor's Profit, & Construction Contingency	$	1,720,000
Base Construction Cost	*$*	*4,860,000*
Implementation and Environmental Mitigation	$	2,916,000
Probable Capital Cost	**$**	**7,776,000**
Annualized Capital Cost (3% over 30 yrs)	$	397,000
Annual Program Administration (5%)	$	390,000
Annual Cost of Water (2 out of every 3 years)	$	222,000
Total Annual Cost	**$**	**1,009,000**
Yield (AFY)		200
Annual Cost per Acre-Foot	**$**	**5,000**

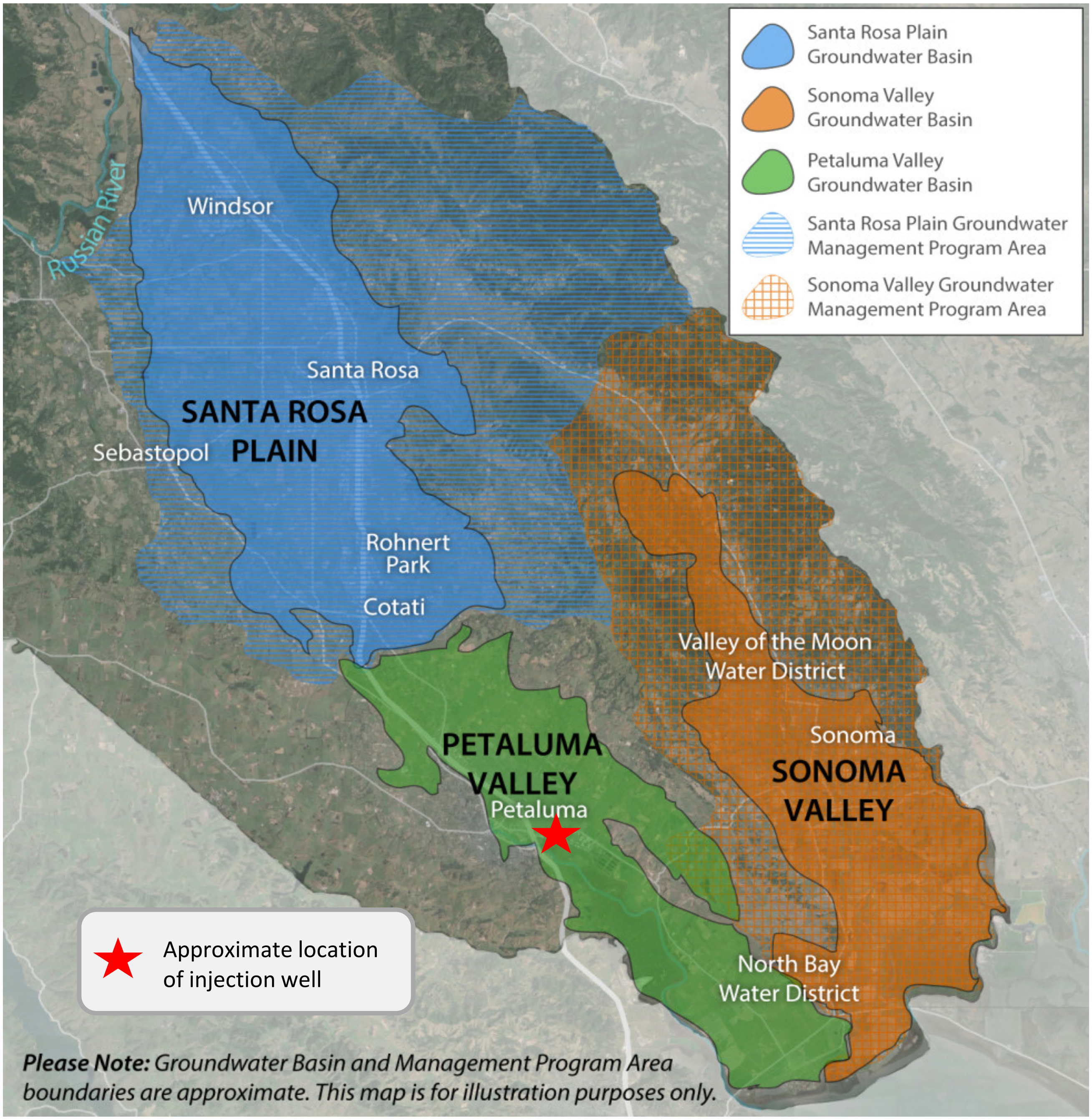
4. Yield and Reliability

Source:	Groundwater	
Average Year Yield (AFY):	0	Assumes take in dry years only (1/3)
Dry Year Yield (AFY):	600	Assumes take in dry years only (1/3)
Seasonality:	None	
Potential Reliability Concerns:	Limited recharge capacity and water quality concerns	

5. Implementation Considerations

Municipal pumping has created a landward gradient inducing sea water intrusion into the basin there may be a risk of renewed sea water intrusion if injection and production is not at equilibrium. Additional study would be required to confirm sizing and capacities of injection and production wells. Coordination with the City of Petaluma would be required to determine if additional wells/pumping capacity is needed for the City to pump additional groundwater. It is estimated that this option could be implemented in 3 years.

6. Conceptual Map/Schematic



Source: radio.krcb.org

Resiliency Option: Storage - Santa Rosa Plain Conjunctive Use (ES07)

1. Description

The DWR investigation of groundwater in the Santa Rosa Plain determined that there was about 3,900,000 AF of groundwater in storage. The basin covers an area of about 116,000 acres including the cities and communities of Rohnert Park, Sebastopol, Santa Rosa, and Windsor. This option would involve partnering with a city/agency that draws water from the Santa Rosa Plain Groundwater Basin and engage in an in-lieu transfer. Based on the below table, the Cities of Rohnert Park and Santa Rosa would be the most likely candidates for exchange.

	Wet Year	
Customer	Groundwater Pumped (AFY)	SCWA Supply (AFY)
City of Petaluma	194	9,421
City of Rohnert Park	766	3,840
City of Santa Rosa	792	20,808
City of Sonoma	80	2,111
Town of Windsor	50	404
Valley of the Moon Water District	327	2,589

For costing, it was assumed that MMWD would partner with Rohnert Park, where Rohnert Park would reduce pumping by 500 AFY in wet and normal years and take 500 AFY of MMWD SCWA supply (MMWD would pay SCWA to deliver its contracted amount of 5300 AFY + 500 AFY). In dry years (assumed to be one every 3 years), Rohnert Park would forgo 900 AF (90% recovery of 1,000 AF) of SCWA supply which would be delivered to MMWD with existing infrastructure.

2. Facilities Required

None; however additional capacity may be required depending on MMWD's allocation at the time the concept is implemented.

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Cost of Water			AF	1000	$500,000

Administrative Costs for Program Initiation	$	1,000,000
Probable Capital Cost	**$**	**1,000,000**
Annualized Capital Cost (3% over 30 yrs)	$	51,000
Annual Program Administration (5%)	$	50,000
Annual Cost of Water (2 out of every 3 years)	$	330,000
Total Annual Cost	**$**	**431,000**
Yield (AFY)		300
Annual Cost per Acre-Foot	**$**	**1,400**

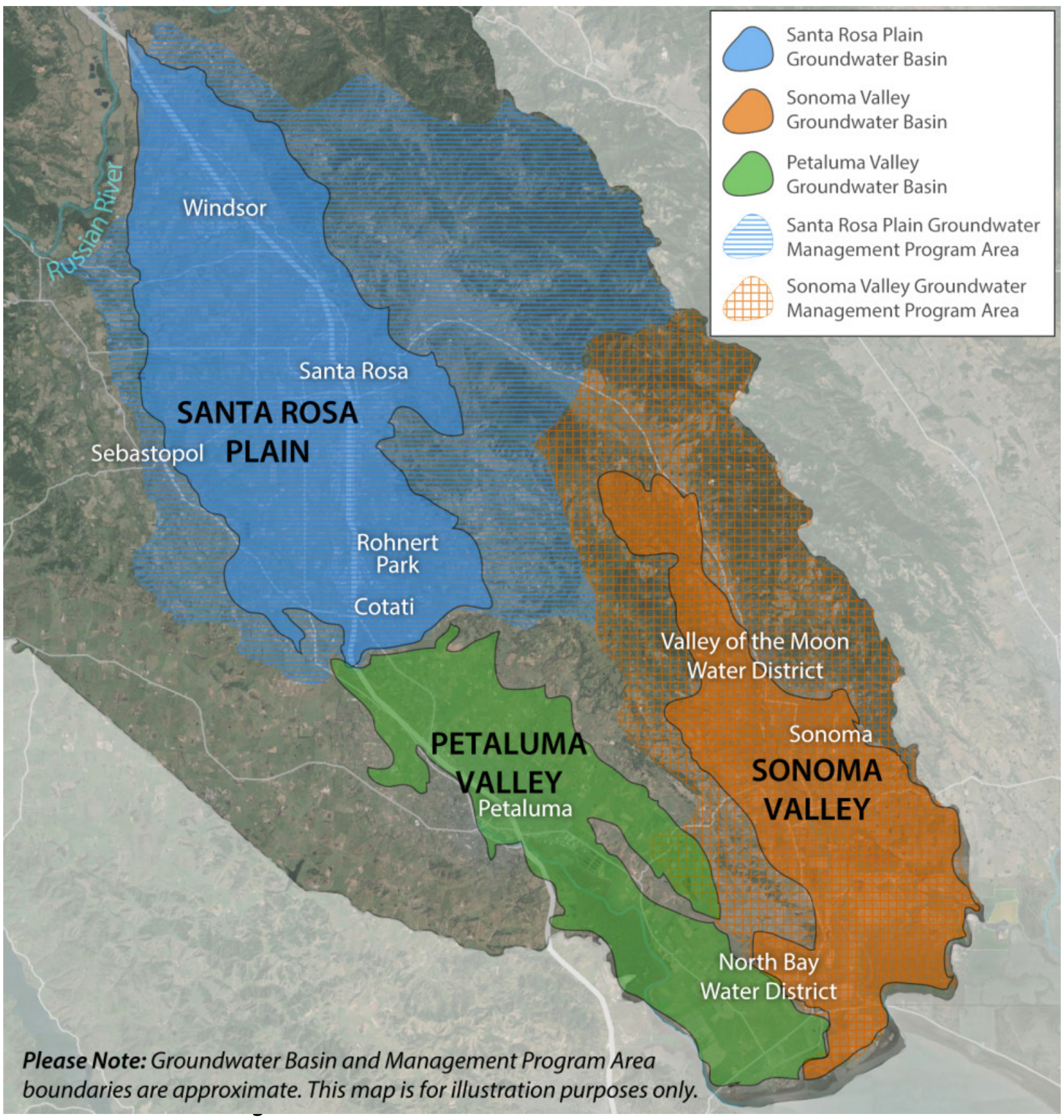
4. Yield and Reliability

Source: Sonoma County Water Agency
Average Year Yield (AFY): 0
Dry Year Yield (AFY): 900 (Assumes 90% recovery rate)
Seasonality: Annual
Potential Reliability Concerns: Minimal. Infrastructure would be susceptible to seismic activity.

5. Implementation Considerations

Implementing this option would change the timing of when MMWD receives SCWA water, not necessarily the amount. The district could either send some of the 5,300 AFY of water it must purchase from SCWA, or purchase water in addition to that to store in the basin. Coordination with the City of Rohnert Park would be required to determine if additional wells/pumping capacity is needed for the City to pump additional groundwater. It is estimated that this option could be implemented in 2 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Storage - Expand Los Vaqueros (ES08)

1. Description

Expanding Los Vaqueros is currently a project being considered in the Bay Area Regional Reliability (BARR) program. MMWD could purchase 5% storage within the new 100,000 AF reservoir expansion. Water would be stored during wet years and wheeled to MMWD during dry years. MMWD would purchase water from a north of Delta water supplier (for costing, the Yuba transfer (A2) option is assumed), which would be wheeled through EBMUD facility Freeport and stored in Los Vaqueros reservoir. In times when MMWD needs water, CCWD could wheel water through the EBMUD system to be delivered to MMWD's Ignacio plant via the Richmond-San Rafael Bridge pipeline (for costing, the A1 pipeline is assumed). Assumes 2,500 AFY is purchased in non-dry years (two of every three years), and 90% of the stored 5,000 AF is delivered to MMWD in dry years (one of every three years).

2. Facilities Required

Richmond-San Rafael Bridge pipeline
Los Vaqueros Dam Increase

3. Sizing and Costs (dam increase represents 5% of total LV increase project costs)

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Pipeline / Intertie			LS	1	$ 47,700,000
Increased Dam			AF	5,000	$ 10,000,000
Pipeline Maintenance			LF	30,000	$ 20,000
Cost of Water			AF	5,000	$ 1,750,000
Freeport Wheeling			AF	5,000	$ 4,250,000
Water Treatment			AF	4,500	$ 481,500

Raw Construction Cost	$ 57,700,000
Mobilization, Contractor's Profit, & Construction Contingency	$ 9,330,000
Base Construction Cost	*$ 67,030,000*
Implementation and Environmental Mitigation	$ 34,530,000
Probable Capital Cost	**$ 101,560,000**
Annualized Capital Cost (3% over 30 yrs)	$ 5,181,000
Annual Pipeline Maintenance Cost (all years)	$ 20,000
Annual Treatment Cost (1 of every 3 years)	$ 490,000
Annual Cost of Water (water + Freeport wheeling) (2 of every 3 years)	$ 4,000,000
Total Annual Cost	**$ 9,691,000**
Yield (AFY)	1,350
Cost per Acre-Foot	**$ 7,200**

4. Yield and Reliability

Source: North of Delta Water
Average Year Yield (AFY): 0
Dry Year Yield (AFY): 4,500

MARIN MUNICIPAL WATER DISTRICT

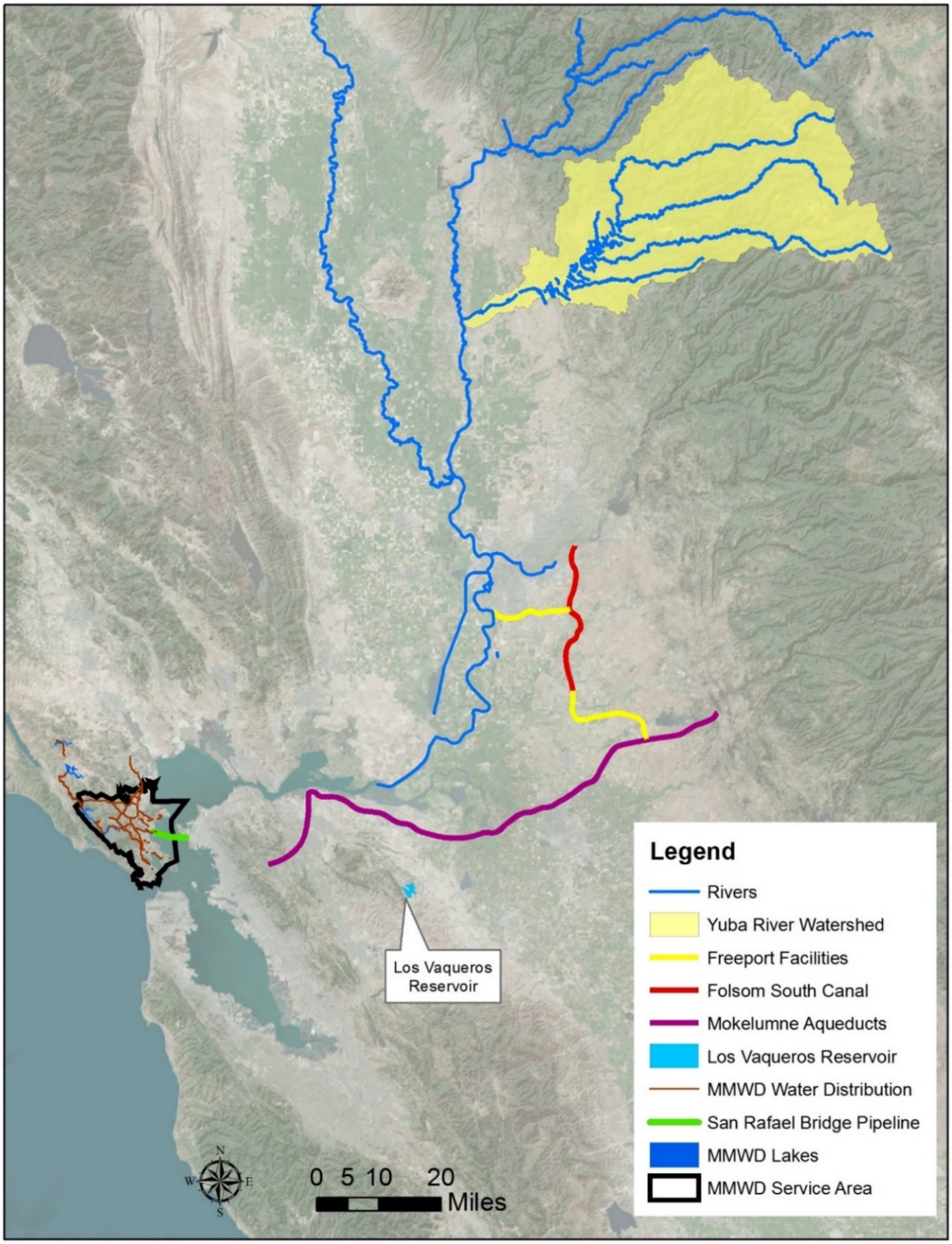
RMC water and environment

Seasonality: Dependent on surplus water from Delta
Potential Reliability Concerns: Subject to curtailment of rights in the Delta

5. Implementation Considerations

Increasing the dam height would likely face strong opposition from environmental groups. Regulatory approval would be similarly contentious, given the size of the project. It is estimated that this option could be implemented in 10 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Storage - Gravel Quarry Storage (ES09)

1. Description

This option involves capturing stormwater and storing it in the San Rafael Rock Quarry for use in the areas surrounding the Quarry. Stormwater would be captured in the vicinity of the Quarry, where feasible. The Quarry is currently owned and operated by the Dutra Group; the costs for this option include purchasing the quarry presumably for profit and include losses assumed for potential future net revenue. For estimating the quantity of stormwater runoff, the EPA provides a Stormwater Calculator program that outputs estimated volume of stormwater given a location and a number of specified parameters. Option does not include cost of treatment, which is likely due to unknown quality of stormwater runoff.

2. Facilities Required

Stormwater Gravity Main
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Force Main	in	36	LF	8,000	$ 5,760,000
Pump Station	hp	470			$ 2,362,000
Pipeline	lf	5,000	in	18	$ 1,800,000
Water Treatment			AF	1,900	$ 203,000

Raw Construction Cost	$ 9,920,000
Mobilization, Contractor's Profit, & Construction Contingency	$ 5,430,000
Base Construction Cost	*$ 15,350,000*
Quarry Purchase Estimate	$ 50,000,000
Implementation and Environmental Mitigation	$ 7,910,000
Probable Capital Cost	**$ 73,260,000**
Annualized Capital Cost (3% over 30 yrs)	$ 3,738,000
Annual Treatment Cost	$ 203,000
Total Annual Cost	**$ 4,144,300**
Yield (AFY)	1,900
Cost per Acre-Foot	**$ 2,200**

4. Yield and Reliability

Source: Stormwater
Average Year Yield (AFY): 1,900
Dry Year Yield (AFY): 1,900
Seasonality: Inflow in winter months; potential year-round use
Potential Reliability Concerns: Subject to reduced inflow during dry periods

5. Implementation Considerations

Availability of quarry for purchase, stormwater regulations, potential uses for captured stormwater, water quality and treatment unknowns. It is estimated that this option could be implemented in 8 years.

6. Conceptual Map/Schematic

Resiliency Option: Purchases/Interties - EBMUD Pipeline (WP01)

1. Description

This supply option includes constructing a pipeline across the San Rafael Bridge to allow MMWD to accept treated water routed through EBMUD's facilities. This option includes the cost of purchasing water from EBMUD and infrastructure, including a tie-in located near the Central Marin Sanitation Agency (CMSA) plant. For costing purposes, it was assumed that MMWD would purchase water from EBMUD through EBMUD's American River water right and that MMWD would only take water during dry years when there is capacity in the Freeport system (assumed 1 out of 3 years). Facilities have been sized to provide capacity for up to 15 mgd (16,800 AFY) of supply.

2. Facilities Required

Bridge Pipeline - 6 Miles
Intertie
Pump Station
Water Treatment

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Cost
Pipeline	in-diameter	27	LF	30,000	$ 26,500,000
Interties / Pump Station			LS	1	$ 21,200,000
Pipeline Maintenance			LF	30,000	$ 20,000
Cost of Water			AF	5,000	$ 500,000
Freeport Wheeling			AF	5,000	$ 4,250,000
Water Treatment			AF	5,000	$ 535,000

Probable Capital Cost	**$**	**47,700,000**
Annualized Capital Cost (3% over 30 yrs)	$	2,434,000
Annual Pipeline Maintenance Cost (all years)	$	20,000
Annual Treatment Cost (1 year every 3 years)	$	180,000
Annual Cost of Water (Water + Freeport Wheeling) (1/3)	$	1,590,000
Total Annual Cost	**$**	**4,224,000**
Yield (AFY)		1,700
Annual Cost per Acre-Foot	**$**	**2,500**

4. Yield and Reliability

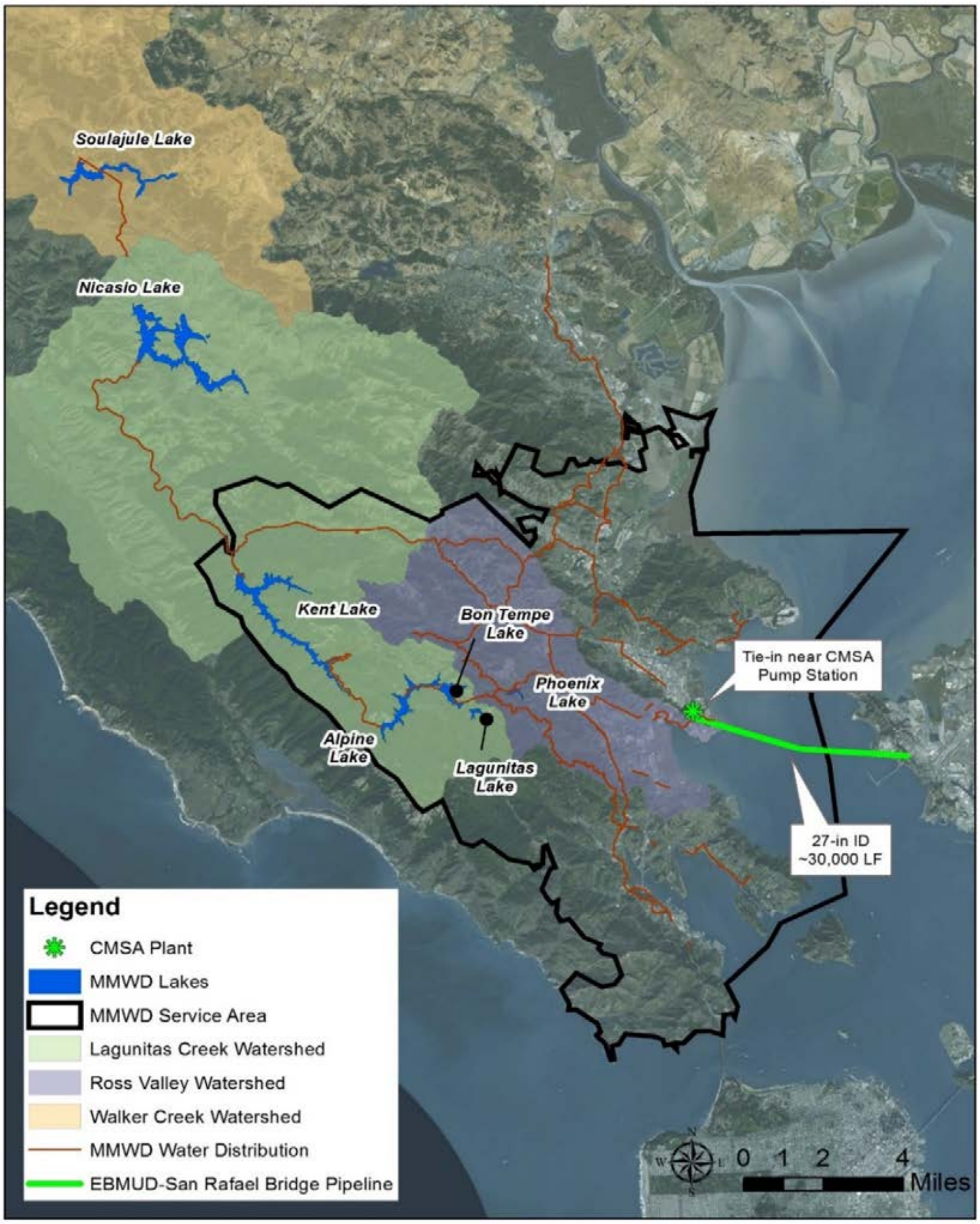
Source:	American River water	
Average Year Yield (AFY):	0	Assumes take in dry years only (0.75/3)
Dry Year Yield (AFY):	0 to 5,000	Assumes take in dry years only (0.75/3)
Seasonality:	Base loaded	

Potential Reliability Concerns: System reliability concerns under seismic events. Reliability during dry periods is a concern.

5. Implementation Considerations

This project requires the implementation of a supply transfer through the EBMUD system. Water would be delivered treated, but may need additional polishing at the Ignacio water treatment facility. The pipeline likely has significant permitting requirements and environmental documentation, as well as technical complexities associated with construction. A number of regulatory approval processes will likely apply to the water transfer, depending on source and the structure of the final agreement. It is estimated that this option could be implemented in 8 years.

6. Conceptual Map/Schematic



Resiliency Option: Purchases/Interties - Yuba County Transfer (WP02)

1. Description

Yuba County Water Agency has been active on the transfer market since the 1980's. This supply option involves initiating a long-term transfer with Yuba County Water Agency. For costing, it was assumed that the water would be wheeled through EBMUD's Freeport system and delivered to MMWD's service area through the Richmond-San Rafael Bridge Pipeline (see option A1). Freeport wheeling costs include administrative, treatment, and operation costs; it is also assumed that this transfer water would be mixed with EBMUD's Mokelumne River supply.

2. Facilities Required

Bridge Pipeline - 6 Miles
Intertie
Pump Station
Water Treatment

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Cost
Bridge Pipeline	in-diameter	27	LF	30,000	$ 26,500,000
Interties / Pump Station			LS	1	$ 21,200,000
Pipeline Maintenance			LF	30,000	$ 20,000
Cost of Water			AF	5,000	$ 1,750,000
Freeport Wheeling			AF	5,000	$ 4,250,000
Water Treatment			AF	5,000	$ 535,000

Probable Capital Cost	**$**	**47,700,000**
Annualized Capital Cost (3% over 30 yrs)	$	2,434,000
Annual Pipeline Maintenance Cost (all years)	$	20,000
Annual Treatment Cost (1.5 years every 3 years)	$	270,000
Annual Cost of Water (Water + Freeport Wheeling) (1.5/3)	$	3,000,000
Total Annual Cost	**$**	**5,724,000**
Yield (AFY)		2,500
Annual Cost per Acre-Foot	**$**	**2,300**

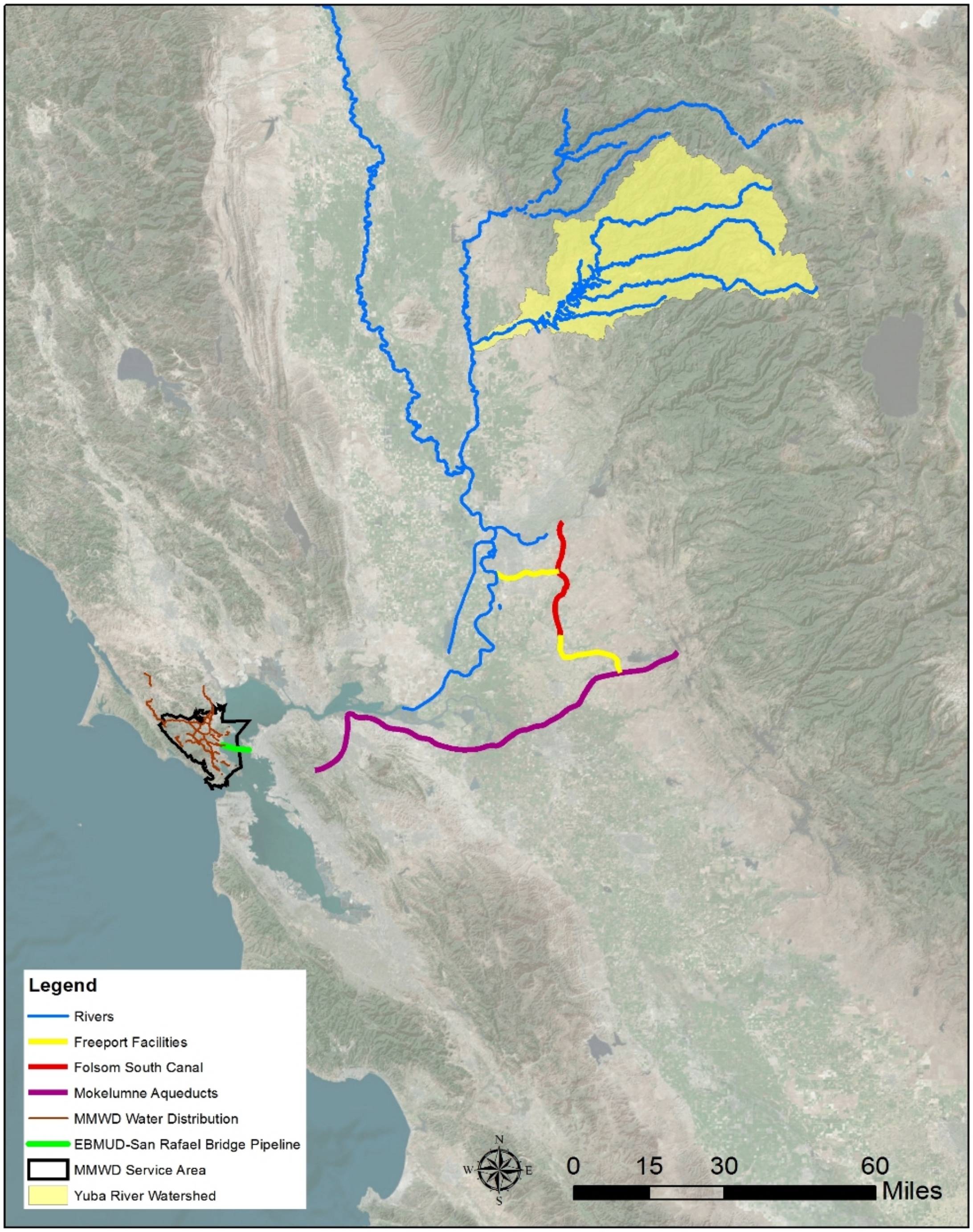
4. Yield and Reliability

Source:	Yuba County	
Average Year Yield (AFY):	5,000	Assumes take in average years only (1.5/3)
Dry Year Yield (AFY):	0	Assumes take in average years only (1.5/3)
Seasonality:	Base loaded	
Potential Reliability Concerns:	If a long-term contract is not initiated, opportunities may be limited in dry periods. Seismic activity.	

5. Implementation Considerations

This project requires initiating a long-term purchase of water from the Yuba County Water Agency, which would be transferred through the EBMUD system. Water would be delivered treated, but may need additional polishing at the Ignacio water treatment facility. The pipeline likely has significant permitting requirements and environmental documentation, as well as technical complexities associated with construction. A number of regulatory approval processes will likely apply to the water transfer, depending on source and the structure of the final agreement. It is estimated that this option could be implemented in 8 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Purchases/Interties - Humboldt County Transfer (WP03)

1. Description

This supply option involves securing a water transfer from Humboldt Bay Municipal Water District. The water would be delivered via a new 160 mile pipeline from Eureka to the City of Ukiah. This project would be implemented as a regional effort through partnerships with other agencies. Assuming Marin receives 10% of the total water transferred, sizing and costs reflect 10% of the total project.

2. Facilities Required

Pipeline from Eureka to Ukiah - 160 Miles
Pump Station

3. Sizing and Costs (represents 10% of total project)

Project Element	Units	Size/Number	Units	Quantity	Cost
Pipeline	in-diameter	48	LF	844,800	$ 81,100,800
Pump Station	hp	46,000	EA	1	$ 4,314,500
Cost of Water			AF	5,000	$ 1,750,000
Water Treatment			AF	5,000	$ 535,000

Costs reflect Marin's 10% of total project costs

Raw Construction Cost	$ 85,420,000	*10% of Whole Project*
Mobilization, Contractor's Profit, & Construction Contingency	$ 46,730,000	*10% of Whole Project*
Base Construction Cost	*$ 132,150,000*	
Implementation and Environmental Mitigation	$ 67,401,500	
Initial Administration Cost	$ 375,000	
Probable Capital Cost	**$ 199,926,500**	
Annualized Capital/Initial Admin Cost (3% over 30 yrs)	$ 10,200,000	
Annual O&M (treatment, power, pipeline maintenance)	$ 3,910,000	
Annual Cost of Water	$ 175,000	
Total Annual Cost	**$ 14,285,000**	
Yield (AFY)	500	
Annual Cost per Acre-Foot	**$ 28,600**	

4. Yield and Reliability

Source: Humboldt County
Average Year Yield (AFY): 500
Dry Year Yield (AFY): 0 to 500
Seasonality: Base loaded
Potential Reliability Concerns: A project of this scale should only be implemented under a long term transfer contract. Drought reliability will be a concern. Seismic activity.

5. Implementation Considerations

In addition to the infrastructure required for this project, there are also costs associated with developing relationships, transfer arrangements, and agreements for wheeling. There will be costs and significant challenges associated with permitting and environmental requirements associated this large scale infrastructure project and the water transfers it requires. It is estimated that this option could be implemented in 15 years.

6. Conceptual Map/Schematic

Resiliency Option: Purchases/Interties - Spot Market Transfer (WP04)

1. Description

This supply option includes initiating a spot market transfer from a North-of-Delta water agency and wheeling the water through EBMUD's Freeport facilities. The water would then be delivered to MMWD's system after being treated to meet MMWD water quality standards. For costing purposes, it was assumed that MMWD would utilize the spot market transfer in dry or critically dry years only (1 out of every 3 years).

2. Facilities Required

Bridge Pipeline - 6 Miles
Intertie
Pump Station
Water Treatment

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Cost
Pipeline	in-diameter	27	LF	30,000	$ 26,500,000
Interties / Pump Station			LS	1	$ 21,200,000
Pipeline Maintenance			LF	30,000	$ 20,000
Cost of Water			AF	5,000	$ 5,000,000
Freeport Wheeling			AF	5,000	$ 4,250,000
Water Treatment			AF	5,000	$ 535,000

Base Construction Cost	*$*	*47,700,000*
Implementation and Environmental Mitigation	$	480,000
Probable Capital Cost	**$**	**48,200,000**
Annualized Capital Cost (3% over 30 yrs)	*$*	*2,459,000*
Annual Pipeline Maintenance Cost (all years)	*$*	*20,000*
Annual Treatment Cost (1 of every 3 years)	*$*	*180,000*
Annual Cost of Water (water + Freeport wheeling) (1 of every 3 years)	*$*	*3,080,000*
Total Annual Cost	**$**	**5,739,000**
Yield (AFY)		1,700
Annual Cost per Acre-Foot	**$**	**3,400**

4. Yield and Reliability

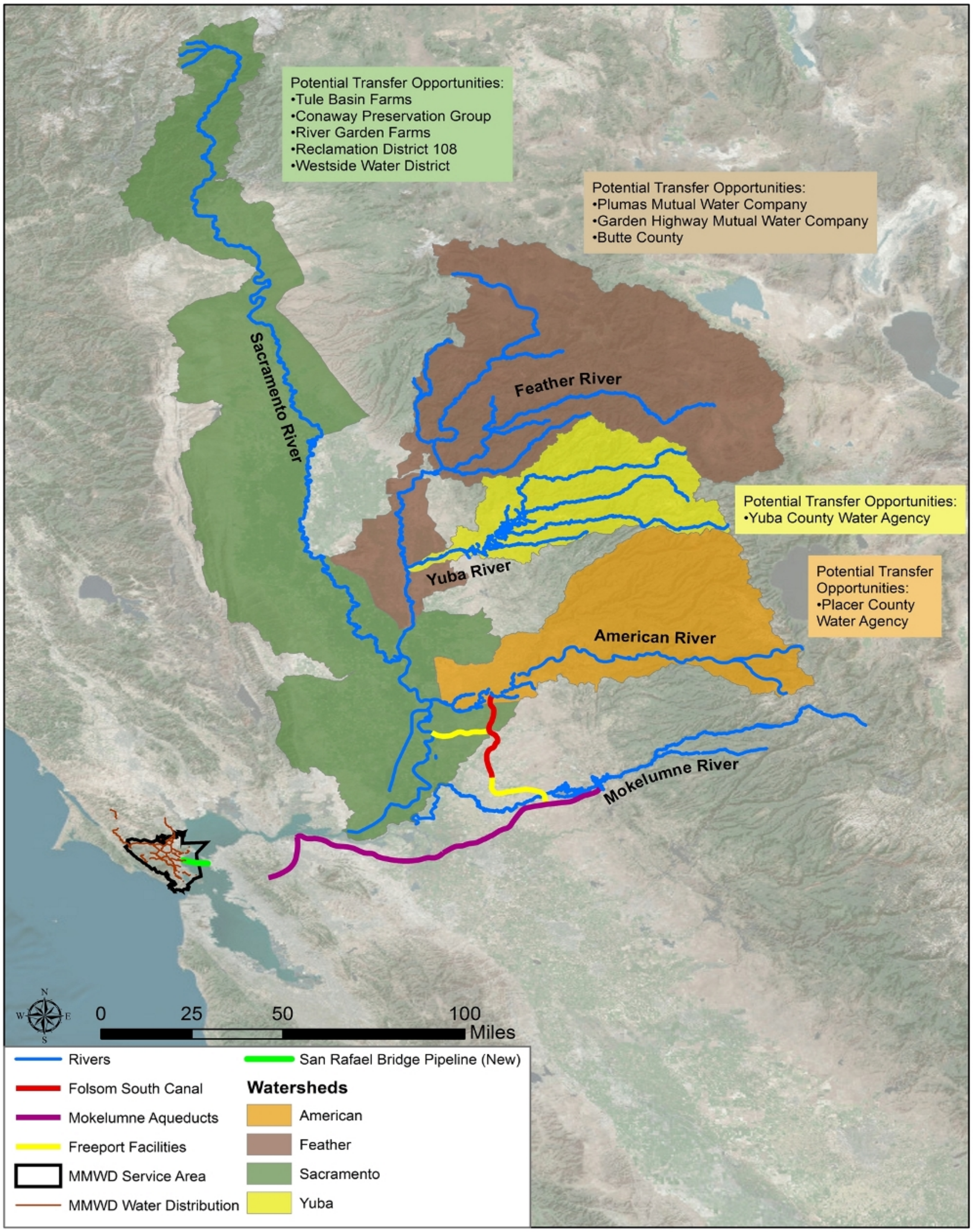
Source:	North of Delta	
Average Year Yield (AFY):	0	
Dry Year Yield (AFY):	5,000	Yield depends on transfer contract
Seasonality:	Base loaded	
Potential Reliability Concerns:	Water available on the spot market may be limited during dry and critically dry periods when demands are high and market	

supply is low. Seismic activity.

5. Implementation Considerations

A number of regulatory approval processes will likely apply to the water transfer, depending on source and the structure of the final agreement. The San Rafael Bridge pipeline likely has significant permitting requirements and environmental documentation, as well as technical complexities associated with construction. It is estimated that this option could be implemented in 8 years.

6. Conceptual Map/Schematic



Resiliency Option: Purchases/Interties- North Bay Aqueduct (WP05)

1. Description

This supply option involves constructing a pipeline connecting the North Bay Aqueduct and MMWD systems at the Ignacio pump station. The option includes purchasing surplus capacity from Solano or Napa Counties and may require increased capacity within the Aqueduct. The cost for increased Aqueduct capacity is not included.

2. Facilities Required

Pump station
Pipeline
Tie in facilities to connect to MMWD system

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Pump Station	Ea	1	HP	1,100	$ 3,722,000
Pipeline	In-Diameter	42	LF	143,000	$ 54,114,000
Cost of Water			AF	5,000	$ 6,000,000

Raw Construction Cost	$	57,840,000
Mobilization, Contractor's Profit, & Construction Contingency	$	31,640,000
Base Construction Cost	*$*	*89,480,000*
Implementation and Environmental Mitigation	$	44,740,000
Environmental Mitigation Measures Costs	$	13,430,000
Probable Capital Cost	**$**	**147,700,000**
Annualized Capital Cost (3% over 30 yrs)	$	7,536,000
Annual O&M (treatment, power, pipeline maintenance)	$	1,340,000
Annual Cost of Water	$	6,000,000
Total Annual Cost	**$**	**14,876,000**
Yield (AFY)		5,000
Annual Cost per Acre-Foot	**$**	**3,000**

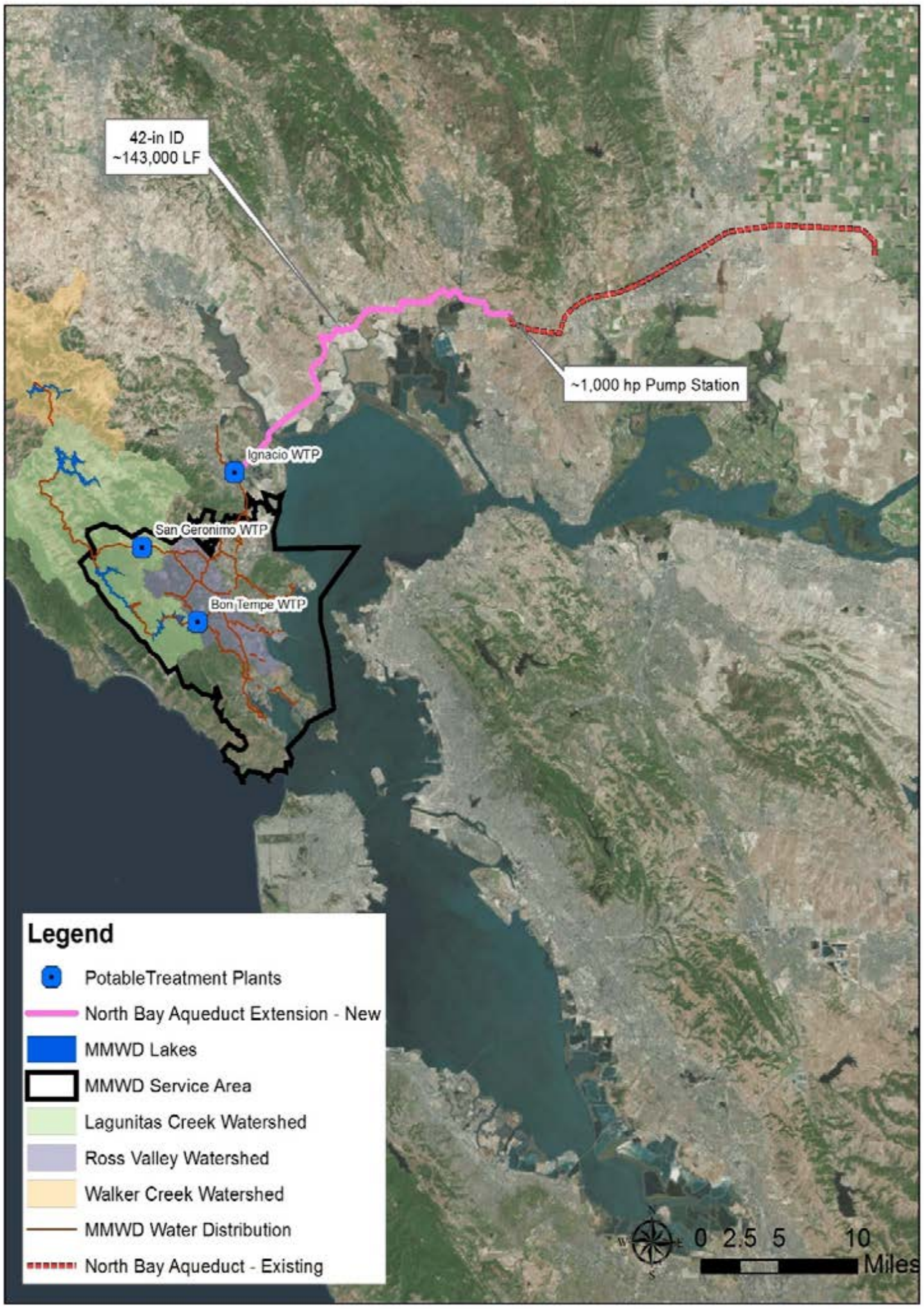
4. Yield and Reliability

Source: Solano or Napa County supply
Average Year Yield (AFY): 5,000
Dry Year Yield (AFY): 0 to 5,000
Seasonality: Supply will be seasonal with deliveries higher in the winter months and lower in the summer months due to available aqueduct capacity.
Potential Reliability Concerns: Drought can limit availability of water from the Delta. Seismic events could disrupt the North Bay Aqueduct.

5. Implementation Considerations

Implementation will require coordination with Solano County Water Agency, City of Napa, City of Vallejo, and/or Delta agencies. A significant number of permits and substantial environmental documentation will be required. Technical challenges for implementation include pipeline alignment concerns, numerous trenchless crossings within wetland areas, and pipeline routes on congested thoroughfares. It is estimated that this option could be implemented in 8 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Desal - Richmond-San Rafael Bridge Desalination (DS01)

1. Description

This option involves constructing a San Francisco Bay desalination facility on the west side of the Richmond-San Rafael Bridge. It would initially be sized at 5 mgd with possible expansion up to 15 mgd. With an initial sizing of 5 mgd, the plant would intake 10 mgd of Bay water and include a 50 horsepower pump station and 1,000 linear feet of conveyance pipeline to deliver water to the distribution system through a connection near CMSA. For the purposes of determining yield, it was assumed that the plant would be operational 75% of the time (25% downtime).

2. Facilities Required

Desalination Plant and Brine Disposal
Conveyance Pipeline
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Desalination Plant	mgd input	10	mgd output	5	$ 61,040,000
Conveyance Pipeline	diameter - in	24	lf	1,000	$ 432,000
Pump Station	hp	350	capacity (gpm)	3,500	$ 1,901,000

Raw Construction Cost	$	63,370,000
Mobilization, Contractor's Profit, & Construction Contingency	$	30,890,000
Contractors Overhead and Profit	$	11,410,000
Construction Contingency	$	18,850,000
Base Construction Cost	*$*	*113,280,000*
Implementation and Environmental Mitigation	$	58,340,000
Probable Capital Cost	**$**	**171,600,000**
Annualized Capital Cost (3% over 30 yrs)	$	8,755,000
Annual O&M	$	2,350,000
Total Annual Cost	**$**	**11,110,000**
Yield (AFY)		4,200
Annual Cost per Acre-Foot	**$**	**2,600**

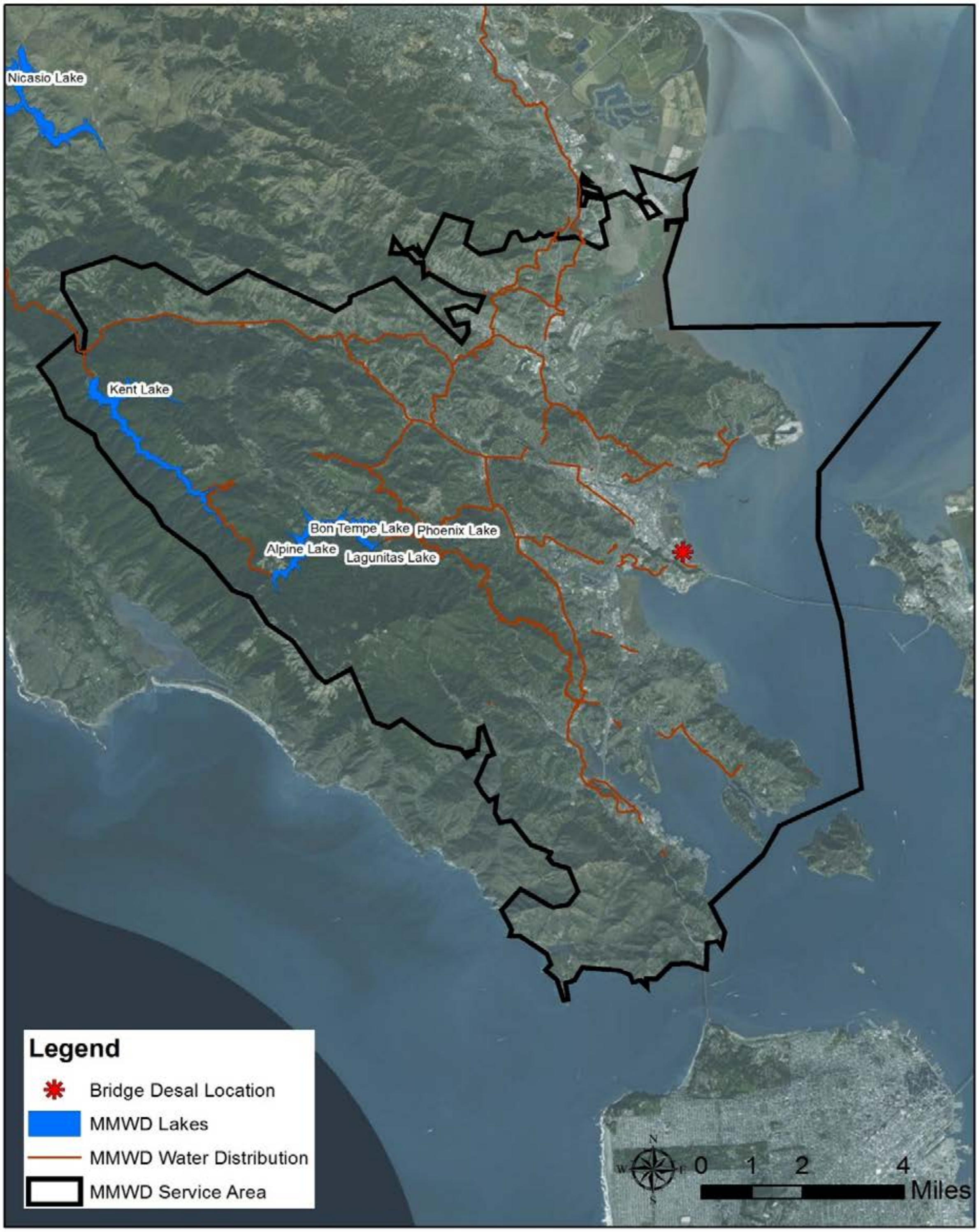
4. Yield and Reliability

Source:	San Francisco Bay
Average Year Yield (AFY):	4,200
Dry Year Yield (AFY):	4,200
Seasonality:	Annual
Potential Reliability Concerns:	Environmental restrictions on withdrawing water from and releasing brine into the Bay. Seismic activity.

5. Implementation Considerations

There could be significant opposition by the public and environmental groups, as well as significant regulatory hurdles involving construction, permitting, environmental documentation, and brine management. All desalination options in Marin County will be subject to a vote. It is estimated that this option could be implemented in 10 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Desal - Richardson Bay Desalination (DS02)

1. Description

This option involves constructing a 5 mgd desalination facility at Richardson Bay that would serve potable water to the City of Mill Valley. With an initial sizing of 5 mgd, the plant would intake 10 mgd of Bay water and would include a 100 horsepower pump station and 500 linear feet of conveyance pipeline to deliver water to the MMWD distribution system. For the purposes of determining yield, it was assumed that the plant would be operational 75% of the time (25% downtime).

2. Facilities Required

Desalination Plant and Brine Disposal
Conveyance Pipeline
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Desalination Plant	mgd intake	10	mgd output	5	$ 61,040,000
Conveyance Pipeline	diameter - in	12	lf	500	$ 108,000
Pump Station	hp	400	capacity (gpm)	2,800	$ 2,071,000

Raw Construction Cost	$	63,220,000
Mobilization, Contractor's Profit, & Construction Contingency	$	53,390,000
Contractors Overhead and Profit	$	11,380,000
Construction Contingency	$	41,380,000
Base Construction Cost	*$*	*116,610,000*
Implementation and Environmental Mitigation	$	60,060,000
Probable Capital Cost	**$**	**176,700,000**
Annualized Capital Cost (3% over 30 yrs)	$	9,015,000
Annual O&M	$	3,425,700
Total Annual Cost	**$**	**12,440,700**
Yield (AFY)		4,200
Annual Cost per Acre-Foot	**$**	**3,000**

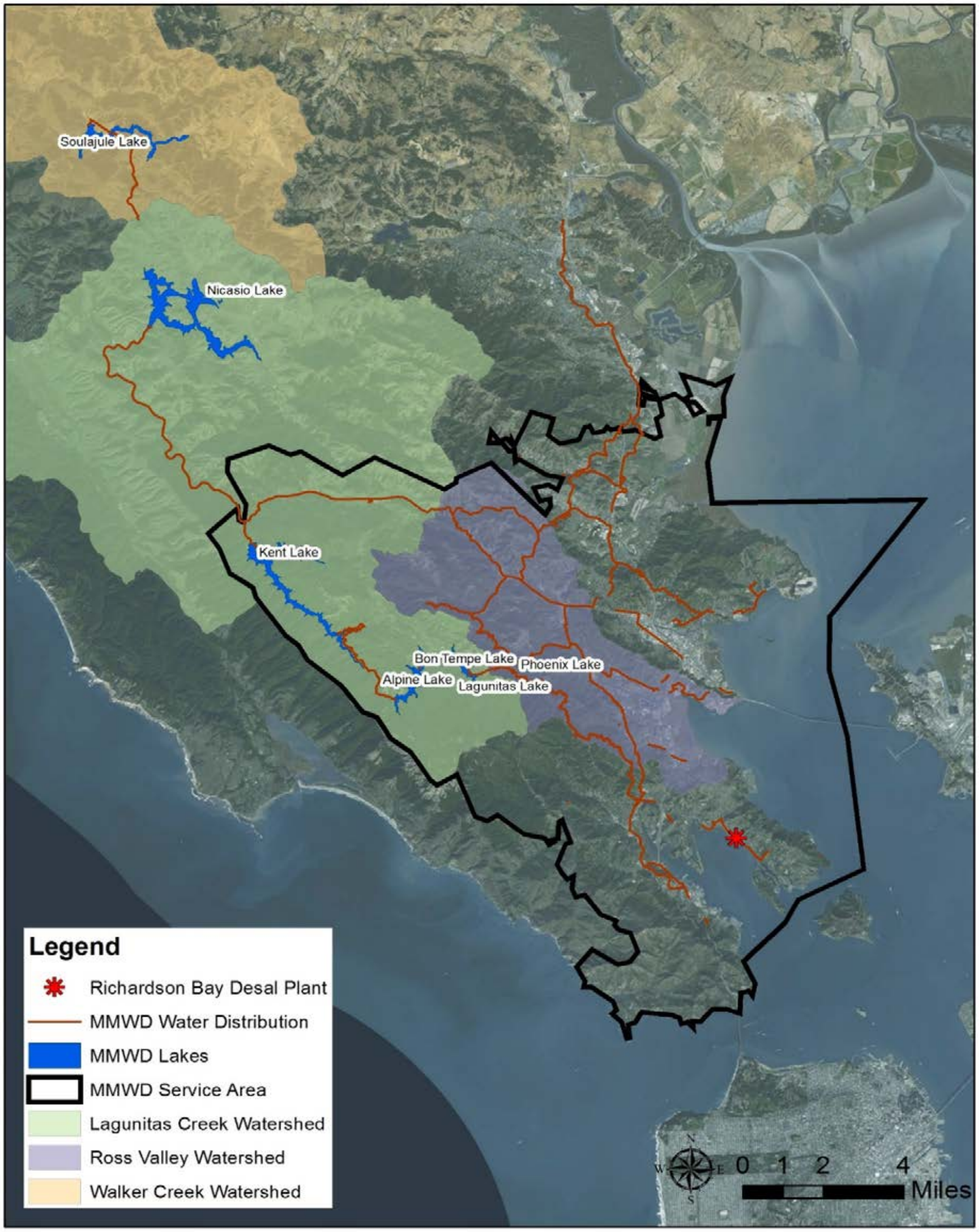
4. Yield and Reliability

Source:	Richardson Bay
Average Year Yield (AFY):	4,200
Dry Year Yield (AFY):	4,200
Seasonality:	Annual
Potential Reliability Concerns:	Environmental restrictions on withdrawing water from and releasing brine into the Bay. Seismic activity.

5. Implementation Considerations

There could be significant opposition by the public and environmental groups, as well as significant regulatory hurdles involving construction, permitting, environmental documentation, and brine management and disposal. All desalination options in Marin County are subject to a vote. It is estimated that this option could be implemented in 10 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Desal - Ocean Desalination (DS03)

1. Description

This option involves constructing a 5 MGD ocean desalination facility in the Muir Beach area. The facility would take in 10 MGD of ocean water and include a 700 horsepower pump station and 35,000 linear feet of conveyance pipeline to deliver water to MMWD's distribution system. For the purposes of determining yield, it was assumed that the plant would be operational 75% of the time (25% downtime).

2. Facilities Required

Desalination Plant and Brine Disposal
Conveyance Pipeline
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Desalination Plant	mgd	10	mgd output	5	$ 61,040,000
Conveyance Pipeline	diameter - in	18	lf	35,000	$ 11,340,000
Pump Station	hp	1,250	capacity (gpm)	3500	$ 3,558,000

Raw Construction Cost	$	75,940,000
Mobilization, Contractor's Profit, & Construction Contingency	$	64,130,000
Base Construction Cost	*$*	*140,070,000*
Implementation and Environmental Mitigation	$	72,140,000
Probable Capital Cost	**$**	**212,200,000**
Annualized Capital Cost (3% over 30 yrs)	$	10,826,000
Annual O&M	$	4,050,000
Total Annual Cost	**$**	**14,880,000**
Yield (AFY)		4,200
Annual Cost per Acre-Foot	**$**	**3,500**

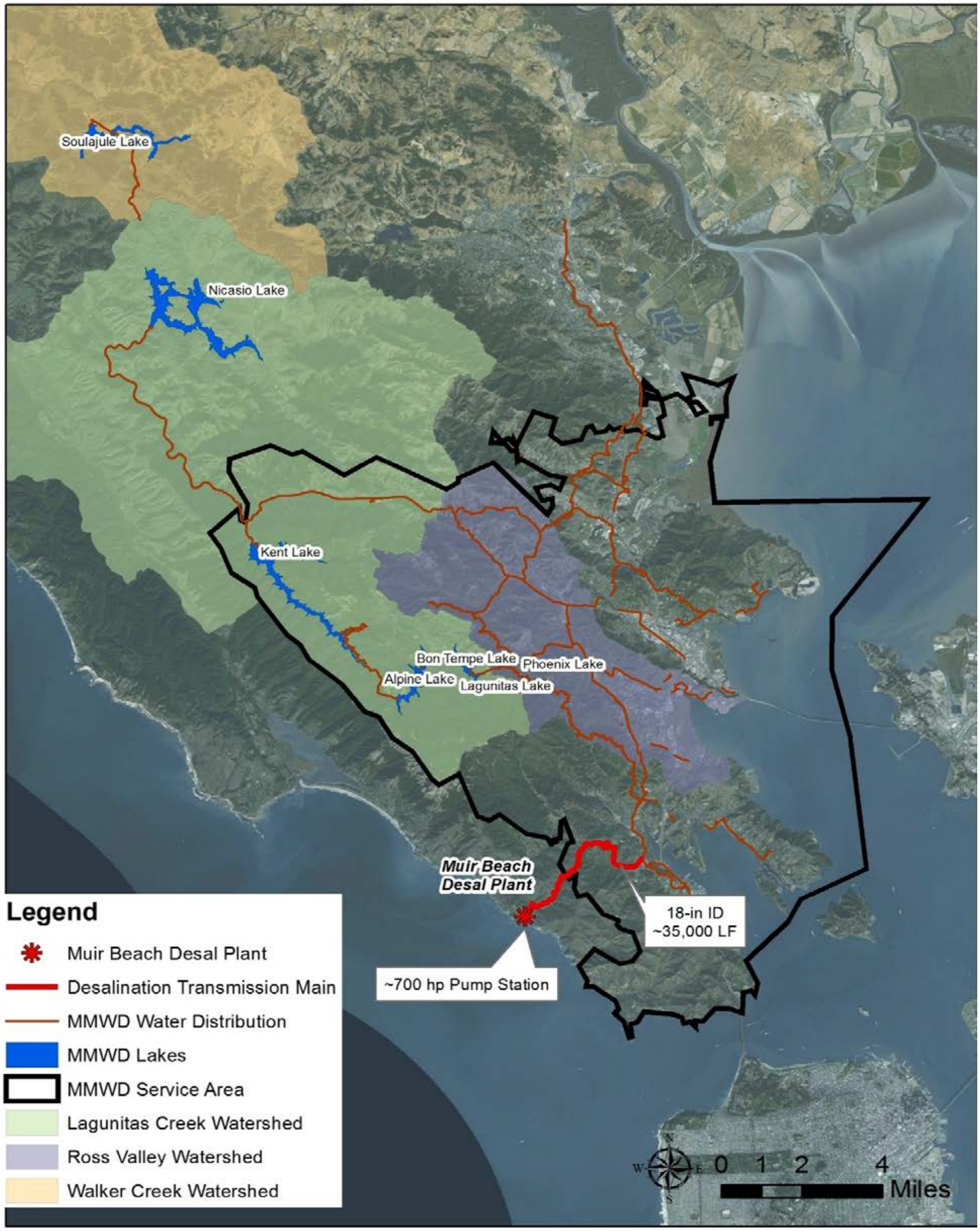
4. Yield and Reliability

Source: Pacific Ocean
Average Year Yield (AFY): 4,200
Dry Year Yield (AFY): 4,200
Seasonality: Annual
Potential Reliability Concerns: Environmental restrictions on releasing brine into the Ocean. Seismic activity.

5. Implementation Considerations

There could be significant opposition by the public and environmental groups, as well as significant regulatory hurdles involving construction, permitting, environmental documentation, and brine management and disposal. All desalination options in Marin County are subject to a vote. It is estimated that this option could be implemented in 10 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Desal - Regional Desalination (DS04)

1. Description

A 70 mgd Regional Desalination plant (56 mgd of product water), located in the East San Francisco Bay area, is currently being considered in the Bay Area Regional Reliability (BARR) program. MMWD would purchase approximately 5 MGD of the capacity and receive 4.5 MGD of the product water. For costing purposes, it was assumed that the Richmond-San Rafael Bridge pipeline (A1) is needed to deliver the water to MMWD.

2. Facilities Required

Richmond-San Rafael Bridge Pipeline
Regional Desalination Plant

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Pipeline / Intertie			LS	1	$ 47,700,000
Desalination Plant	mgd	5	mgd output	4.5	$ 61,040,000
Pipeline Maintenance			LF	30,000	$ 20,000

Raw Construction Cost	$ 108,740,000
Mobilization, Contractor's Profit, & Construction Contingency	$ 59,480,000
Base Construction Cost	*$ 168,220,000*
Implementation and Environmental Mitigation	$ 86,630,000
Probable Capital Cost	**$ 254,850,000**
Annualized Capital Cost (3% over 30 yrs)	$ 13,002,000
Annual pipeline maintenance	$ 20,000
Annual O&M (treatment, staffing, and pumping)	$ 4,980,000
Total Annual Cost	**$ 18,002,000**
Yield	4,000
Cost per Acre-Foot	**$ 4,500**

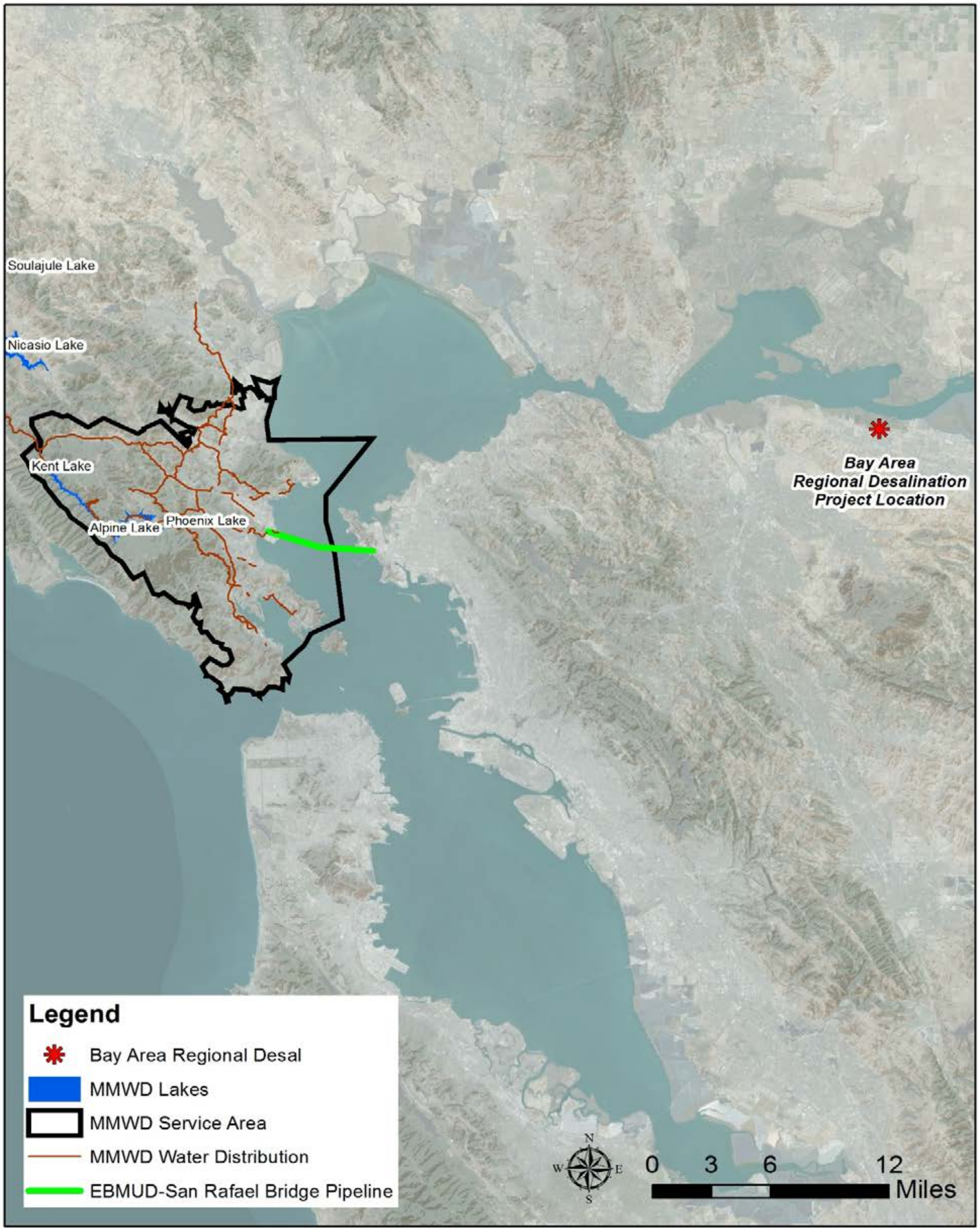
4. Yield and Reliability

Source: Bay Delta
Average Year Yield (AFY): 4,480
Dry Year Yield (AFY): 4,480
Seasonality: Annual
Potential Reliability Concerns: Environmental restrictions on withdrawing water from and releasing brine into the Bay. Seismic activity.

5. Implementation Considerations

There would likely be significant opposition by the public and environmental groups. There would also likely be significant regulatory hurdles involving construction, permitting, environmental documentation, and brine management and disposal. It is estimated that this option could be implemented in 15 years.

6. Conceptual Map/Schematic



MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Desal - Skid Mount/Packaged System (DS05)

1. Description

Packaged Desal systems are typically faster to deploy than those designed and built to a specification. They can have lower effective costs for small systems, but often are more expensive and take up a larger footprint for larger systems. The system would be developed in a manner consistent with the desalination plant E1 located along the San Rafael Bridge and requiring similar infrastructure to connect to MMWD's system, though it would be smaller, 1 MGD.

2. Facilities Required

Desalination Plant and Brine Disposal
Conveyance Pipeline
Pump Station

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Desalination Plant	mgd	2.2	mgd output	1.1	$ 23,105,750
Conveyance Pipeline	diameter - in	10	lf	1,000	$ 180,000
Pump Station	hp	100	capacity (gpm)	800	$ 853,000

Raw Construction Cost	$	24,140,000
Mobilization, Contractor's Profit, & Construction Contingency	$	11,770,000
Base Construction Cost	*$*	*43,150,000*
Implementation and Environmental Mitigation	$	23,280,000
Probable Capital Cost	**$**	**66,430,000**
Annualized Capital Cost (3% over 30 yrs)	$	3,389,000
Annual O&M	$	546,771
Total Annual Cost	**$**	**3,935,771**
Yield (AFY)		1,120
Annual Cost per Acre-Foot	**$**	**3,510**

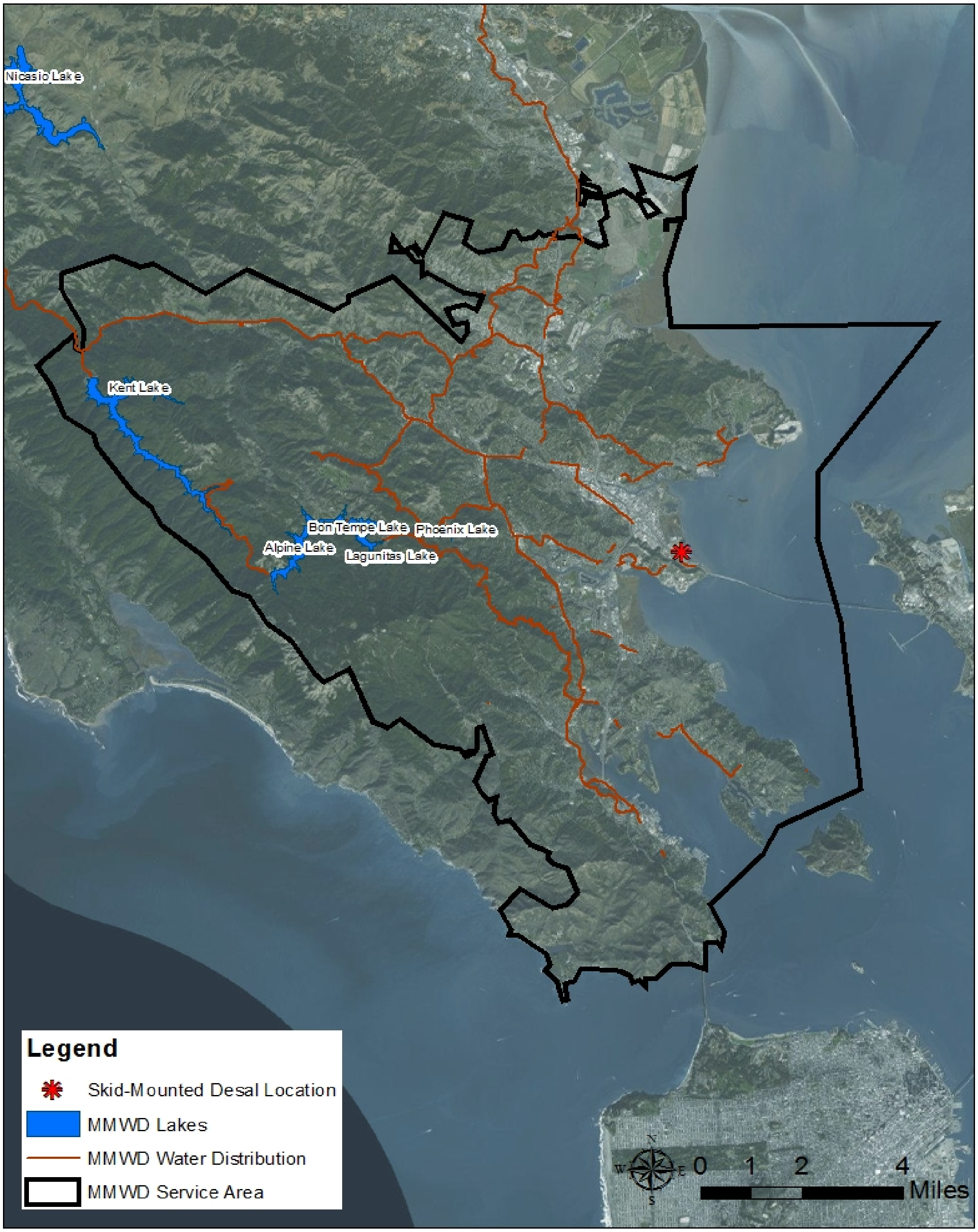
4. Yield and Reliability

Source: San Francisco Bay
Average Year Yield (AFY): 1,120
Dry Year Yield (AFY): 1,120
Seasonality: Annual
Potential Reliability Concerns: Environmental restrictions on withdrawing water from and releasing brine into the Bay. Seismic activity.

5. Implementation Considerations

There could be significant opposition by the public and environmental groups, as well as significant regulatory hurdles involving construction, permitting, environmental documentation, and brine management. All desalination options in Marin County will be subject to a vote. It is estimated that this option could be implemented in 5 years.

6. Conceptual Map/Schematic



Resiliency Option: Emerging Option - Fog Capture (EO01)

1. Description

This supply option would capture and collect moisture within fog. Mesh nets would be installed in areas with high wind and fog, typically on the top of ridges. As the wind blows fog through the nets, water droplets accumulate on the mesh and drop into a catchment container for collection. For the purposes of costing, it was assumed that up to 10 AFY could be captured for use.

2. Facilities Required

Fog collectors (65,360 square feet of mesh)

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Fog Collector	430	square feet		152	$2,534,000

Costs from FogQuest: Sustainable Water Solutions (fogquest.org)

Raw Construction Cost	$	2,530,000
Mobilization (1%), Contractor's Profit (10%), & Construction Contingency (15%)	$	700,000
Base Construction Cost	*$*	*3,230,000*
Implementation and Environmental Mitigation	$	1,670,000
Probable Capital Cost	**$**	**4,900,000**
Annualized Capital Cost (3% over 30 yrs)	$	250,000
Annual O&M	$	-
Total Annual Cost	**$**	**250,000**
Yield (AFY)		10
Annual Cost per Acre-Foot	**$**	**25,000**

4. Yield and Reliability

Source:	Fog
Average Year Yield (AFY):	10
Dry Year Yield (AFY):	10
Seasonality:	Most yield likely in fog-heavy months; potable use potentially all-year round; non-potable landscape use in summer months.
Potential Reliability Concerns:	Earthquakes could cause the fog collectors to fail, requiring reinstallation; furthermore, yield in drier years would be reduced.

5. Implementation Considerations

Large scale implementation of fog collecting is limited by available land and appropriate geography for installation. Because fog collectors produce the highest yield when installed in areas with high wind and fog, likely installation would be along the ridges on Mt. Tamalpais. Access to these areas may be limited; as a result, there would likely be environmental concerns associated with installation and maintenance. Furthermore, transportation of the collected water, either through trucking or pipelines, would pose logistical challenges. It is estimated that this option could be implemented in 2 years.

6. Conceptual Map/Schematic

Source: bbc.com

Source: ourworld.unu.edu

MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Emerging Option - Cloudseeding (EO02)

1. Description

This supply option includes spreading silver iodide (or another particle) into the atmosphere. This would be done through two methods: (1) attaching flares filled with the particle to a small airplane, which would be ignited during flight, releasing the particles into the air; and (2) installing ground systems that would spray the particle into the surrounding air. In both applications, the water droplets within the atmosphere condense around the particle and fall as precipitation.

2. Facilities Required

Airplane
Flare rack
6 Flare Trees
Flares

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Cost
Flare Trees			ea	6	$ 216,000.00

Cost based on annual costs for Santa Barbara's cloudseeding program and quote from Weather Modification, Inc.

Raw Construction Cost (for flare trees)	$	216,000
Mobilization, Contractor's Profit, & Construction Contingency	$	122,000
Base Construction Costs	*$*	*338,000*
Implementation and Environmental Mitigation	$	24,000
Probable Capital Cost	**$**	**362,000**
Annualized Capital Cost (3% over 30 yrs)	$	18,000
Annual O&M	$	400,000
Total Annual Cost	**$**	**1,484,000**
Yield		200
Cost per Acre-Foot	**$**	**7,400**

4. Yield and Reliability

Source: Rainfall
Average Year Yield (AFY): 0
Dry Year Yield (AFY): 500
Yield assumes that 50% of storms are seeded with a 14% increase in inflow and that 25% of increase is captured.
Seasonality: Winter
Potential Reliability Concerns: Yield may vary greatly and depends on the number of storms seeded each year

5. Implementation Considerations

Weather patterns would need to be studied to determine the best times of the year to engage in cloudseeding, though it would be assumed that the rainy, winter months would be ideal. During the designated time, a meteorologist would need to be consulted to identify upcoming storms that the District could implement cloudseeding. Additionally, the type of particle (or mix of particles) to be used in the flares would need to be identified. It is estimated that this option could be implemented in 2 years.

6. Conceptual Map/Schematic

Source: North American Weather Consultants, Inc. Summary of Operations June 2016 Report for Santa Barbara County

Source: keyt.com

Source: scientificamerican.com

MMWD Water Resources Plan 2040
Resiliency Options - Draft

Resiliency Option: Emerging Option - Watershed Management (EO03)

1. Description

This option involves managing watershed lands to maximize supply availability. This would also provide fuels management benefits for wildfire mitigation. Based on a 2015 report from the Sierra Nevada Adaptive Management Project (SNAMP), it was assumed that thinning vegetation by 8% in 5% of the watersheds contributing to MMWD's water supply will result in an estimated increase in runoff of 5% for those areas. Cost determined using management action 23 in MMWD's 2016 Draft Biodiverstiy, Fire, and Fuels Integrated Plan (BFIPP). This option is an ancillary benefit to the existing fire protection program; it is assumed that this option could have a partner agency with 25% matching funds.

2. Facilities Required

None

3. Sizing and Costs

Project Element	Units	Size/Number	Units	Quantity	Facility Cost
Forest Thinning	acres	10,800			$ 132,840,000

Raw Construction Cost	$	132,840,000
Probable Capital Cost	**$**	**132,840,000**
Annualized Capital Cost (3% over 30 yrs)	$	6,777,000
Annual O&M	$	-
Total Annual Cost	**$**	**6,777,000**
MMWD Share (75%)	**$**	**5,080,000**
Yield (AFY)		210
Annual Cost per Acre-Foot	**$**	**24,200**

4. Yield and Reliability

Source: Watershed runoff
Average Year Yield (AFY): 210
Dry Year Yield (AFY): 110
Seasonality: Annual
Potential Reliability Concerns: Reliability will be linked to quality of thinning. Poor thinning may prevent benefits of increased runoff or may induce landslides.

5. Implementation Considerations

Impementation of this option could be a coordinated effort with the district's BFFIP. Funding may be available for such projects that have both water supply and fire management benefits. It is estimated that this option could be implemented in 2 years.

6. Conceptual Map/Schematic

Source: fsl.orst.edu

Appendix G

MMWD Decision Process and Criteria to Rank Resiliency Options Technical Memorandum

Technical Memorandum

MMWD Water Resources Plan 2040

Subject:	**MMWD Decision Process and Criteria to Rank Resiliency Options**
Prepared For:	Carl Gowan and Lucy Croy, MMWD
Prepared by:	Enrique Lopezcalva, RMC
Reviewed by:	Alyson Watson, RMC
Date:	April 1, 2016
Reference:	0041-010

The purpose of this Technical Memorandum (TM) is to briefly describe the decision process for the 2040 Water Resiliency Study and to list the criteria to be used in ranking resiliency options and evaluating alternatives. Feedback received on the information presented in this memorandum, in writing and during the weekly team check-in calls, will be used in the analysis and decision process and will be documented in the final report.

1 Overall Decision Process

Nomenclature

The nomenclature was agreed upon by the project team and will be used in planning process and in this memorandum:

Term	Meaning	Example
Events	Events or conditions that may happen impacting supply and demand balance	Intensity and length of drought, earthquakes, climate change, etc.
Reliability Threats	A probable future or condition that includes at least one event	Year 2040 under a 6 year and 9 year drought, climate change, existing system with a 30 day interruption of San Geronimo Treatment Plant, etc.
Options	Individual projects, programs, arrangements to increase supply, increase reliability, or manage demand	Indirect Potable Reuse, Direct Potable Reuse, increased storage, increase capacity of conveyance, increased water purchases, conservation measures, etc.
Alternatives	Combination of options	Combine increased conveyance with increased conservation, combine increased reuse with increased storage, etc.

Scenarios	Combination of a given alternative, with an uncertainty state, to evaluate that alternative under the conditions associated with the uncertainty state (also applicable to base case). This is consistent with the GoldSim use of the Scenario.	Reuse and storage alternative with increased length of droughts; increased conveyance and conservation with climate change, etc.

Process

The process for developing final recommendations to achieve resiliency and reliability under different reliability threats includes the development of multiple resiliency options and the use of criteria to identify the most favorable options to be combined into alternatives. The alternatives will then be tested under different reliability threats. Critical steps in the process include:

1. Develop resiliency options
2. Develop evaluation criteria (documented in this memorandum)
3. Weight the criteria
4. Apply the weighted criteria to rank options
5. Develop alternatives
6. Develop reliability threats
7. Evaluate the alternatives under multiple reliability threats
8. Make final recommendations

The detailed decision process is in a flow chart attached to this memorandum.

2 Evaluation Criteria

The following draft criteria were developed by the project team and discussed during a team check-in call on March 14, 2016.

For some of the criteria, quantification is not practicable as part of this project and options will be scored qualitatively using technical information and professional experience and judgment. Qualitative scores will be reviewed and discussed with MMWD staff, and modified as necessary, before finalizing the ranking of resiliency options.

The criteria presented below are listed in no significant order. The relative importance of the criteria will be established through a collaborative process with MMWD staff once the criteria themselves have been confirmed.

Cost

The cost criterion will measure costs incurred by MMWD to implement the resiliency option and the costs of operating and maintain the infrastructure associated with the option. Costs of purchasing water will also be included.

Potential metrics for this criterion include capital costs, operation and maintenance costs, and unit costs ($/AF).

This will be a quantitative criterion.

Reliability

This criterion will measure the impact of different reliability threats on the anticipated yield of the resiliency option and/or the ability of the option to continue to supply water under each reliability threat. Once alternatives are developed (by combining resiliency options) the reliability of alternatives will be measured in terms of the size and frequency and duration of any shortages under each reliability threat.

Potential metrics for this criterion include average yield, yield under dry conditions and climate change, and ability to generate supply during multiple reliability threats. For alternatives, the primary metric will be remaining shortages under each future when the alternative is implemented.

This will be a quantitative criterion.

Technical Complexity

This criterion will measure the level of technical complexity associated with implementing a resiliency option, including the degree to which technology required to implement the option is considered "proven." Institutional complexity and the time or cost to implement a resiliency option will *not* be included (to avoid redundancy with other criteria).

This will be a qualitative criterion.

Environmental Stewardship

This criterion will measure the level of potential environmental impact or benefit associated with a resiliency option, during construction and during operation. The complexity of preparing environmental documentation and clearing CEQA will *not* be included to avoid redundancy with the criteria "Time to Implement" and "Institutional Complexity," but considerations related to mitigation for potential impacts will be included here.

This will be a qualitative criterion.

Local Control

This criterion will measure MMWD's anticipated level of ownership over decisions related to the operation of a resiliency option, as well as the extent to which the supply operation is controlled by MMWD. Considerations related to how the resiliency option is managed under drought conditions and other reliability threats, and how much of this management is under the direction of MMWD will be included in this criterion. The implementation aspect of the resiliency option will *not* be included in the scores for this criterion to avoid redundancy with the "Institutional Complexity" criterion.

This will be a qualitative criterion.

Institutional Complexity

This criterion will measure not only the number of parties involved in implementing an option but also the level of complexity anticipated in negotiating and agreeing with those parties. An option that requires coordination and agreement with a party where a history of collaboration exists will be scored more favorably than one where no previous collaboration has occurred. Considerations relate to State and Federal agency approvals and involvement (beyond permitting) will be included.

This will be a qualitative criterion.

Time to Implement

This criterion will measure the expediency with which an option can be implemented. This will be an overarching criterion that will take into account various considerations related to the schedule for implementing an option.

This will be a qualitative criterion that can potentially be made quantitative with estimates of months or years for project implementation.

Public Support

This criterion will measure anticipated public support or opposition to a resiliency option by different groups in the community and the community as a whole, based on prior experience of MMWD staff.

This will be a qualitative criterion.

Appendix H

Resiliency Option Evaluation Technical Memorandum

Technical Memorandum

MMWD Water Resources Plan 2040

Subject:	**Resiliency Options Evaluation**
Prepared For:	Carl Gowan, MMWD
Prepared by:	Rachel Gross, RMC Simon Kobayashi, RMC
Reviewed by:	Enrique Lopezcalva, RMC Alyson Watson, RMC
Date:	September 26, 2016
Reference:	0041-010

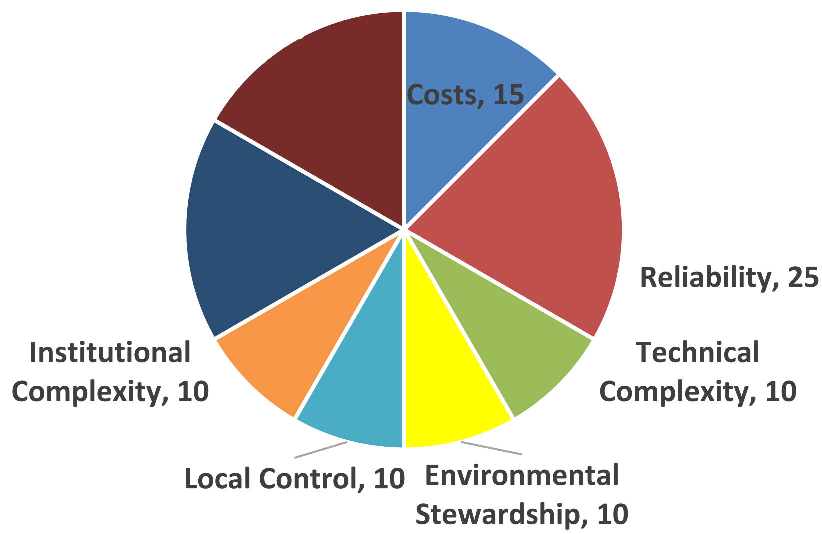
1 Background and Objective

As part of the Water Resources Plan 2040 (WRP 2040), 40 water resiliency options were developed by RMC and reviewed by MMWD. High-level fact sheets including yield and cost were developed for each option, as described in the Resiliency Options Technical Memorandum of the WRP 2040. Each option was analyzed against the following criteria: cost, reliability, technical complexity, environmental stewardship, local control, institutional complexity, project readiness, and public support. Each of these criteria are described in the MMWD Decision Process and Criteria to Rank Resiliency Options Technical Memorandum of the WRP 2040. This technical memorandum describes how the options were scored against these criteria.

2 Evaluation Criteria Weights

MMWD staff provided feedback on the weighting of the resiliency option evaluation criteria by ranking each of the criteria. Criteria weights were used for a preliminary rank for discussion during a Workshop on July 5, 2016. Feedback from the workshop was used to derive the criteria weights shown in **Figure 2-1**. Reliability was chosen as the most important criteria, followed by public support and project readiness.

Figure 2-1: Resiliency Option Criteria Weights



3 Assessment Methodology

While costs for each resiliency option were already quantified in the resiliency option fact sheets, the options required further assessment against the various evaluation criteria. Each criterion other than cost was scored from either 1 to 5 or 1 to 3, as described below. Scales varied between criteria based on the level of granularity or resolution required. For those criteria that required a "yes" or "no" response, either a 0 or 1 was assigned. To compare across criteria, all scores were normalized. For all criteria scales, the higher the number, the better the option performed.

Reliability

The reliability score for each option was based both on two components: its expected average yield and its reliability under the different reliability threats (reliability threats are described in the Reliability Threats Technical Memorandum).

The yield component was scored from 1 to 3; a score of 3 for options yielding more than 3,000 AFY, a score of 2 for options yielding between 500 and 3,000 AFY, and a score of 1 for options yielding less than 500 AFY. The reliability threats component considered how the option would be impacted by four reliability threats: Drought/Climate Change, Treatment Plant Outage, Ignacio Pump Station Outage, and Lake Water Quality Issue. For the Treatment Plant Outage, Ignacio Pump Station Outage, and Lake Water Quality Issue categories of reliability threats, the option was scored either 0 or 1. A score of 0 was assigned if the option would be impacted by the reliability threat and a score of 1 was assigned if the option would not be impacted by the reliability threat. For example, the EBMUD pipeline option would not be impacted by an outage of an MMWD treatment plant, so it was given a score of 1 for this reliability threats component. However, the water supply from the EBMUD pipeline would be impacted by an outage of Ignacio Pump Station, so it was given a score of 0.

For the fourth reliability threat, Drought/Climate Change, each option was scored from 1 to 3 based on the degree to which it would be impacted by drought or climate change. A score of 1 was given to options that could be severely impacted by drought or climate change, a score of 2 was given to options that could be somewhat impacted by drought or climate change, and a score of 3 was given to options that would not likely be impacted by drought or climate change. For example, the DPR SASM resiliency option was given a 3 for its Drought/Climate Change reliability threats score since DPR is considered to be a drought-proof supply. Conversely, the Watershed Management resiliency option was given a score of 1 in the Drought/Climate Change reliability threats category since it would not help produce additional water supply in very dry conditions.

Table 3-1 summarizes the scoring scales for the two components of the Reliability criterion, yield and reliability threats. Combined, these two components comprise the Reliability criterion.

Table 3-1: Reliability Component Scoring

Reliability Sub-criteria		Scores			
		0	**1**	**2**	**3**
Yield		N/A	<500 AFY	500 AFY to 3,000 AFY	>3,000 AFY
Reliability Threats	**Drought/Climate Change**	N/A	Severely Impacted	Somewhat Impacted	No Impact
	Treatment Plan Outage	Impact	No Impact	N/A	N/A
	Ignacio Outage	Impact	No Impact	N/A	N/A
	Lake Water Quality Issue	Impact	No Impact	N/A	N/A

Technical Complexity

The technical complexity score for each resiliency option includes the operational complexity and feasibility of the option. Options were scored from 1 to 5 against this criteria; a score of 1 indicates that the technology used in the resiliency option is not proven or scalable to address MMWD's needs or has significant technical complexity to operation or construct, or operational complexity increases with implementation. A score of 5 indicates that the technology used in the resiliency option is proven and/or easily scalable, and implementation does not result in significant complexity of operations. For example, the Cloud Seeding resiliency option was given a score of 1 in technical complexity as cloud seeding technology is not at all proven and is likely not scalable to address MMWD's needs. The Conservation resiliency option was given a score of 5 against this criteria because it is a proven method of reducing demand (and thus increasing available supply) and it is relatively easy to implement quickly.

Environmental Stewardship

Each resiliency option was scored from 1 to 3 for environmental stewardship. A score of 1 indicates that the option uses resources from other regions or results in impacts that will have to be mitigating during construction or operation. A score of 2 indicates that the options implementation has generally small impacts that can be easily mitigated or no impacts. A score of 3 indicates that the option's implementation maximizes use of existing resources and has generally no significant impacts to mitigate. For example, the Humboldt County Transfer resiliency option was given a 1 for environmental stewardship, as it requires a water transfer from a region that is very far away and would necessitate an extremely long and environmentally impactful pipeline. The recycled water resiliency options received scores of 3 for this criteria because they maximize the use of existing resources and would require relatively little new infrastructure compared to the other options.

Local Control

Resiliency options were scored from 1 to 3 for local control. A score of 1 indicates that the resiliency options heavily relies on resources outside of MMWD's control or service area. A score of 3 indicates that the resiliency option is within MMWD's service area and control. Resiliency options that require a transfer of water from somewhere outside of MMWD's service area, such as the Yuba County Transfer, Humboldt County Transfer, and North Bay Aqueduct all received a score of 1 for local control. DPR, IPR, and recycled water options all received a score of 3 for local control, as they would use wastewater generated in MMWD's service area and would be treated and reused within MMWD's service area.

Institutional Complexity

Resiliency options were scored from 1 to 3 for institutional complexity. A score of 1 indicates the options implementation and operation requires significant coordination with a few agencies or some coordination with a great number of agencies. A score of 3 indicates that the resiliency option can be implemented without coordination with other agencies or without requiring new agreements or contracts. For example, the Los Vaqueros resiliency option was given a score of 1, as it would require a great deal of coordination with the agencies that would supply the water, store the water, and wheel the water to MMWD. Options like Improve Nicasio Pump Station and Soulajule Power were given a score of 3, as they don't require any coordination with other agencies.

Public Support

Each resiliency option was scored for public support on a scale of 1 to 3. A score of 1 indicates that there is known local or statewide opposition to the implementation of the option. A score of 2 indicates that there is no known opposition or support for the implementation of the option. A score of 3 indicates that there is known support for implementation of the option. For example, the DPR resiliency options received scores of 1 against this criterion, as there has been public resistance to DPR projects across the state. Onsite reuse was given a score of 3, as there is known support for this type of project in MMWD's service area.

Project Readiness

Resiliency options were scored from 1 to 3 for project readiness. A score of 1 indicates that extensive studies or extended preparation would have to occur before the project could be implemented. A score of 3 indicates that the option is known to be feasible and could thus be implemented in the near future. For example, the local ground water projects in the Upper Lagunitas Watershed and Ross Valley were given scores of 1 for project readiness, as extensive groundwater testing and modeling would be required to determine the presence and accessibility of groundwater before the project could be implemented. The resiliency option to expand Sonoma County Water Agency (SCWA)/MMWD transfer facilities was given a score of 3 because the project could proceed almost immediately, assuming agreements with SCWA and North Marin Water District (NMWD) are in place.

4 Assessment Results

After each resiliency option was scored against each criteria, the option scores and criteria weights were input into Criterium Decision Plus (CDP) software. The raw scores for all options (scores before applying weights to the criteria in CDP) are included in Attachment A along with a figure showing the unit cost and annual yield for each option.

4.1 CDP Results

The CDP was used to compute a "decision score" for each option. CDP applies the weight of each criterion to the score for that criterion and sub-criterion, and computes the sum of the weighted criteria score as the "decision score."

The Final CDP decision scores are shown below, both with cost in **Figure 4-1** and without cost in **Figure 4-2**. When decision scores consider costs, resiliency options that score particularly well include conservation, recycled water, watershed management, and groundwater. When decision scores do not consider costs, project types that score well include recycled water, conservation, watershed management, IPR and expanding SCWA imported water.

The decision scores from CDP both considering and not considering cost are relatively similar. Recycled water, conservation, and watershed management score well with and without cost. Conversely, the DPR, desalination, and imported water options tend to not score well both with and without cost.

Figure 4-1: Resiliency Option Assessment with Cost

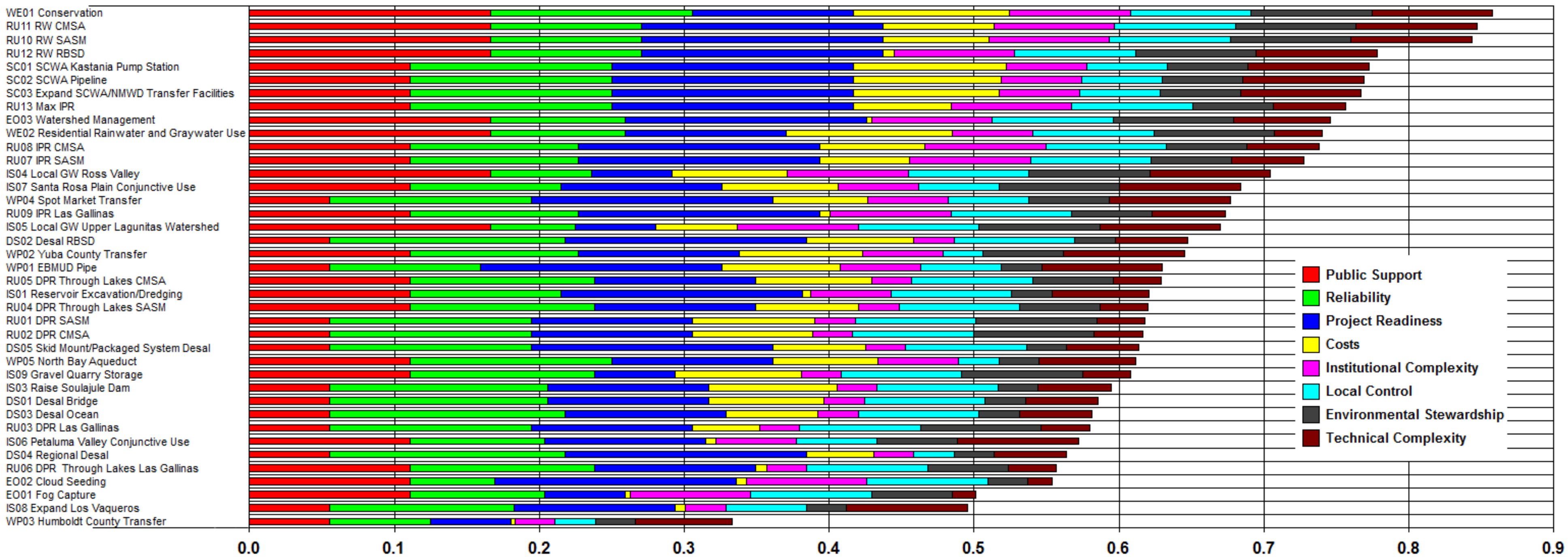
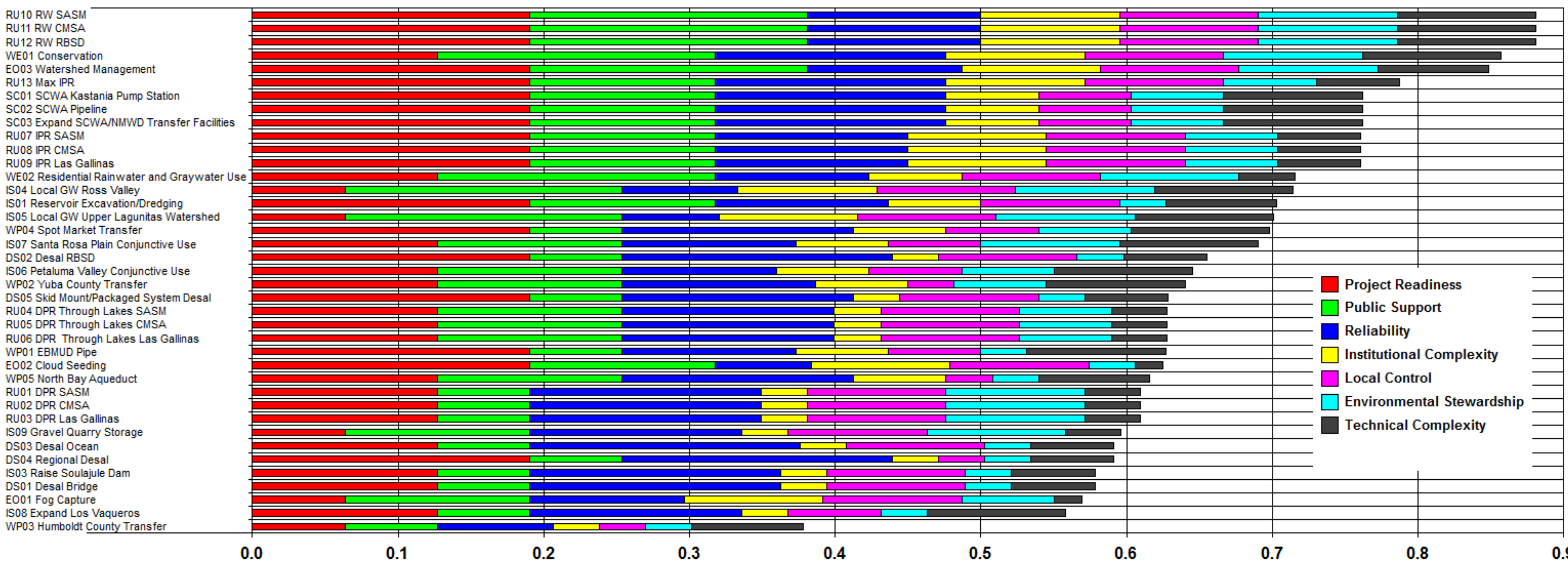


Figure 4-2: Resiliency Option Assessment without Cost

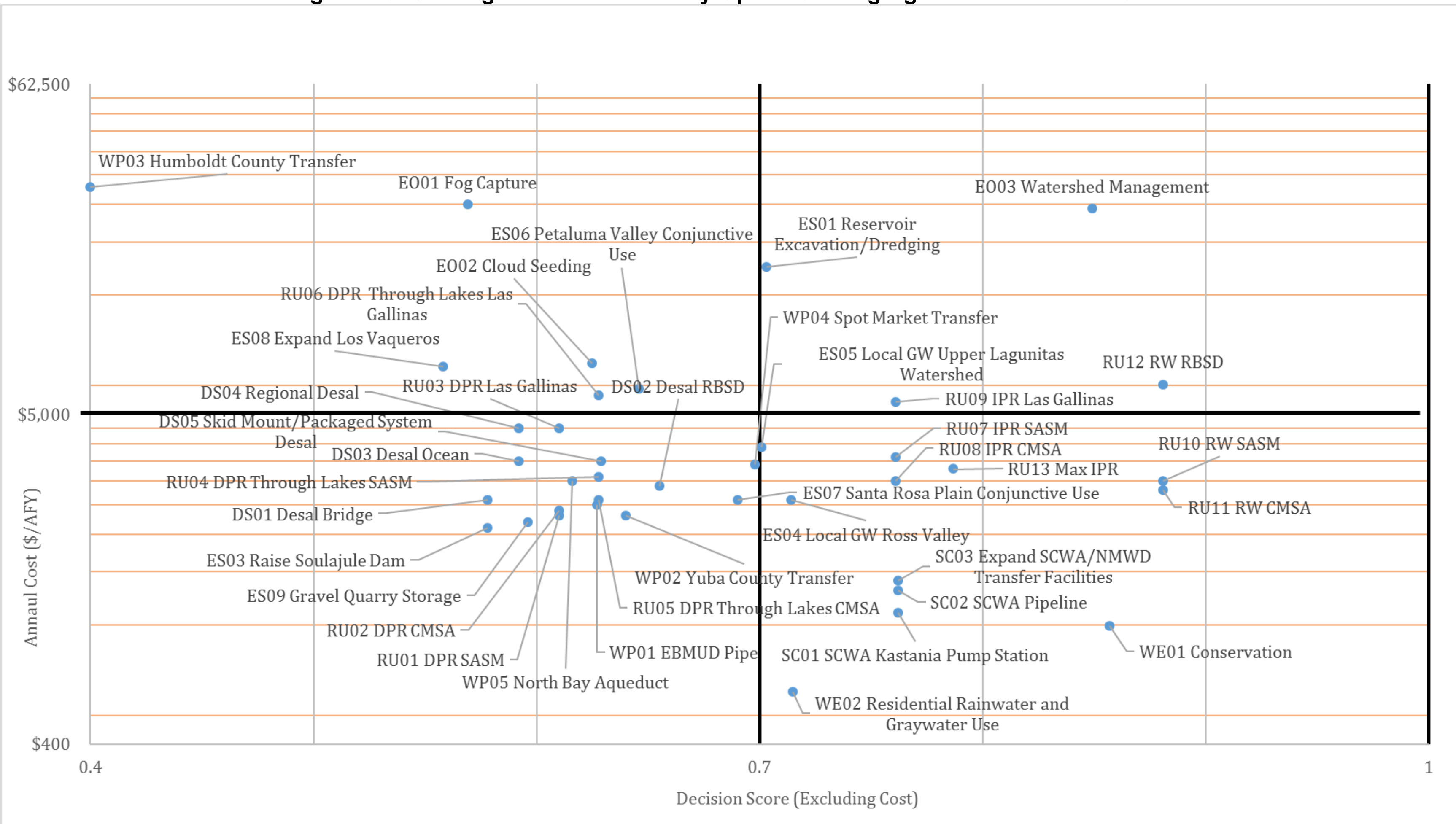


4.2 Quadrant Analysis

After the options were assessed using the CDP software, the options were put into a tradeoff curve divided in four quadrants. The tradeoff curve compared the decision score (without cost) to the cost per acre-foot ($/AF). The resulting quadrant graphic is shown **Figure 4-3**.

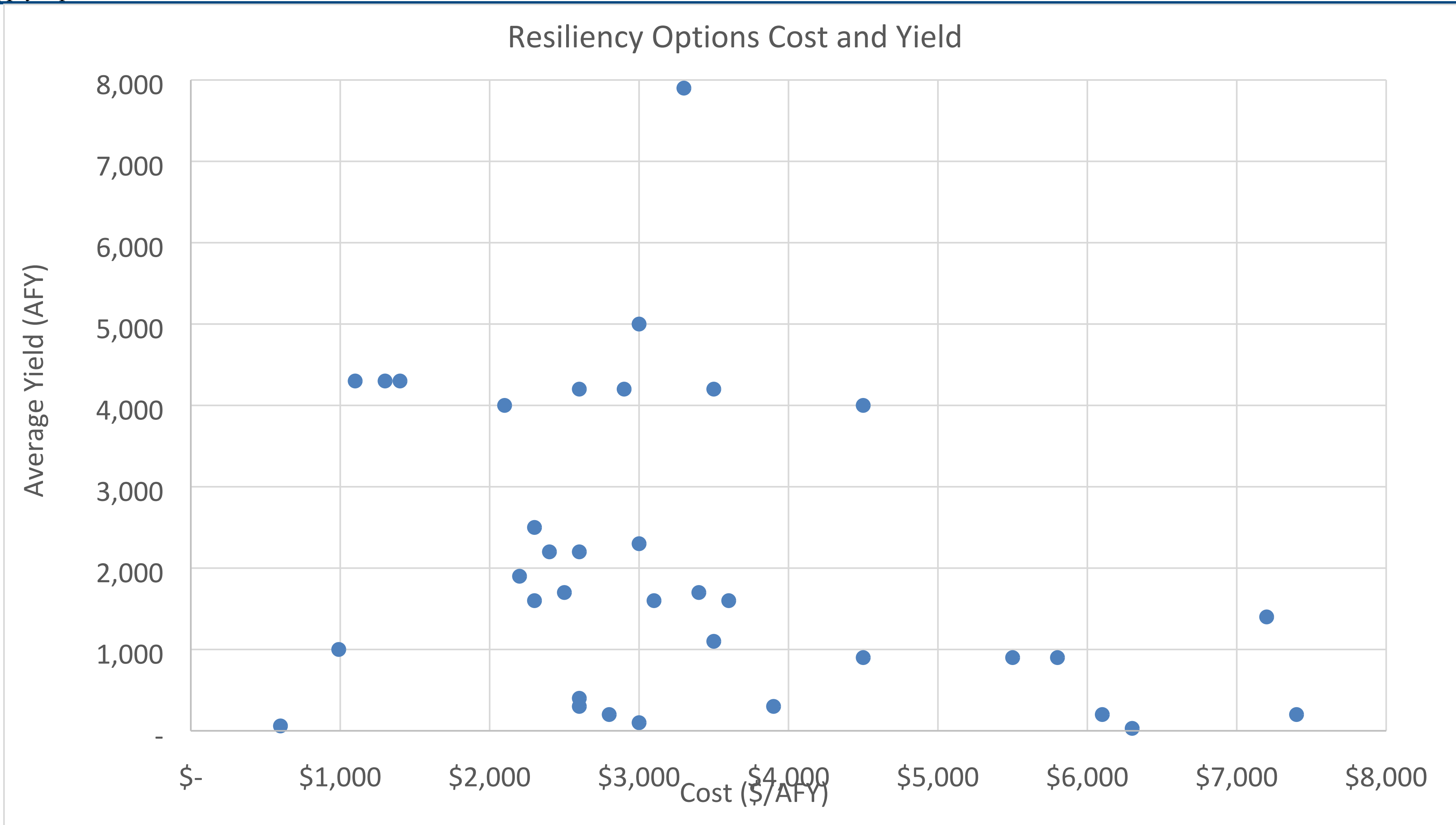
The vertical quadrant line was set at the approximate median decision score and the horizontal quadrant line was set at $5,000 AFY, as this was determined to be a reasonable boundary for the price of new water supplies (at conceptual level costs)

Figure 4-3: Scoring Matrix of Resiliency Option Scoring Against Total Annual Cost



Attachment A: Raw Resiliency Option Scores

			Reliability						Technical Complexity	Environmental Stewardship	Local Control	Institutional Complexity	Public Support	Project Readiness
				Reliability Under Futures										
	Cost ($/AFY)	Average Yield (AFY)	Average Yield (score)	Uncertainty	Drought/ Climate Change	BT or SG Out	Ignacio Out	Lake WQ Issue	1 to 5	1 to 3	1 to 3	1 to 3	1 to 3	0-3
WE01 Conservation	$ 990	1,000	2	1	1	1	1	1	5	3	3	3	3	3
WE02 Residential Rainwater and Graywater Use	$ 600	60	1	1	1	1	1	1	2	3	3	2	3	2
RU01 DPR SASM	$ 2,300	1,600	2	1	3	1	1	1	2	3	3	1	1	2
RU02 DPR CMSA	$ 2,400	2,200	2	1	3	1	1	1	2	3	3	1	1	2
RU03 DPR Las Gallinas	$ 4,500	900	2	1	3	1	1	1	2	3	3	1	1	2
RU04 DPR Through Lakes SASM	$ 3,100	1,600	2	1	3	0	1	1	2	2	3	1	2	2
RU05 DPR Through Lakes CMSA	$ 2,600	2,200	2	1	3	0	1	1	2	2	3	1	2	2
RU06 DPR Through Lakes Las Gallinas	$ 5,800	900	2	1	3	0	1	1	2	2	3	1	2	2
RU07 IPR SASM	$ 3,600	1,600	2	1	3	0	1	0	3	2	3	3	2	3
RU08 IPR CMSA	$ 3,000	2,300	2	1	3	0	1	0	3	2	3	3	2	3
RU09 IPR Las Gallinas	$ 5,500	900	2	1	3	0	1	0	3	2	3	3	2	3
RU10 RW SASM	$ 3,000	100	1	1	2	1	1	1	5	3	3	3	3	3
RU11 RW CMSA	$ 2,800	200	1	1	2	1	1	1	5	3	3	3	3	3
RU12 RW RBSD	$ 6,300	30	1	1	2	1	1	1	5	3	3	3	3	3
RU13 Max IPR	$ 3,300	7,900	3	1	3	0	1	0	3	2	3	3	2	3
SC01 SCWA Kastania Pump Station	$ 1,100	4,300	3	1	2	1	0	1	5	2	2	2	2	3
SC02 SCWA Pipeline	$ 1,300	4,300	3	1	2	1	0	1	5	2	2	2	2	3
SC03 Expand SCWA/NMWD Transfer Facilities	$ 1,400	4,300	3	1	2	1	0	1	5	2	2	2	2	3
ES01 Reservoir Excavation/Dredging	$ 15,500	1,000	2	1	2	0	1	0	4	1	3	2	2	3
ES03 Raise Soulajule Dam	$ 2,100	4,000	3	1	3	0	1	1	3	1	3	1	1	2
ES04 Local GW Ross Valley	$ 2,600	400	1	0	1	1	1	1	5	3	3	3	3	1
ES05 Local GW Upper Lagunitas Watershed	$ 3,900	300	1	0	1	1	1	0	5	3	3	3	3	1
ES06 Petaluma Valley Conjunctive Use	$ 6,100	200	1	1	2	1	0	1	5	2	2	2	2	2
ES07 Santa Rosa Plain Conjunctive Use	$ 2,600	300	1	1	3	1	0	1	5	3	2	2	2	2
ES08 Expand Los Vaqueros	$ 7,200	1,400	2	1	2	1	1	1	5	1	2	1	1	2
ES09 Gravel Quarry Storage	$ 2,200	1,900	2	1	2	1	1	1	2	3	3	1	2	1
WP01 EBMUD Pipe	$ 2,500	1,700	2	1	1	1	0	1	5	1	2	2	1	3
WP02 Yuba County Transfer	$ 2,300	2,500	2	1	2	1	0	1	5	2	1	2	2	2
WP03 Humboldt County Transfer	$ 28,600	500	1	0	2	1	0	1	4	1	1	1	1	1
WP04 Spot Market Transfer	$ 3,400	1,700	2	1	3	1	1	1	5	2	2	2	1	3
WP05 North Bay Aqueduct	$ 3,000	5,000	3	1	2	1	0	1	4	1	1	2	2	2
DS01 Desal Bridge	$ 2,600	4,200	3	1	3	1	0	1	3	1	3	1	1	2
DS02 Desal RBSD	$ 2,900	4,200	3	1	3	1	1	1	3	1	3	1	1	3
DS03 Desal Ocean	$ 3,500	4,200	3	1	3	1	1	1	3	1	3	1	1	2
DS04 Regional Desal	$ 4,500	4,000	3	1	3	1	1	1	3	1	1	1	1	3
DS05 Skid Mount/Packaged System Desal	$ 3,500	1,100	2	1	3	1	1	1	3	1	3	1	1	3
EO01 Fog Capture	$ 25,000	10	1	1	1	1	1	1	1	2	3	3	2	1
EO02 Cloud Seeding	$ 7,400	200	1	1	1	0	0	0	1	1	3	3	2	3
EO03 Watershed Management	$ 24,200	200	1	1	1	1	1	1	4	3	3	3	3	3



Resiliency Options with a unit cost greater than $8,000 per AFY have not been included in this figure. These options include ES01: Reservoir Excavation, EO03: Watershed Management, EO01: Fog Capture, and WP03: Humboldt County Transfer.

Appendix I

Recommended Alternatives Technical Memorandum

Technical Memorandum

MMWD Water Resources Plan 2040

Subject:	**Recommended Alternatives**
Prepared For:	Carl Gowan, MMWD
Prepared by:	Rachel Gross, RMC
	Enrique Lopezcalva, RMC
Reviewed by:	Alyson Watson, RMC
Date:	October 25, 2016
Reference:	0041-010

1 Background and Objective

A wide variety of Resiliency Options were developed and evaluated to explore how MMWD could increase its resiliency and meet demands in times of potential supply shortages caused by variable hydrology or system disruption. The original 40 options are described in detail in the Resiliency Options TM and the associated evaluation process is described in the Resiliency Option Evaluation TM (Appendix H). This technical memorandum describes how five alternatives were developed from the options list, based on the themes of expanding existing programs, minimizing infrastructure, dry year actions, maximizing reuse, and maximizing resiliency. These alternatives were also organized to produce different yield volumes of around 2,000 AFY, 4,000 AFY, 6,000 AFY, 9,000 AFY, and 11,000 AFY to meet a variety of potential demand deficits.

2 Resiliency Options Shortlist

Based on the evaluation process described in the Resiliency Options Evaluation TM, projects with a decision score of 0.7 or greater and a unit cost of $5,000 per AFY or less were selected for the shortlist of options to be considered for inclusion in the supply alternatives. The projects shortlisted for further consideration are the following:

- WE01 Enhanced Conservation
- WE02 Residential Rainwater and Graywater Use
- RU07 IPR SASM
- RU08 IPR CMSA
- RU10 RW SASM
- RU11 RW CMSA
- RU13 Regional IPR
- SC03 Expand SCWA/NMWD Transfer Facilities
- SC01 SCWA Kastania Pump Station
- SC02 SCWA Pipeline

- ES04 Local Groundwater – Ross Valley
- ES05 Local Groundwater – Upper Lagunitas Watershed
- ES07 Santa Rosa Plain Conjunctive Use
- WP04 Spot Market Transfer
- EO03 Watershed Management

Within a specific type of project or category, the preferred option was used. For example, although several groundwater alternatives met the criteria, only the most beneficial alternative at the lowest cost (Santa Rosa Conjunctive Use) was used in developing alternatives. Options were organized into alternatives based on their fit with one or more of the themes of expanding existing programs, minimizing infrastructure, dry year actions, maximizing reuse, and maximizing resiliency and based on their ability to contribute to the total yield goals of 2,000 AFY, 4,000 AFY, 6,000 AFY, 9,000 AFY, and 11,000 AFY for the most reasonable price. The alternatives are described in detail below.

3 Alternatives

The alternatives below were created from combinations of resiliency options and then simulated in GoldSim to determine their ability to improve water supply availability and reliability during various Reliability Threats.

Minimize Infrastructure

The Minimize Infrastructure alternative includes resiliency options that improve resiliency while minimizing the requirement to construct new infrastructure. The options included in this alternative are Enhanced Conservation (WE01), SCWA Kastania Pump Station Upgrade (SC01), and Santa Rosa Plain Conjunctive Use (ES07. These options scored highly on the environmental stewardship, technical complexity, local control, project readiness, and public support criteria due to the lack of additional infrastructure required. The total yield of this alternative in an average year is 5,200 AFY with a total annual cost of approximately $6.1M.

Dry Year Actions

The Dry Year Actions alternative includes options that are targeted to yield maximum benefit in dry year needs, as opposed to resiliency actions that generally provide the same level of supply or resiliency in all year types. A dry year is defined as a year that falls in below the 33rd percentile of precipitation and inflow. The options included in this alternative are Enhanced Conservation (WE01) and Spot Market Transfer (WP04). These options scored well in the reliability, technical complexity, and project readiness criteria as they could provide additional water supply reliability when it is most needed. The total yield of this alternative in an average year is about 900 AFY, but its yield increases during dry years to about 5,900 AFY. The total annual cost of this alternative is approximately $6.3M.

Maximize Reuse

The Maximize Reuse alternative only includes one resiliency option: Regional IPR (RU013). This resiliency option was developed to determine the maximum amount of water reuse possible for MMWD. Maximizing reuse scores well against reliability, local control, and project readiness criteria and has the highest yield of any single option explored in the WRP. The average yield from this alternative is about 7,900 AFY with an annual cost of about $26.2M.

Maximize Resiliency

The Maximize Resiliency alternative includes resiliency options that have both high yield and high reliability to allow MMWD to obtain a significant level of supply under a variety of Reliability Threats. This alternative includes Enhanced Conservation (ES01), Regional IPR (RU13), SCWA Pump Station Upgrade (SC01), and Watershed Management (EO03). Resiliency options included in this alternative would allow MMWD to access significant new volumes of supply through expanded imports from SCWA and additional volume in storage from indirect potable reuse and watershed management. These resiliency options scored well in the reliability and project readiness criteria. The average yield from this alternative is about 13,400 AFY and the average annual cost is approximately $40.6M.

Expand Existing Programs

After the previously described alternatives were developed, the Expand Existing Programs alternative was developed to present an option without major infrastructure changes and to explore how MMWD's existing efforts could be expanded to increase its water supply incrementally. This alternative includes Enhanced Conservation (WE01), Santa Rosa Plain Conjunctive Use (ES07) and Watershed Management (EO05). These options all score well in reliability, environmental stewardship, technical complexity, public support, and project readiness because they are all expansions of practices that MMWD already has in place. The average year yield of this alternative is 1,200 AFY, with an increased dry year yield of 2,000 AFY. The total annual project cost for this alternative is approximately $10.4M.

3.1 Summary

Detailed costs and yields for each of the alternatives can be found in **Table 3-1** below.

Table 3-1: Cost, Yield, and Included Resiliency Options for Alternatives

Options to Include in Alternatives	Minimize Infrastructure	Dry Year Actions	Maximize Reuse	Maximize Resiliency	Expand Existing Programs
WE01 Enhanced Conservation	X	X		X	X
RU13 Regional IPR			X	X	
SC01 SCWA Kastania Pump Station Upgrade	X			X	
ES07 Santa Rosa Plain Conjunctive Use	X				X
WP04 Spot Market Transfer		X			
EO03 Watershed Management				X	X
Total Dry Year Yield (AFY)	***3,900***	***6,000***	***7,900***	***11,000***	***2,000***
Total Average Year Yield (AFY)	***5,300***	***1,000***	***7,900***	***13,400***	***1,200***
Capital Costs ($M)	***$5.9***	***$48.2***	***$359.3***	***$497.0***	***$133.8***
Cost of Water ($M)	***$5.0***	***$3.1***	***N/A***	***$4.3***	***$0.7***
O&M Costs ($M/Yr)	***$0.8***	***$0.8***	***$7.9***	***$8.7***	***$0.6***
Total Annual Cost ($M/Yr)	***$8.4***	***$8.6***	***$26.2***	***$40.6***	***$10.4***

4 Alternatives Evaluation

Each of the Reliability Threats described above was incorporated into the Marin WaterSim model to evaluate how the alternatives would help improve MMWD's supply reliability during the modeled future events. All alternatives and Reliability Threats were modeled using base level projected demand (24,000 AFY) and the most impactful Reliability Threats were modeled using high level projected demand (29,000 AFY). The "Baseline" Reliability Threat is defined as business as usual, historical hydrology with no events that disrupt operation. Similarly, the "No Action" alternative represents normal operations under each Reliability Threat. Detailed information on the Reliability Threat events used in this Plan can be found in the Reliability Threats TM and detailed information on the WaterSim model can be found in the Marin WaterSim TM.

4.1 Metrics

The effectiveness of the alternatives under different Reliability Threats was measured through several metrics, defined in

Table 4-1 below. Most of these metrics, including average annual deficit, maximum monthly deficit, maximum annual deficit, year and month of deficit, and exceedance probability of monthly deficit show the extent to which alternatives would allow MMWD to meet demand under different Reliability Threats. Other metrics, such as supply mix and months with Soulajule usage, show how MMWD might need to change its standard operation practices under different Reliability Threats with new alternatives. Finally, total system storage and total system overflows are good indicators to see how the overall system reacts to different alternatives and Reliability Threats. Together, these metrics show how effective alternatives are under different Reliability Threats and show how incorporating those alternatives may change MMWD operations.

Table 4-1: Alternatives Evaluation Metrics

Metric	Definition	Unit
Average Annual Deficit	Average volume by which demand exceeds supply per year during the years affected by the future event.	AFY
Maximum Monthly Deficit	Maximum volume by which demand exceeds supply in a single month.	AFM
Maximum Annual Deficit	Maximum volume by which demand exceed supply in a single year.	AFY
Year and Month of Max Deficit	Identifies the year and month in which the maximum deficit occurs	Month, Year
Exceedance Probability of Monthly Deficits	Graphical output with monthly deficits on the y-axis and the probability that any given month will exceed that level of deficit on the x-axis. This graph is used to visualize the frequency and magnitude of monthly deficits.	Graph of probability (%) vs monthly deficit (AFM)

Metric	Definition	Unit
Supply Mix	Graphical output of a pie chart that shows the amount of water produced from all of MMWD's water sources: SGTP, BTTP, SCWA, Las Gallinas, Raw Water, and New Resiliency Options. If there is unmet demand, this chart will show the volume of the deficit along with the other supply sources.	Pie chart based on relative production volume (unit-less)
Total System Storage	Total volume of storage measured monthly presented as a box chart.	AFM
Total System Overflows	Total volume of water spilled from lakes measured monthly.	AFM
Months with Soulajule Usage	Number of months over the course of the simulation during which water must be drawn from Soulajule in order to meet demand.	Number of months

4.2 Alternatives Evaluation Results under Severe Drought Reliability Threats

As described in the Reliability Threats TM, the Six-Year and Nine-Year Severe Drought Reliability Threats are the only future scenarios under which the WaterSim model predicts that MMWD's current system may have deficits under base demand projections for 2040. Thus, these are the most useful Reliability Threats to test alternatives against to determine their benefits. Additionally, the climate change Reliability Threat is expected to significantly decrease overall storage levels, and deficits were observed under this Reliability Threat under the high demand projections. Deficits were also observed under high demand projections if an earthquake were to incapacitate SGTP. Thus, the climate change and earthquake impacting SGTP Reliability Threats were also considered when evaluating alternatives.

Figure 4-1 below shows how each alternative performs under the Six-Year Severe Drought in terms of deficits. The Dry Year Actions, Maximize Reuse, and Maximize Resiliency alternatives all eliminate deficits under the Six-Year Severe Drought, while Expand Existing Programs and Minimize Infrastructure both continue to show deficits. Monthly and annual deficits are reduced under these alternatives, but still significant. Similarly,

Figure 4-2 shows the total number of months with deficits for each alternative under the Six-Year and Nine-Year Severe Drought. The performance of the alternatives for both Reliability Threats is similar, although the Dry Year Actions alternative is not able to fully prevent deficits under the Nine-Year Severe Drought.

Figure 4-1: Deficits under Six-Year Severe Drought Reliability Threat

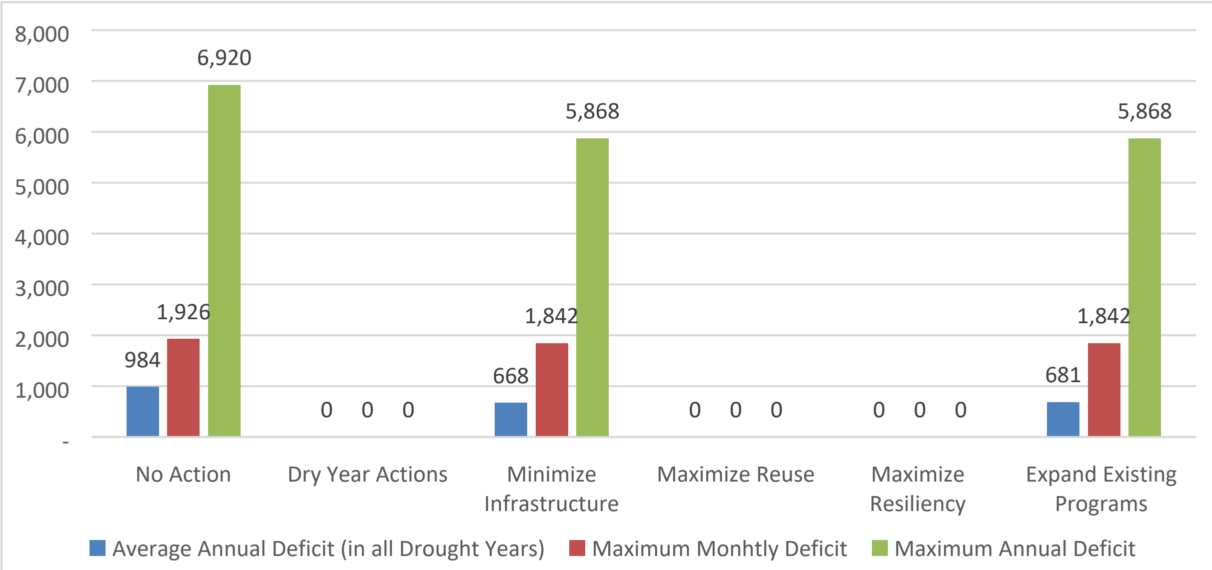


Figure 4-2: Number of Months with Deficits under Six-Year and Nine-Year Severe Drought Reliability Threat

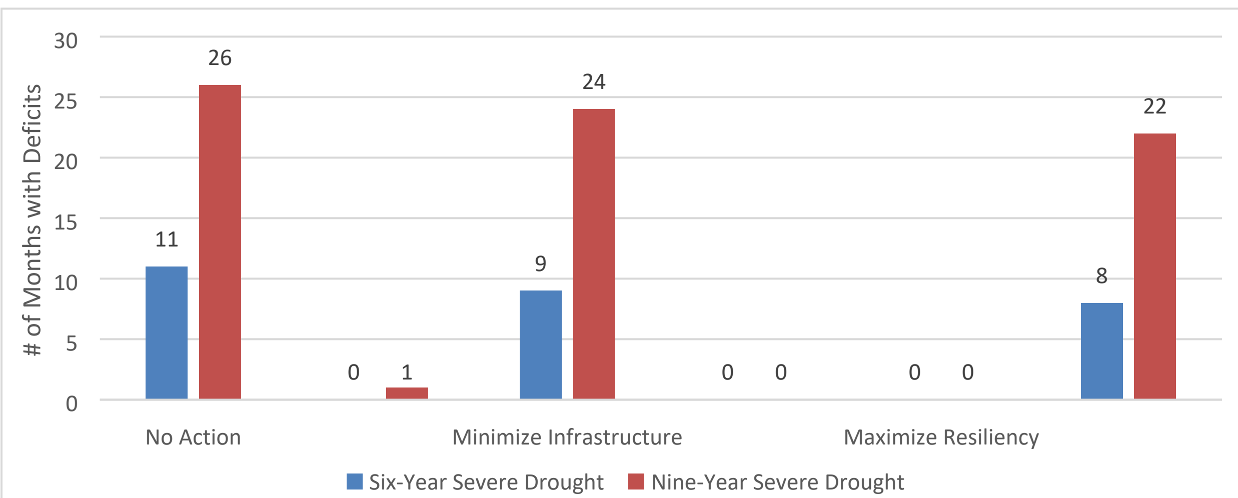
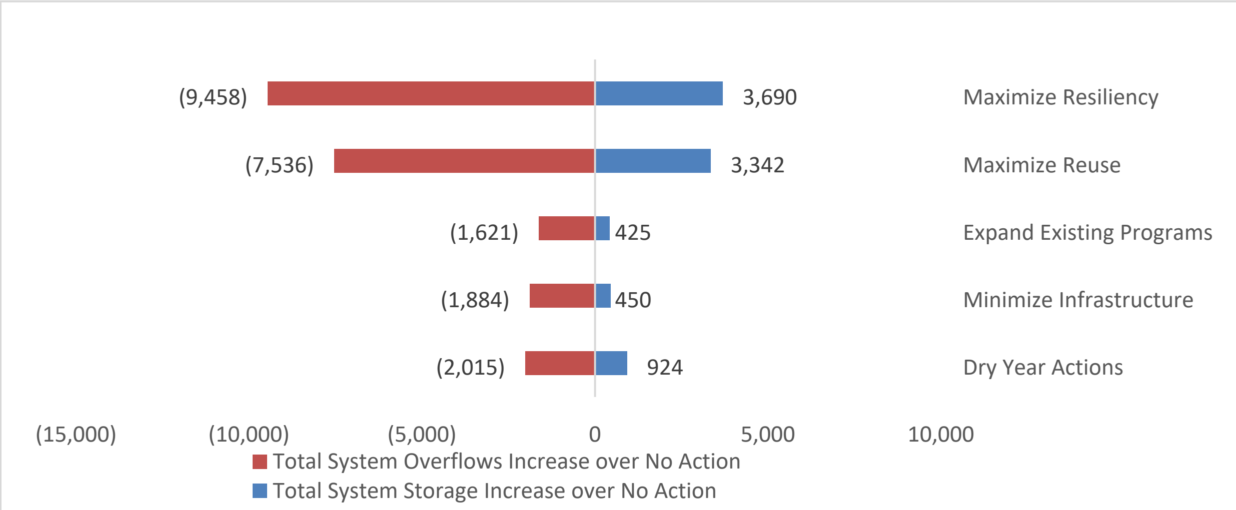


Figure 4-3 below shows the change in system storage and overflows between each resiliency alternative and the no action alternatives under the Six-Year Severe Drought conditions. While all options increase total system storage, they also significantly increase reservoir spilling such that much of the benefit of the alternatives may be lost through increased spills. It is important to note that the overflows most often occur in winter months when demand is low and storage is high, while the benefit of increased storage is realized during summer months when demand is high, storage is low, and deficits are more likely to occur. Thus there is a benefit to increased storage from an option such as Minimize Infrastructure, even though it actually leads to higher levels of spills than total storage.

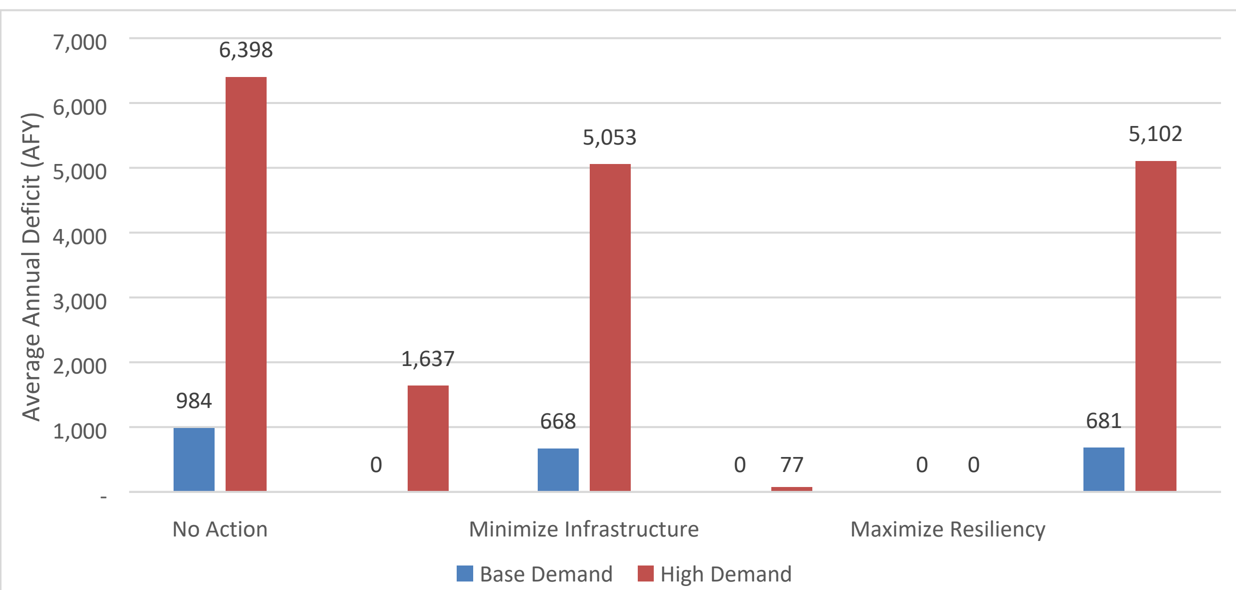
Figure 4-3: Increase in System Storage and Increase in Overflows under Six-Year Drought Reliability Threat (AF)



4.3 Alternatives Results under High Demand Reliability Threats

In addition to evaluating the performance of all of the alternatives against all of the Reliability Threats under base demand projections, the alternatives were tested against several of the most impactful Reliability Threats under high demand projections. This yields further insight into the relative performance of the alternatives when the system is severely stressed. Figure 4-4 shows that under the high demand scenario, only Maximize Resiliency provides enough supply such that there are no deficits. As expected, the average annual deficit under high demand is much greater than under base demand.

Figure 4-4: Average Annual Deficit in Six-Year Severe Drought under Base Demand and High Demand



Additionally, more Reliability Threats under high levels of demand would result in deficits than under base demand. When future demand is high, the climate change Reliability Threat and earthquake impacting

SGTP Reliability Threat both result in deficits under the No Action Scenario. All of the resiliency alternatives would alleviate the deficits caused by an earthquake impacting SGTP. However, Dry Year Actions, Maximize Reuse, and Maximize Resiliency would be the only alternatives that prevent deficits under climate change with high demand. The Minimize Infrastructure and Expand Existing Programs alternatives would greatly reduce deficits, but they would not be eliminated. See data tables in Appendix A for more detailed results.

4.4 Alternatives Evaluation Results Considering Cost

In addition to reliability and other criteria, the alternatives were compared and evaluated based on cost. Costs developed for each resiliency option were input into WaterSim along with current operating costs to compare the alternatives. Figure 4-5 shows the cost per AF of operating each alternative under the Six-Year Severe Drought. Clearly, No Action is the least costly alternative and is comparable to the Minimize Infrastructure and Expand Existing Programs alternatives. Dry Year Actions, Maximize Reuse, and Maximize Resiliency are all much more expensive and have similar costs per AF.

Figure 4-5: Operating Cost for Each Alternative under Six-Year Severe Drought Reliability Threat

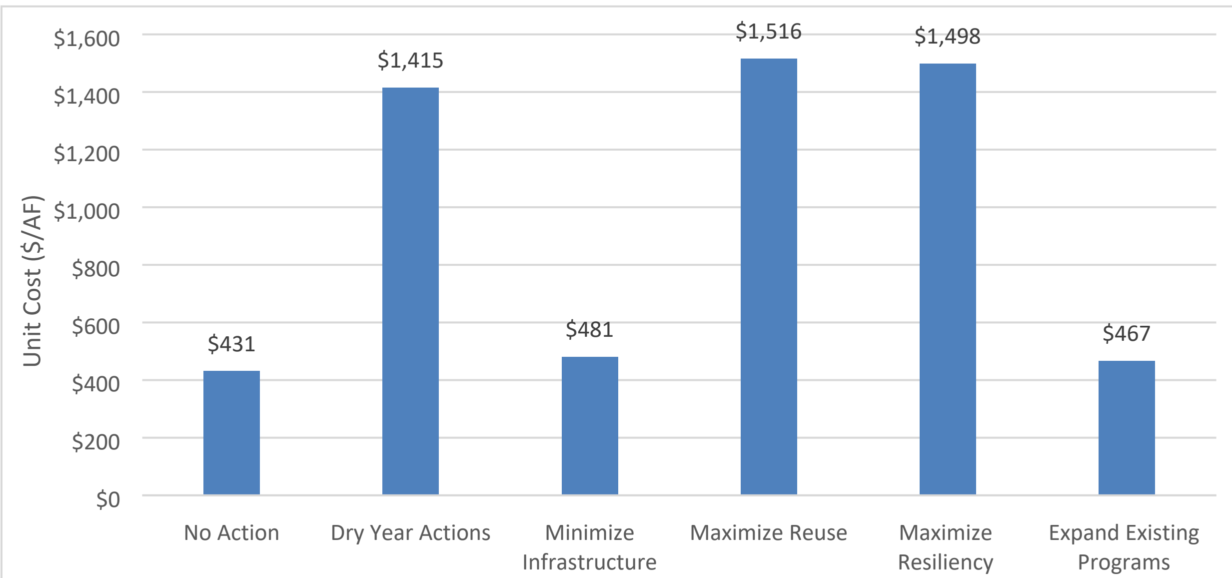
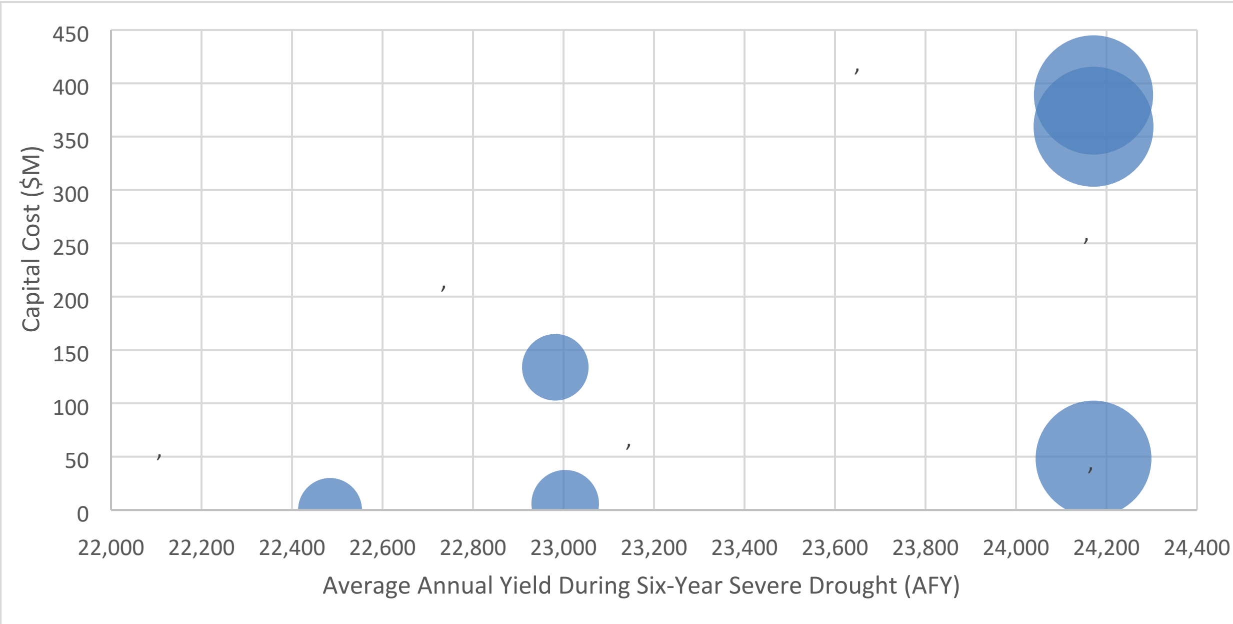


Figure 4-6 graphs the total capital cost of each alternative against its anticipated yield in a Six-Year Severe Drought, with the size of the bubble for each alternative representing the cost per AF for each alternative. This indicates that Minimize Infrastructure and No Action have very similar capital and unit costs, while Maximize Resiliency, Maximize Reuse, and Dry Year Actions all have much greater unit costs and yields. Note that the Dry Year Actions Alternative has a much lower capital cost than the other high-yield, high unit cost alternatives. Both Expand Existing Programs and Minimize Infrastructure have similar unit costs and higher average annual yield than the No Action Alternative, but the Expand Existing Programs alternative has a greater capital cost.

Figure 4-6: Alternatives Capital Cost, Unit Cost, and Average Annual Yield under Six-Year Severe Drought Reliability Threat (Bubble Size is $/AF)



There is a clear tradeoff between maximum reliability and cost during SevereDrought conditions. The only options that are likely to fully prevent deficits (Dry Year Actions, Maximize Resiliency, and Maximize Reuse) are also the most expensive alternatives, both in capital cost and unit cost. The Expand Existing Programs and Minimize Infrastructure alternatives offer a middle ground with reduced deficits and slightly higher costs than the No Action Alternative.

4.5 Results Summary

Detailed results for each alternative under the Six-Year Severe Drought, Nine-Year Severe Drought, climate change, and an earthquake impact SGTP can be found in Appendix A. The most impactful results are summarized below.

Alternatives and Reliability Threats under Base Demand

Deficits were observed under the No Action alternative for the Six-Year and Nine-Year Severe Drought. The Six-Year Severe Drought deficits were eliminated by three of the proposed alternatives: Dry Year Actions, Maximize Reuse, and Maximize Resiliency. All alternatives increased storage under climate change compared to the No Action Alternative.

Alternatives and Reliability Threats under High Demand

Deficits were observed under the No Action alternative for the Six-Year Severe Drought, Nine-Year Severe Drought, earthquake impacting SGTP, and climate change Reliability Threats. Under high demand, only the Maximize Resiliency alternative eliminated all deficits under the Six-Year Severe Drought. All alternatives increase storage under climate change compared to no action, but the Expand Existing Programs and Minimize Infrastructure alternatives would have deficits under high demand and climate change. All alternatives prevented deficits for an earthquake impacting SGTP under high demand.

5 Recommended Alternative

The recommended alternative is a variation of the Expand Existing Programs alternative. Given the low expected frequency of droughts as extreme as the Six or Nine-Year Severe Drought, a major infrastructure investment designed to provide reliability during this type of drought is not recommended until lower cost and less infrastructure-intensive alternatives have been exhausted. Although the capital cost and unit cost of the Expand Existing Programs alternative is relatively high, it is the most flexible of all of the options. The costs for the Conservation and Watershed Management resiliency options within the alternative represent the maximum possible cost and effort that MMWD could expend on the option. It is recommended that MMWD implement these options within reasonable budgetary constraints, yielding a benefit up to the maximum reflected in the options presented. in addition, despite relatively high capital costs, the operating cost of the Expand Existing Programs alternative is comparable to the current No Action cost, as seen in Figure 4-5.

The Expand Existing Programs alternative, if implemented fully, would provide an additional 2,000 AFY of supply, which would be sufficient to meet demands under all base demand and high demand Reliability Threats except for the Six and Nine-Year Severe Droughts. The options are flexible, allowing MMWD to experience benefits when needed during critically dry years, while postponing or avoiding investment in major infrastructure that would not be needed under the most probable future scenarios.

Given the cost, flexibility, minimal infrastructure requirements, and high level of project readiness, it is recommended that MMWD investigate expanding its existing planned conservation and watershed management programs and pursue potential conjunctive sue arrangements with other SCWA partner agencies to provide improved resiliency in the near term.

Appendix A: Alternatives Evaluation under Severe Drought, Climate Change, and Earthquake Reliability Threats

Base Demand

Severe Drought (6 Year)	No Action	Dry Year Actions	Minimize Infrastructure	Maximize Reuse	Maximize Resiliency	Expand Existing Programs
Number of Months with Deficit	11	0	9	0	0	8
Average Monthly Deficit	1,070	0	839	0	0	955
Maximum Monthly Deficit	1,926	0	1,842	0	0	1,842
Maximum Annual Deficit	6,920	0	5,868	0	0	5,868
Total System Storage	71,827	72,800	72,327	75,153	75,527	72,299
Total System Overflows	67,886	69,988	69,863	75,422	77,431	69,601
Months with Soulajule Usage	13	6	12	0	0	12

Severe Drought (9 Year)	No Action	Dry Year Actions	Minimize Infrastructure	Maximize Reuse	Maximize Resiliency	Expand Existing Programs
Number of Months with Deficit	26	1	24	0	0	22
Average Monthly Deficit	1,145	148	949	0	0	1,038
Maximum Monthly Deficit	1,926	279	1,843	0	0	1,843
Maximum Annual Deficit	6,884	296	5,935	0	0	5,935
Total System Storage	70,533	71,635	71,030	74,353	74,899	71,004
Total System Overflows	67,059	69,119	68,987	74,266	76,254	68,731
Months with Soulajule Usage	22	13	18	5	0	18

High Demand

Severe Drought (6 Year)	No Action	Dry Year Actions	Minimize Infrastructure	Maximize Reuse	Maximize Resiliency	Expand Existing Programs
Number of Months with Deficit	25	10	21	1	0	21
Average Monthly Deficit	1,536	993	1,444	536	0	1,458
Maximum Monthly Deficit	2,729	1,943	2,646	536	0	2,646
Maximum Annual Deficit	11,229	5,949	10,443	536	0	10,360
Total System Storage	69,121	70,639	70,173	73,129	73,599	69,903
Total System Overflows	61,288	63,960	64,439	68,476	71,727	62,844
Months with Soulajule Usage	17	13	17	10	7	17

Earthquake (SGTP)	No Action	Dry Year Actions	Minimize Infrastructure	Maximize Reuse	Maximize Resiliency	Expand Existing Programs
Number of Months with Deficit	3	0	0	3	0	1
Average Monthly Deficit	78	0	0	78	0	65
Maximum Monthly Deficit	148	0	0	148	0	65
Maximum Annual Deficit	234	0	0	234	0	65
Total System Storage	70,713	72,279	71,881	74,620	74,912	71,547
Total System Overflows	62,639	65,461	66,007	70,415	73,798	64,305
Months with Soulajule Usage	0	0	0	0	0	0

Climate Change (Lowest Inflows Scenario)	No Action	Dry Year Actions	Minimize Infrastructure	Maximize Reuse	Maximize Resiliency	Expand Existing Programs
Number of Months with Deficit	10	0	6	0	0	8

Average Monthly Deficit	925	0	327	0	0	758
Maximum Monthly Deficit	1,313	0	594	0	0	1,204
Maximum Annual Deficit	5,788	0	1,576	0	0	3,955
Total System Storage	62,908	67,226	64,539	70,281	71,125	63,920
Total System Overflows	39,080	44,958	42,029	46,526	49,574	40,560
Months with Soulajule Usage	23	5	11	6	5	12

Appendix J

Water Shortage Contingency Plan Technical Memorandum

Technical Memorandum

MMWD Water Resources Plan 2040

Subject:	**Water Shortage Contingency Plan**
Prepared For:	Carl Gowan, MMWD
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Reviewed by:	Alyson Watson, RMC
Date:	March 6, 2017
Reference:	0041-010

1 Background and Objective

As part of the 2015 Urban Water Management Plan (UWMP), the Marin Municipal Water District (MMWD) provided a Water Shortage Contingency Plan (WSCP) outlining how the district will prepare for and respond to water shortages. In developing the Water Resources Plan (WRP) 2040, the district used the Marin WaterSim model as a tool to understand how various events, such as drought and earthquakes, would impact the district's ability to meet demands. As a result of the WRP 2040 modeling effort, the district has opted to update the stages of action triggering a reduction and prohibitions on end uses.

The State is currently undergoing an effort to update the requirements for water shortage contingency planning. Executive Order (EO) B-37-16, issued on May 29, 2016, builds on the existing requirements from SB X7-7 and includes a provision to strengthen the requirements for urban WSCPs. Draft requirements will be publicly released by January 10, 2017. As a result, the current WSCP as contained in the district's 2015 UWMP will remain in place until the State's requirements are finalized. At that time, the district will revisit the proposed WSCP as presented in this TM to confirm compliance with the new requirements.

2 Past Drought and Emergency Conservation Information

The local region experienced a brief, but deep drought in the period from 1975 through 1977. This drought was the most severe experienced by the district and, as such, became the district's drought of record. A more prolonged drought punctuated with brief periods of rainfall occurred from 1987 through 1992.

During the 1970s drought, the district explored the feasibility of groundwater use and found that groundwater was both very limited and also impacted by the drought. The district increased its efforts to distribute low-flow showerheads, toilet tank displacement bottles and water conservation literature, and constructed pipelines (both temporary and permanent) across the Richmond-San Rafael Bridge and to Sonoma County to import water. Ultimately, the district relied heavily on the ability of its consumers to make radical reductions in the amount of water they consumed. During the final stage of the 1976-77 drought, consumers reduced their water use by approximately 63 percent when the district went into a mandatory water use reduction program.

Following the 1970s drought, the district continued to add water conservation programs, added more surface water storage, and developed its recycled water program. By 1987, the water demand had returned to pre-drought levels. However, with improved supplies and the ability to import water from the SCWA, the district was able to reduce the requested mandatory water use reductions during the late 1980s and early 1990s drought. The water use reductions that were requested and achieved during this drought depressed water use for years after the drought had ended. Water use did not return to 1980 levels until the year 2001. Subsequently, increased water conservation efforts stabilized water use until the financial recession that began in 2008 reduced water demand to about the same low levels experienced during the early 1990s drought.

More recent drought conditions have indicated a need for additional system storage in an effort to accommodate more climate variability. For instance, on December 31, 2012, MMWD's reservoirs were full (79,566 AF) and fiscal year to-date rainfall was 33 inches, compared to average rainfall of 19 inches. The following calendar year (2013), MMWD received 10.68 inches of rainfall, far below the previous record low of 19 inches set in 1929. By January 16, 2014, storage levels had dropped to 43,600 AF, roughly 18,700 AF below normal for that date. A high pressure system, referred to as the Ridiculously Resilient Ridge, had settled in the Pacific Ocean and was preventing storm events from reaching the Bay Area and much of California. With no rainfall in the forecast, reservoir storage levels were on course to be below 50,000 AF on April 1, which would have prompted implementation of MMWD's Dry Year Water Use Reduction Program.

Over the course of 14 months, MMWD's water supply circumstances had changed dramatically, going from full reservoirs to conditions nearly requiring mandatory reductions. Water supply circumstances changed again in early February 2014 when the district received 15 inches of rain, more than had been received during the prior 400 days. Storage levels were above 50,000 AF on April 1, negating the need for mandatory use reductions. However, because storage levels remained below normal, the district continued its campaign of urging customers to further improve water use efficiency.

Recent variability in rainfall patterns emphasizes the need to investigate, evaluate, and develop water supply resiliency. In response to this need, the district has updated the stages of action that trigger water use reductions.

3 Stages of Action

In 1999, the district developed a rationing plan (Title 13 sections 13.020.30-13.02.040), with updates in 2011, 2014, and 2015. The district's prior WSCP included three triggers at 10 percent, 25 percent, and 50 percent rationing levels. This new WSCP includes five triggers selected because they provide the district more flexibility in addressing dry periods early. Developed through the GoldSim modeling effort, the triggers allow the district to successfully manage supplies through a Six-Year Severe Drought and are designed to reduce the likelihood of a water shortage that will negatively affect customers.

Table 3-1 shows the five stages of water shortage currently used by the district, including a 10 percent voluntary rationing and mandatory rationing levels set at 20 percent, 25 percent, and 30 percent. A 50 percent mandatory rationing level is included for water shortage emergencies. The water rationing stages are linked to the amount of water in the district's reservoirs as shown in **Table 3-1**[1]. The 10 percent voluntary rationing stage (Advisory Stage) is triggered when total reservoir storage is less than 60,000 AF on April 1st. The 20 percent mandatory rationing stage (Alert Stage) is triggered when total reservoir storage is less than 50,000 AF on April 1st. The 25 percent mandatory rationing stage (Severe Stage) is triggered when total reservoir storage is less than 40,000 AF on April 1st. The 30 percent mandatory rationing stage (Critical Stage) is triggered when total reservoir storage is less than 30,000 AF on April 1st.

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[1] The amount of water in the district's reservoirs includes emergency storage and dead storage.

The 50 percent mandatory rationing stage (Emergency Stage) is triggered when total reservoir storage on December 1st is projected to be in the vicinity of, or less than, 25,000 AF.

Table 3-1: Stages of WSCP

Stage	Complete One or Both	
	Percent Supply Reduction	Water Supply Condition
1: Advisory Stage (Voluntary Rationing)	10%	Total reservoir storage[1] is less than 60,000 acre-feet on April 1
2: Alert Stage (Mandatory Rationing)	20%	Total reservoir storage is less than 50,000 acre-feet on April 1
3: Severe Stage (Mandatory Rationing)	25%	Total reservoir storage is less than 40,000 acre-feet on April 1
4: Critical Stage (Mandatory Rationing)	30%	Total reservoir storage is less than 30,000 acre-feet on April 1
5: Emergency Stage (Mandatory Rationing)	50%	Total reservoir storage on December 1 is projected to be in the vicinity of, or less than, 25,000 acre-feet
NOTES: (1) Total reservoir storage includes emergency storage and dead storage.		

3.1 Addressing Reductions Determined Outside of District Control

On January 14, 2014, the Governor of California declared a drought state of emergency and called on Californians to reduce water use by 20 percent. On April 1, 2015, the Governor set a precedent in California by issuing Executive Order B-29-15 which mandated water use reductions to achieve a 25 percent statewide reduction. To achieve this statewide goal, the State Water Resources Control Board adopted regulations specific to each agency; as a result, MMWD was mandated to reduce water use by 20 percent on a monthly basis in 2015, as compared to corresponding monthly use in 2013.

Recognizing that outside factors beyond supply conditions could generate a need for demand reduction, the district has opted to include an additional trigger in its updated Water Shortage Contingency Plan that is not directly related to current water supply conditions. This offers the district added flexibility to address future potential state mandates or any other needed demand reductions that are not directly triggered by the district's local water supply outlook. The stage resulting from the trigger would be dependent on the reduction required, as indicated below in **Table 3-2**.

Table 3-2: Additional Trigger for Responding to External Factors

Trigger	Stage
Reduction required due to external factors	To be selected from one of the 5 stages of action based on level of reduction needed (see **Table 1**).

4 Prohibitions on End Users

The district has a number of prohibitions that it implements during periods of rationing. Additionally, the district implements on-going prohibitions to reduce baseline water waste. **Table 4-1** below highlights these prohibitions. The prohibitions implemented by the district respond to high consumption end uses and increase in severity from Stages 1 through 5.

Table 4-1: Restrictions and Prohibitions on End Users

Stage	Restrictions and Prohibitions to End Users	Additional Explanation or Reference (optional)	Penalty, Charge, or Other Enforcement? Y/N
Landscape Irrigation			
On-going	Restrict or prohibit runoff from landscape irrigation	Irrigation shall not be conducted in a manner or to an extent that allows water to run off or overspray the areas being watered. Every consumer is required to have his/her water distribution lines and facilities under control at all times to avoid water waste.	Y
On-going	Other landscape restriction or prohibition	Irrigating outdoors during, and within 48 hours after, measurable rainfall is prohibited	Y
1	Other landscape restriction or prohibition	Request that landscape water is avoided during the hottest portion of the day.	N
2	Limit landscape irrigation to specific times	No irrigation between the hours of 10 AM and 6 PM.	Y
2, 3, 4, 5	Other landscape restriction or prohibition	Customer must repair controllable water leaks, correct overspray, or repair excessive landscape watering.	Y

Stage	Restrictions and Prohibitions to End Users	Additional Explanation or Reference (optional)	Penalty, Charge, or Other Enforcement? Y/N
3, 4, 5	Limit landscape irrigation to specific times	Irrigation is prohibited between the hours of 9 AM and 7 PM.	Y
3, 4, 5	Other landscape restriction or prohibition	No irrigation of new turf areas.	Y
3, 4, 5	Limit landscape irrigation to specific days	Landscape irrigation is limited to three days a week	Y
4, 5	Limit landscape irrigation to specific days	Landscape irrigation is limited to two days a week	Y
4, 5	Prohibit certain types of landscape irrigation	Golf course irrigation will be restricted to greens and trees if potable or raw water is sole source.	Y
5	Prohibit all landscape irrigation		Y
Commercial Industrial Institutional (CII)			
On-going	Lodging establishment must offer opt out of linen service	Lodging establishments must provide patrons the option of not having towels and linen laundered daily	Y
1	Restaurants may only serve water upon request	Request that restaurants only serve water to patrons upon request	N
2, 3, 4, 5	Restaurants may only serve water upon request	Prohibit restaurants from serving water to patrons, except on request.	Y
Water Features and Swimming Pools			
On-going	Require covers for pools and spas	Pool covers are required for all new outdoor swimming pools.	Y
On-going	Restrict water use for decorative water features, such as fountains	Prohibit non-recycling decorative water fountains.	Y

Stage	Restrictions and Prohibitions to End Users	Additional Explanation or Reference (optional)	Penalty, Charge, or Other Enforcement? Y/N
3, 4, 5	Other water feature or swimming pool restriction	Prohibit use of potable water for refilling or as make-up water for decorative fountains or pools.	Y
5	Other water feature of swimming pool restriction	Prohibit filling new or existing pools.	Y
Other			
On-going	Prohibit use of potable water for washing hard surfaces	Prohibit washing sidewalks, walkways, driveways, parking lots, and all other hard-surfaced areas by direct hosing, except to properly dispose of flammable or other dangerous liquids or substances or to prevent or eliminate materials dangerous to public health and safety.	Y
On-going	Customers must repair leaks, breaks, and malfunctions in a timely manner	Prohibit escape of water through breaks or leaks within the consumer's plumbing or private distribution system for any substantial period of time within which such break or leak should reasonably have been discovered and corrected. It shall be presumed that a period of forty-eight hours after the consumer discovers such a leak or break, or receives notice from the district of such leak or break, whichever occurs first, is a reasonable time within which to correct such leak or break.	Y
On-going	Other	New connections may not install single-pass cooling systems for air conditioning or other cooling system applications unless required for health or safety reasons.	Y
On-going	Other	New connections may not install non-recirculating systems for conveyer carwash applications.	Y

Stage	Restrictions and Prohibitions to End Users	Additional Explanation or Reference (optional)	Penalty, Charge, or Other Enforcement? Y/N
On-going	Other	Prohibit installation of reverse-osmosis water purifying systems not equipped with an automatic shutoff unit.	Y
2, 3, 4, 5	Other	Any use of potable water that results in excessive runoff from the property and/or gutter flooding is prohibited	Y
3, 4, 5	Require automatic shut-off hoses	Prohibit washing of cars, boats, airplanes with hose without a shut-off nozzle	Y
4, 5	Other	Request that local fire departments limit training exercises that use potable water and cease hydrant testing.	N
4, 5	Limit use of potable water for construction and dust control	Potable water shall not be used for construction or dust control if recycled or raw water is reasonable available	Y
5	Other	New water service applications will be granted upon the condition that water shall be used for interior purposes and landscaping shall be delayed until the district determines that Stage 5 rationing levels are no longer needed.	Y

Stage 0: Ongoing Prohibitions

Stage 0 contains prohibitions which are always in place, regardless of the District's water supply conditions. The water waste prohibitions are designed to decrease baseline water use and encourage responsible use of local supplies. The following list identifies on-going prohibitions:

- Irrigation shall not be conducted in a manner or to an extent that allows water to run off or overspray the areas being watered. Every consumer is required to have his/her water distribution lines and facilities under control at all times to avoid water waste.
- Irrigating outdoors during, and within 48 hours after, measurable rainfall is prohibited.
- Lodging establishments must provide patrons the option of not having towels and linen laundered daily.
- Pool covers are required for all new outdoor swimming pools.
- Non-recycling decorative water fountains are prohibited.

- Prohibit washing sidewalks, walkways, driveways, parking lots, and all other hard-surfaced areas by direct hosing, except to properly dispose of flammable or other dangerous liquids or substances or to prevent or eliminate materials dangerous to public health and safety.
- Prohibit escape of water through breaks or leaks within the consumer's plumbing or private distribution system for any substantial period of time within which such break or leak should reasonably have been discovered and corrected. It shall be presumed that a period of forty-eight hours after the consumer discovers such a leak or break, or receives notice from the district of such leak or break, whichever occurs first, is a reasonable time within which to correct such leak or break.
- New connections may not install single pass cooling systems for air conditioning or other cooling system applications unless required for health or safety reasons.
- New connections may not install non-recirculating systems for conveyer carwash applications.
- Prohibit installation of reverse osmosis water purifying systems not equipped with an automatic shutoff unit.

Stage 1: Advisory Stage (Voluntary Actions)

During Stage 1, the water supply shortage is triggered when the district's total reservoir storage is less than 60,000 acre-feet on April 1. This Stage includes voluntary measures that the District may suggest to customers.

Stage 1 includes the following voluntary measures:

- Request that landscape water is avoided during the hottest portion of the day.
- Request that restaurants only serve water to patrons upon request.

Stage 2: Alert Stage (Mandatory Prohibitions)

Stage 2 is designed to respond to a shortage where the district's total reservoir storage is less than 50,000 acre-feet on April 1. During Stage 2 of a water supply shortage, demand must be reduced by at least 20 percent for the District to meet the immediate needs of its customers.

Stage 2 includes the following mandatory prohibitions:

- Irrigation is prohibited between the hours of 10 AM and 6 PM.
- Customers must repair controllable water leaks, correct overspray, or repair excessive landscape watering.
- Restaurants are prohibited from serving water to patrons, except on request.
- Any use of potable water that results in excessive runoff from the property and/or gutter flooding is prohibited.

Stage 3: Severe Stage (Mandatory Prohibitions)

During Stage 3, the water supply shortage is severe and triggered when the district's total reservoir storage is less than 40,000 acre-feet on April 1. As a result, district demand must be reduced by at least 25 percent in order for the District to meet the immediate needs of its customers.

All Stage 2 prohibitions remain in effect and the following mandatory prohibitions are added:

- Irrigation is prohibited between the hours of 9 AM and 7 PM.
- No irrigation of new turf areas.
- Landscape irrigation is limited to three days a week.
- Prohibit use of potable water for refilling or as make-up water for decorative fountains or pools.
- Prohibit washing of cars, boats, airplanes with hose without a shut-off nozzle.

Stage 4: Critical Stage (Mandatory Prohibitions)

Stage 4 is structured to respond to a critical shortage and is triggered when the district's total reservoir storage is less than 30,000 acre-feet on April 1. During Stage 4 of a water supply shortage, demand must be reduced by at least 30 percent for the District to meet the immediate needs of its customers.

All Stage 3 prohibitions remain in effect and the following mandatory prohibitions are added:

- Landscape irrigation restrictions are implemented to limit the allowable frequency of irrigation to a maximum of two days per week and based on the following schedule:
    - Premises having odd-numbered street addresses irrigate only on Wednesdays and Sundays.
    - Premises having even-numbered street addresses irrigate only on Tuesdays and Saturdays.
- No watering will be allowed by any addresses on Mondays, Thursdays, and Fridays.
- Golf course irrigation will be restricted to greens and trees if potable or raw water is the sole source.
- Request that local fire departments limit training exercises that use potable water and cease hydrant testing.
- Potable water shall not be used for construction or dust control if recycled or raw water is reasonably available.

Stage 5: Emergency Stage (Mandatory Prohibitions)

During Stage 5 of a water supply shortage, a 50 percent or greater reduction in water use is required for the District to meet the immediate needs of its customers. This stage is triggered when total reservoir storage on December 1 is projected to be in the vicinity of, or less than, 25,000 acre-feet.

All Stage 4 prohibitions remain in effect and the following mandatory prohibitions are added:

- All landscape irrigation is prohibited.
- Filling new or existing pools is prohibited.
- New water service applications will be granted only on the condition that water shall be used exclusively for interior purposes and landscaping shall be delayed until the District determines that Stage 5 rationing levels are no longer needed.

4.1 Variances to Dry Period Regulations

The district does allow for certain variances to the water shortage stage requirements previously discussed. All variance requests must be submitted in writing to the district and include the account name, service number, and service address.

Residential Customers

Variance requests will be considered for the following:

- Medical hardship - Requires letter from physician supporting applicant's request.
- For business use in home - Requires copy of business license.

Commercial, Institutional, and Other Uses

Requests will be considered when the customer can show that severe financial handicap will occur without additional water. The written request should include a statement addressing the following:

- What has been done to reduce consumption,
- Why is the customer unable to further reduce consumption, and
- How much water the customer needs.

In granting variances, water saving retrofits or modifications may be required if deemed practical by district personnel. For example, a licensed home day care center may be required to retrofit 1.6 gallon ultra-low flow toilets (ULFTs) and flow restricting faucet aerators before being granted a variance allotment.

Variances will not be granted for:

- Home businesses without a business license,
- Temporary residents (less than 6 months),
- Pets or livestock (except cattle and horses),
- Gardening or landscaping needs,
- Parks or athletic fields, or
- Normal expansion of a business or institution.

5 Penalties, Charges, and Other Enforcement of Prohibitions

Any customer violating the regulations and restrictions on water use set forth above in **Table 2** shall receive a written warning for the first such violation. Upon a second violation, the customer shall receive a written warning and the district may require a flow restrictor to be installed in the service. If a flow restrictor is placed, the cost of installation and removal shall be paid by the violator. Any willful violation occurring subsequent to the issuance of the second written warning shall constitute a misdemeanor and may be referred to the Marin County District Attorney's office for prosecution. The district may also disconnect the water service. If water service is disconnected, it shall be restored only upon payment of the turn-on charge fixed by the district’s Board of Directors.

Penalties for failure to comply with the restrictions in **Table 4-1** are as follows:

- First Violation: The district will issue a written warning and deliver a copy of Title 13 by mail, hand, facsimile or email.

- Second Violation: A second violation within the preceding twelve (12) calendar months is punishable by a fine not to exceed one hundred dollars ($100).
- Third Violation: A third violation within the preceding twelve (12) calendar months is punishable by a fine not to exceed two hundred and fifty dollars ($250).
- Fourth and Subsequent Violations: A fourth and any subsequent violation is punishable by a fine not to exceed five hundred dollars ($500).

Each day that a violation of Title 13 occurs is considered a separate offense. In addition to financial penalties, penalties may include installation of flow restrictors and shut-off of service.

6 Consumption Reduction Methods

Consumption reduction methods are actions that are taken by the district to reduce water consumption, while prohibitions on end uses, addressed in Section 4, are actions that restrict end uses that are the responsibility of the end users. In addition to the actions described in Section 4, the district also engages in consumption reduction actions to support the varying rationing stages. These actions include aggressive public information campaigns, water saving retrofit incentives, and technical support such as water audits and leak detection surveys. These actions are highlighted in **Table 6-1**, below.

Table 6-1: Stages of WSCP - Consumption Reduction Methods

Stage	Consumption Reduction Methods by Water Supplier	Additional Explanation or Reference (optional)
On-going	Extend Public Information Campaign	
On-going	Offer Water Use Surveys	
On-going	Provide Rebates on Plumbing Fixtures and Devices	
On-going	Provide Rebates for Landscape Irrigation Efficiency	
On-going	Provide Rebates for Turf Rebates	
4	Allow Access to Emergency Storage	The district reserves 25% of useable storage as emergency storage. During this stage, the 25% level would be lifted, allowing the district access to the emergency storage to meet demands.

7 Determining Reductions

The district uses database tools that have been integrated into the district's Systems Application Programming (SAP) system and SCADA archive system to track and report on changes in water consumption. These tools can be used to determine actual water reductions once the district issues a water alert.

8 Revenue and Expenditure Impacts

The district recognizes that rationing will have an adverse effect on revenues and available reserves and that operational costs often rise in time of drought because of the level of customer service activities required and increased water management costs. The following sections discuss the district's rate structure and reserve funds to safeguard against these revenue and expenditure impacts.

8.1.1 Drought Rate Structures, Surcharges

The district's water rate structure includes both a Fixed Bi-Monthly Service Charge and a Commodity Charge. The Service Charge is a flat bi-monthly charge based on the size of the meter serving a property and generally recovers the district's costs of billing, customer service, meter replacement and repair, meter reading, and a portion of general administrative overhead. The Commodity Charge is a variable per-unit charge measured in hundred cubic feet (CCF), or per 748 gallons, and is designed to recover the costs of water supply, treatment and distribution, and watershed maintenance. The district's rates for the Commodity Charge consist of three or four billing tiers that impose higher rates per unit of water as the level of consumption increases.

Predetermined storage levels, as previously described, will trigger set water use reduction goals. This reduction in water use will likely result in decreased revenues. However, district ordinances specify that a voluntary water conservation program of 10 percent will automatically result in a temporary increase of water rates by 10 percent, and a mandatory rationing program of 25 percent will result in a temporary increase of water rates by 25 percent.

In the drought of the 1987-1992, the district established a five-tier rate structure to encourage conservation. While this rate structure no longer exists, if necessary, a similar rate structure may be considered in future rationing periods.

In June 2014, the district began an update to their Cost of Service Analysis. Based on this analysis, the Board of Directors voted to increase the fixed Service Charge and add a new Watershed Management Fee in December 2015. Combined, these two changes increase the district's revenue from fixed charges from 17 percent to 28 percent of total water rate revenue. Additionally, the Board approved adjustments to the tier rates of the Commodity Charge for all customer classes and approved changes in the tier allotments for multi-family and duplex customer classes. The Board also approved an increase of 4% of all water service rates, fees, and charges effective May 1, 2016. Recycled water rates also increased and are based on the customers' water budget or, if one is not in place, of 1986-87 consumption.

8.1.2 Use of Financial Reserves

In 2012, the district created the Rate Stabilization Fund as part of the issuance of revenue bonds. This fund allows the district to set aside surplus to be used to meet the district's annual debt service in any future year or for any other lawful purpose. Such a set-aside needs to happen within 180 days of the financial year end. In December 2014, the district's Board of Directors voted to set aside $4.9 million from operating surplus from the 2013/14 fiscal year to boost the Rate Stabilization Fund. This increased the balance of the Rate Stabilization Fund to $7.3 million, which is equal to one year of debt service. As a result of the drought, the Finance Committee authorized the withdrawal of $1.4 million from the Rate Stabilization Fund in October 2015, decreasing the balance to $5.9 million.

8.1.3 Other Measures

Other measures that the district would implement to safeguard against revenue impacts associated with rationing include implementing staff furloughs, suspending replacement of personnel upon retirement, and moving charges from operations to capital projects.

9 Catastrophic Supply Interruption

In 1999, the district updated its emergency response plan in preparation for the advent of the year 2000 and the various possible energy shortage scenarios suggested by the Y2K event. A subsequent update of the emergency response plan occurred in 2004; another update is currently underway and is expected to be complete in spring of 2016. As a result of these plans, the district has emergency response generators that can power a variety of small- to medium-sized pump stations throughout the service area. To accept the power from the emergency generators, the district has retrofitted most of its pump stations. The remaining stations can be bypassed to allow gas engine driven pumping or have emergency generators onsite.

In addition, the district has installed large fixed generators and fuel supply systems at the Bon Tempe Water Treatment Plant and the Ignacio Water Quality Station. These facilities will allow the district to provide full winter use period water deliveries (about half of summer use demand) to its customers for a month or more in the absence of outside (PG&E) power supplies.

The district is in a seismically active area and a major earthquake could result in a catastrophic supply interruption. The district developed a seismic strengthening program for its treatment and transmission system in 1995. The seismic strengthening is also linked to providing water for fire suppression needs following a significant seismic event and was folded into the district's Fire Flow Master Plan (FFMP). The FFMP was implemented over a 15-year period and extended as Fire Flow Improvement Program (FFIP) in May 2012 for an additional 19 years.

During a declared shortage, the district will issue notifications to its customers to conserve water. If the length of service interruption is to be for an extended period of time, the district will determine if the situation is localized or widespread and develop a specific plan to provide water for health and safety during the situation.

During extended periods of water shortage, the district has worked with other water suppliers to provide modest amounts of water to ultimately reduce the overall level of cutbacks in water use required of the district's customers. Even with the additional supplies, the district requested a 57 percent use reduction by its customers during the drought of the 1970s.

10 References

Carollo Engineers. Marin Municipal Water District Cost of Service Study. December 2015. Available at: https://www.marinwater.org/documentcenter/view/3591.