Marin Municipal Water District

Final Draft Report

Appendix B. System Model Description

May 2023

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APPENDIX B

MarinDSM

B.1 Introduction

A mathematical modeling tool (MarinDSM) was developed for the Marin Municipal Water District (MMWD) Strategic Water Supply Assessment study to evaluate:

- The magnitude of storage deficit and water supply shortages with existing infrastructure under different inflow and demands scenarios
- The performance of potential water management alternatives in resolving storage deficits and delivery shortages

The MarinDSM was developed by applying improvements and significantly more details in the representation of the MMWD system to an existing model developed for Sonoma Water agency. The initial model (prior to 2021) included a simplified representation of the MMWD system. Model improvements and refinements of the MMWD system included:

- details relating to MMWD's seven local reservoirs,
- refinement of MMWD reservoir inflows,
- consistent hydrology applied between MMWD system and Russian River,
- addition of MMWD's three water treatment plants,
- additional model rules to move water between reservoirs,
- model logic relating to MMWD's environmental releases from Kent and Soulajule Reservoirs,
- capacity limitations on the Petaluma aqueduct; as well as,
- several system modifications to be able to run what-if scenarios.

Use of the MarinDSM assisted the project team in comprehensively evaluating impact of drought on MMWD's water supply system as well as to understand the benefit of potential water supply projects compared to previous developed models (MBK Engineers, 2002 and RMC, 2017), that were focused only on the MMWD system.

B.2 Model Platform

The MarinDSM was developed in the general system dynamics modeling platform named GoldSim. GoldSim is a general simulation software solution for dynamically modeling complex systems in business, engineering, and science. GoldSim supports decision and risk analysis by simulating future performance while quantitatively representing the uncertainty and risks inherent in all complex systems. Organizations worldwide use GoldSim simulation software to evaluate and compare alternative designs, plans, and policies to minimize risks and make better decisions under uncertainty. GoldSim, (1) can handle all the complexities of the system, (2) provides for ease of use and alternative analysis, (3) provides a state-of-the-art modeling platform so as to not become outdated in a short time, (4) allows for ease of linkage to other analysis tools used by the District, (5) can be enhanced by District staff, and (6) is relatively economical.

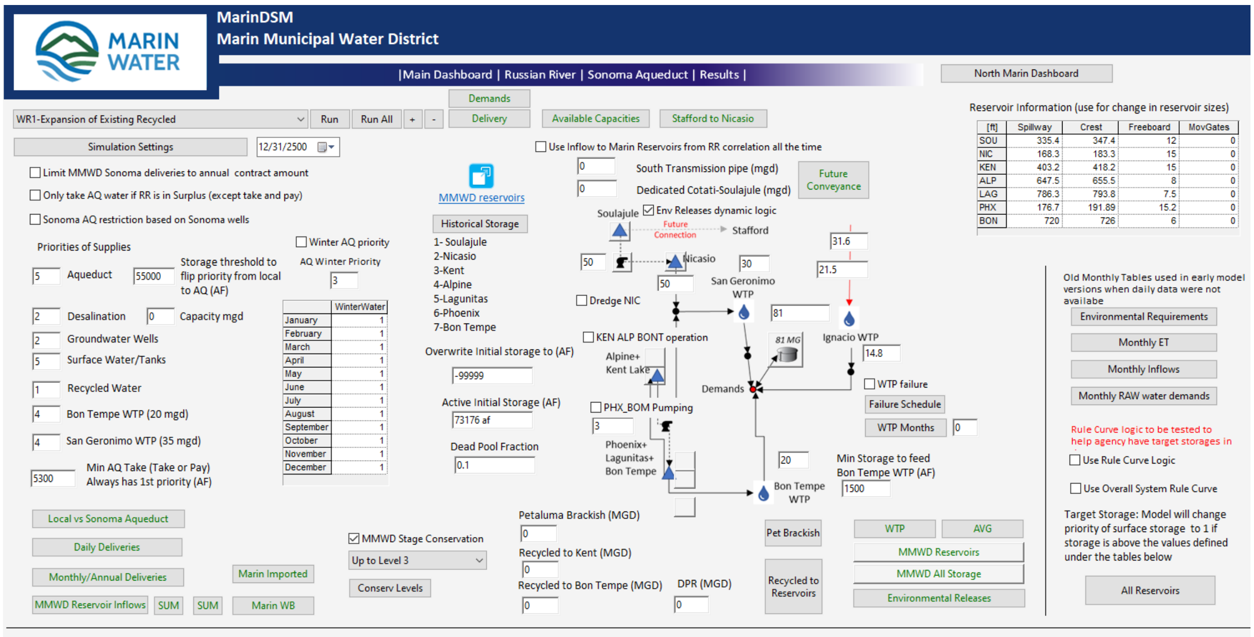
The GoldSim modeling platform includes several key features like the ability to customize operating rules or simulation procedures, the ability to iterate within a time-step to solve non-linear problems and perform pseudo-optimization, the ability to create sub-models for subsystem partitioning or forecast-based decision making, and the ability to perform probabilistic simulation for use in alternative proposed project analyses, climate change studies, or stochastic simulations.

Other important factors in selecting GoldSim for the MarinDSM are the ability of the modeling platform to handle various hydraulic units, data exchange between other programs or spreadsheets, and the handling of array constructs. Also, the District is already familiar with GoldSim having developed it to model (forecast) reservoir storage levels for various hydrological conditions for the 2017 Water Resources Plan 2040 (RMC 2017).

The current model version (GoldSim file) that represents the Russian River, Sonoma transmission system and MMWD system comprises more than 2,700 model elements, 5,100 model inputs and 4,700 model outputs. Model inputs are grouped in 17 different dashboards that serve as a user interface for model usage. A typical model single simulation from 2022 to 2045 takes approximately 40 seconds to run on a daily time step.

Figure B-1 is a sample of one of the MarinSim model dashboards, where the user can interact with the model by changing scenario inputs and verifying model results.

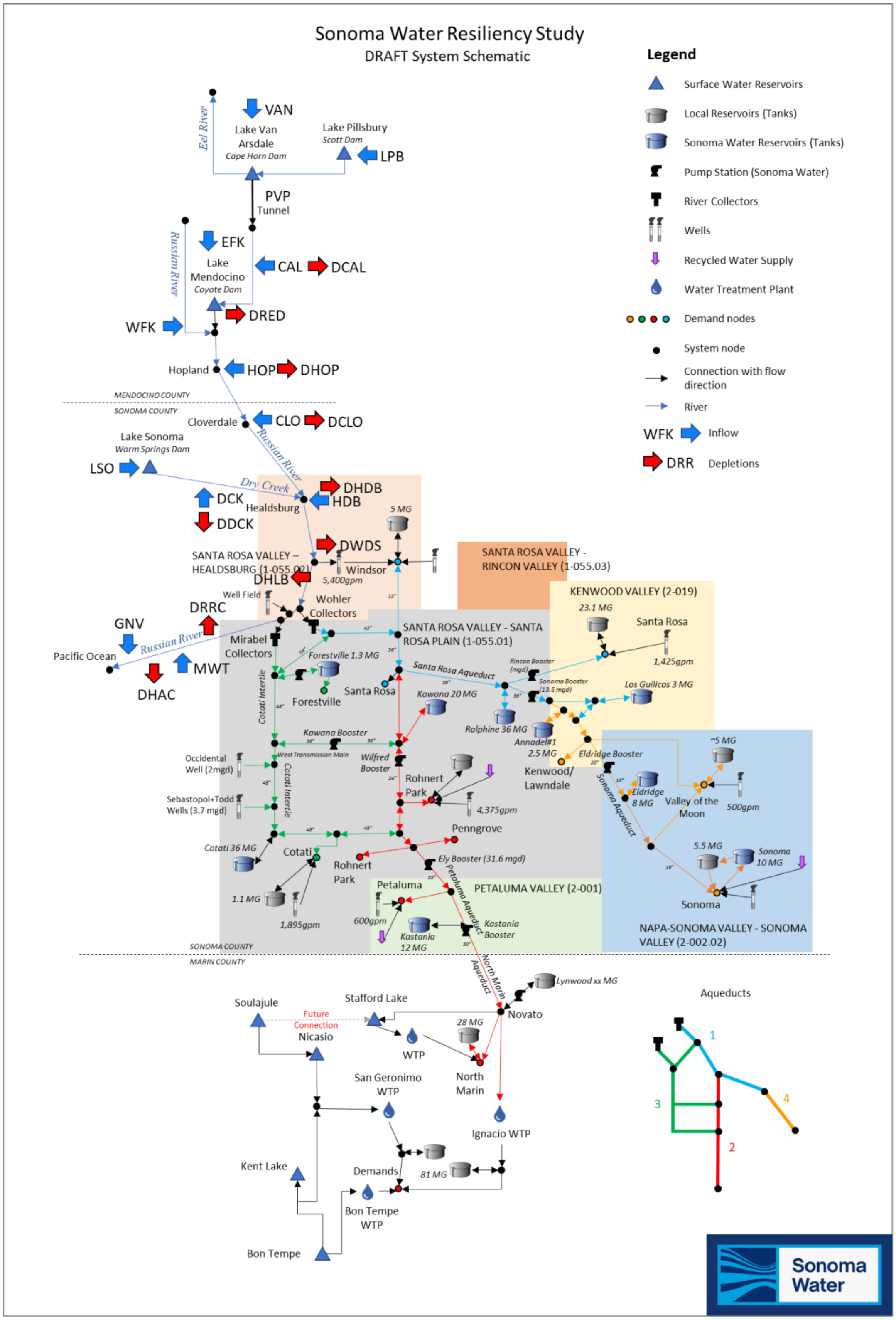
Figure B-1. Example of one MarinDSM model dashboard



B.3 System Representation

The initial model version was developed for Sonoma Water Agency in 2021 and included representation of all the Sonoma Water contractors plus a simplification of the MMWD system that was later upgraded. The initial model version included the Russian River upstream of Sonoma Water collectors, and the upstream reservoirs including Lake Sonoma, Lake Mendocino and Lake Pillsbury. Figure B-2 illustrates the extent and contents of the initial Sonoma Water model.

Figure B-2. MMWD total storage comparison between model results and measured storage for the model validation period



One of the goals of the Strategic Water Supply Assessment study was to evaluate the overall MMWD system supply conditions assuming that water treatment capacities and ability to use local surface storage were being properly used to avoid system shortages and minimize imported water usage. It wasn't in the scope of this study to create a precise representation of each reservoir operation and each water treatment plant. With clear goals and expectations for model results, a system schematic was developed indicating what model components would be expected to be included in the MarinDSM in addition to the initial representation presented in Figure B-2.

The MarinDSM model includes current water system components (further described under this section) included in the model baseline scenario plus potential projects, not yet implemented but that are being considered in the study and have the option to be included in alternative model scenarios.

Figure B-3 shows the MMWD system after the representation upgrade done in 2022 during the Strategic Water Supply Assessment study, the figure shows the MarinDSM domain downstream of Ely booster, with potential projects that could increase water supplies to the system.

The upgraded MMWD system representation includes more details on reservoirs, water/wastewater treatment plant operation, potential facilities, and type of water (imported, local reservoir, desalination and recycled) supplied to MMWD's distribution system. Natural inflows into the reservoirs are from runoff and precipitation. Imported water comes from the Russian River delivered by the Sonoma Water via the Petaluma Aqueduct. Potential future inflows into the system can include new connections to the Sonoma aqueduct, expansion of recycled water production and usage, or desalination production (ocean or brackish). In this study, it is assumed that once the water is treated in one of the three treatment plants, it can reach all the District's system via MMWD distribution system. The system supply of potable water is then limited by San Geronimo and Bon Tempe water treatment plant capacities and a capacity limitation for Ignacio water treatment plant identified in a recent study (W&C, 2022) downstream of Ignacio Water Treatment Plant. This assumption is consistent with the goals of this study, which is concerned about the availability of water supplies to meet system demands without full depletion of local storage reservoirs during drought events.

An important section of the system is the transmission line section between Ely booster and Ignacio pump station which comprises a section of the Petaluma aqueduct and the North Marin transmission line. That section can be a potential bottleneck of imported water to MMWD system due to pipe and booster capacities. The North Marin district is also included in Figure B-3 due to some interactions with MMWD system, mainly in the sharing of existing and future conveyance and pump stations that convey imported water to both systems.

B.3.1 Treatment Plants

The district treats water at its three water treatment plants, the Bon Tempe Treatment Plant (BTTP) near Ross, the San Geronimo Treatment Plant (SGTP) in Woodacre, and the Ignacio treatment facility in Novato. Together, these facilities have a combined design capacity of

71 million gallons per day (MGD) or 79,585 AFY. Shown in Table B-1 below are the supply source and design capacity of each of the District's Treatment Plants. Although the table shows the design capacity, the sustainable production of the plants according to MMWD staff is lower, 28 MGD for San Geronimo and 15 MGD for Bon Tempe and 14.8 MGD for Ignacio based on recent study (W&C 2022) for a total sustainable capacity of 57.8 MGD.

Table B-1. MMWD water treatment plants capacity and supply sources

Treatment Plant	Supply Source	Design Capacity
San Geronimo	Nicasio and Kent	35 MGD (28 MGD sustainable)
Bon Tempe	Bon Tempe	20 MGD (15 MGD sustainable)
Ignacio	Petaluma Aqueduct	16 MGD (14.8 MGD)

B.3.2 Reservoirs

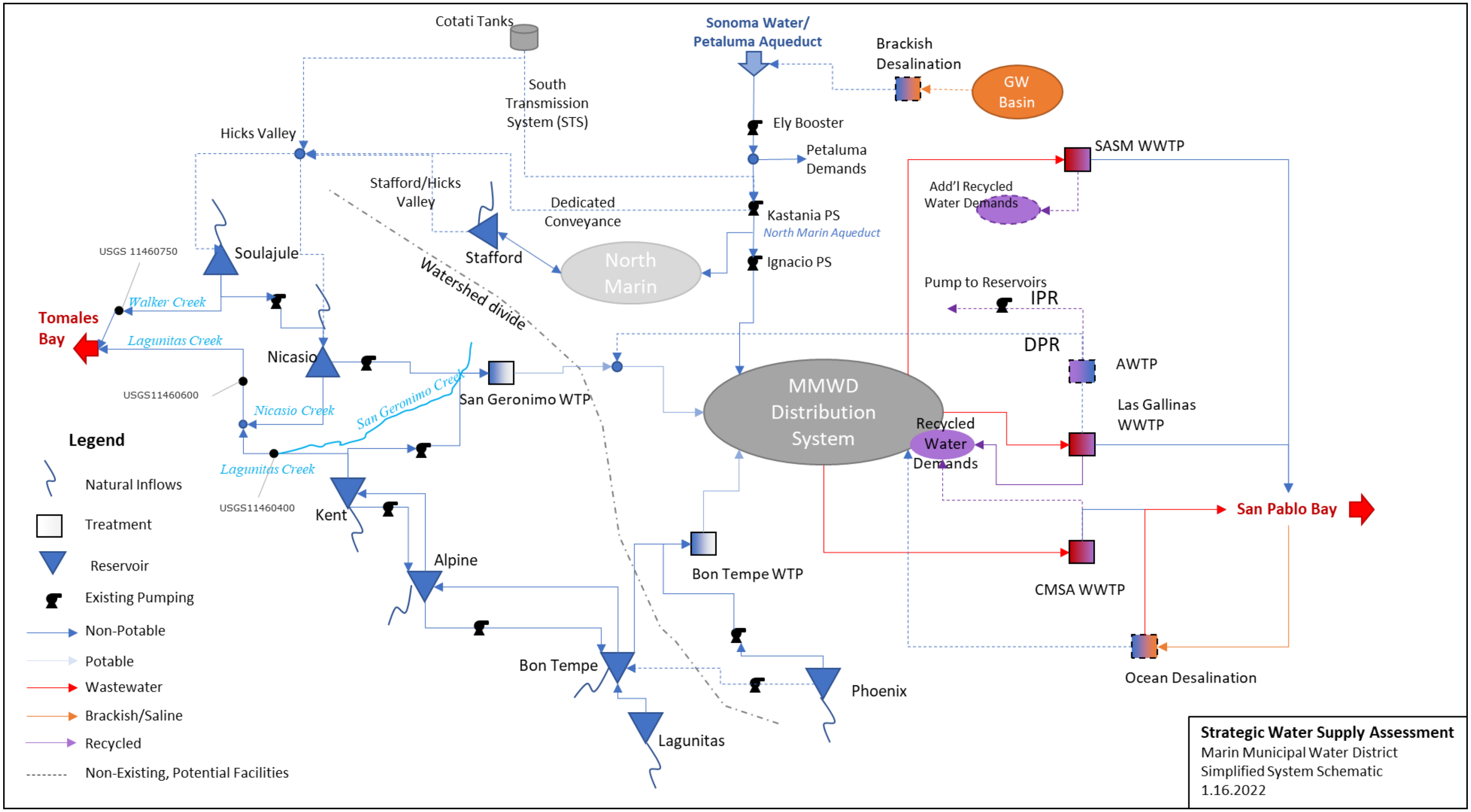
The district's reservoirs include the Alpine, Bon Tempe, Kent, Lagunitas, Phoenix Lake, Nicasio, and Soulajule. Five of the seven District reservoirs (Alpine, Bon Tempe, Kent, Lagunitas, and Phoenix Lake) are located on the north slope of Mt. Tamalpais while the two remaining reservoirs are located outside the District's service areas near western Marin County. A summary of the district reservoir capacities is presented in Table B-2, accounting for a recent 2017 survey that updated the capacity of the reservoirs. A significant difference in storage capacity was verified in Lake Nicasio, a 1,707 AF reduction in Lake volume due to sedimentation.

Table B-2. MMWD surface reservoir storages

Surface Reservoir	Historical Capacity (AF)	2017 Updated Capacity (AF)	Difference (AF)	% Change
Alpine Lake	8,891	8,953*	62	0.7%
Bon Tempe Reservoir	4,017	4,504	487	12.1%
Kent Lake	32,895	33,310	415	1.3%
Nicasio Reservoir	22,430	20,723	-1,707	-7.6%
Soulajule Reservoir	10,572	10,723	151	-3.0%
Lagunitas Lake	350	331	-19	-5.5%
Phoenix Lake	411	306	-105	-25.4%
Total	79,566	78,384	-1,182	-1.5%

*Capacity reported at elevation of high water mark near dam (647.5 ft)

Figure B-3. MMWD total storage comparison between model results and measured storage for the model validation period



B.4 Model Inputs

Model inputs are separated into Inflows, demands, and user controls for the system, which will determine, for example, hydrological sequence of flows to be used, the capacity of a pipeline, or capacity of a booster pumping station. The settings or values chosen in user inputs will determine the different model scenarios or simulation runs. All model scenarios derive from a baseline operation that represents current system configuration, capacities and connectivity of pipelines. The different model inputs which are grouped in model dashboards, and can be changed for different model scenarios. Following is a description of inflows and demands included in the MarinDSM.

B.4.1 Inflows

The main model input to MarinDSM are rivers and reservoir inflows. From rivers and reservoir inflows the model has programmed rules that will operate reservoirs and allocate water supplies to meet system demands.

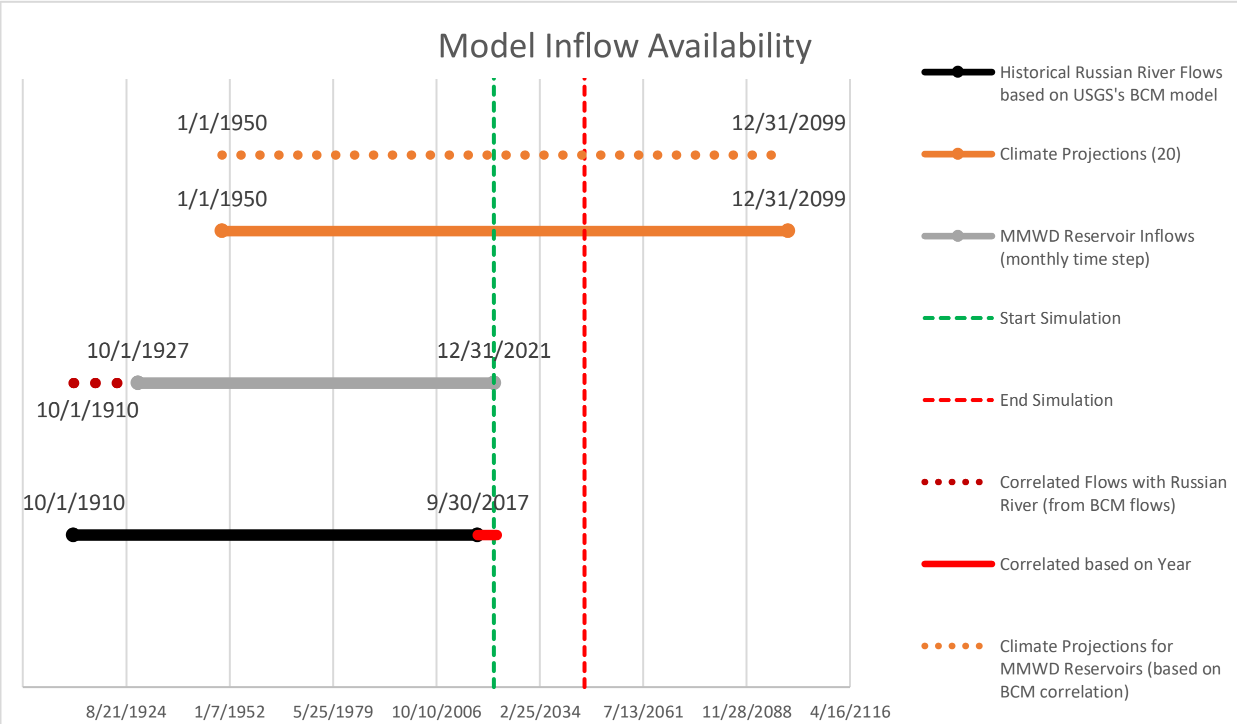
The MarinDSM inflows can be divided into Russian River Inflows and MMWD reservoir inflows. The Russian River inflows will ultimately determine the amount of imported water that is available to MMWD as imported water. MMWD reservoir inflows determine how much local supply is available and will determine how much imported water is needed. There are many options to decide what will be the model flows to be considered in simulations that are predicting future conditions. Below is a description of the multiple time series available and how they can be used for different model runs.

The main inflow dataset driving the MarinDSM is the Russian River inflows from USGS's Basin Characterization Model (BCM) dataset (USGS 2022). The BCM is not a dataset of measured historical flows, but a dataset built from the BCM model that is supposed to replicate historical flows for locations in the watershed that measured flows are not available. Climate projections provide flows for the same Russian River locations available in the USGS BCM model. The time window of historical and climate projection flows available for the Russian River and for MMWD's reservoirs are:

- Russian River flows available from 10/1/1910 to 9/30/2017 in a daily time step extended to 2022 through mapping of water years
- Russian River climate projection flows from January 1, 1950 to December 31, 2099
- MMWD reservoir inflows are available from October 1927 to December of 2021 in a monthly time step extended to 2022 through mapping of water years

Figure B-4 shows the timeline of the historical available data, the climate projections time window (150 years), and data gaps for the different available datasets. The filling of data gaps methodology is described in the following paragraphs.

Figure B-4. Graphical representation of the time window covered by the different inflow options available in MarinDSM



Russian River flows correlate well with inflows to MMWD reservoirs (Figure B-5). Despite not having BCM results between 2017 and 2022, Russian River measure flows were available at Guerneville until 2022. Individual pre 2017 BCM years were selected to replace the years between 2017 and 2022 based on the similarity of flows measured at Guerneville between 2017 and 2022. For example, it was found that Guerneville measured flows in 2021 were similar to Guerneville flows in 1976, therefore the model used the BCM flows from 1976 to fill the 2021 data gap.

Table B-3 shows a summary of the analysis where USGS measured flows at Guerneville were used to map the best past years to be used as surrogates for the years between 2017 and 2022 (Historical Nearest Value column).

Table B-3. Guerneville flow correlation between past and most recent water years

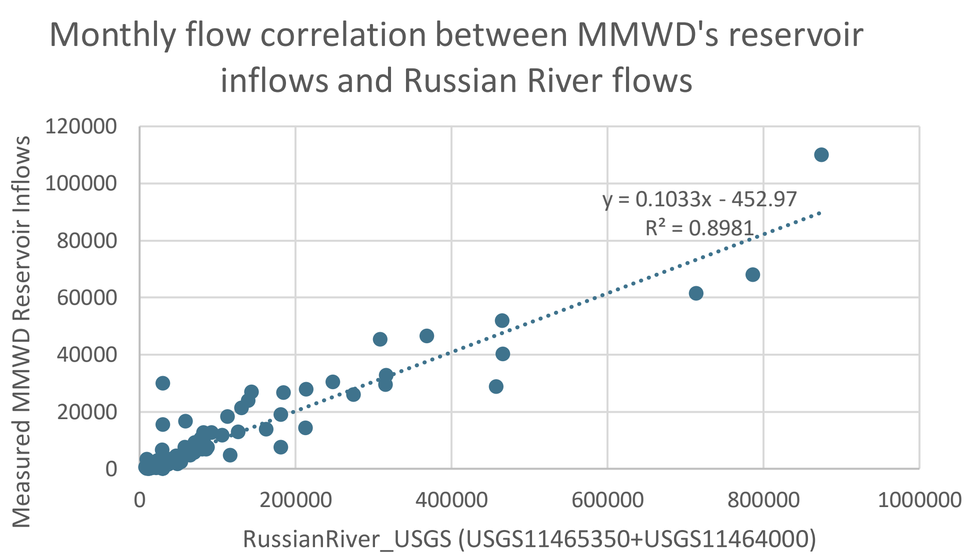
Water Year	USGS measured flow at Guerneville (AF)	BCM simulated flow at Guerneville (AF)	Russian River estimated flow using regression (AF)	Error between BCM flow and estimated flow using regression (%)	Historical Nearest Value Year	Historical Nearest Value Flow (AF)	Flow Fraction (multiplier)
2010	1,412,193	1,381,195	1,355,803	2%	1966	1,369,967	0.99
2011	1,890,577	1,742,533	1,810,747	4%	1984	1,769,276	1.02
2012	687,076	663,902	666,217	0%	2012	663,902	1.00
2013	974,188	1,040,825	939,261	10%	1979	922,387	1.02
2014	387,716	439,165	381,526	13%	1912	391,387	0.97
2015	761,655	974,982	737,142	24%	1957	737,783	1.00
2016	1,242,698	1,427,293	1,194,614	16%	1926	1,139,854	1.05
2017	3,170,695	3,186,030	3,028,139	5%	2006	3,017,237	1.00
2018	526,846		513,839		1972	533,604	0.96
2019	2,237,260		2,140,442		1965	2,169,552	0.99
2020	339,923		336,075		1931	335,563	1.00
2021	149,819		155,286		1976	209,550	0.74
2022	507,977		495,894		1929	485,991	1.02

The 1929 hydrological year with a 1.02 multiplier was selected as surrogate for MMWD's reservoir inflows data gap (from January 2022 to September 2022). The 1929 year was the year that best correlated with the beginning of water year 2022 (data was available from October 2021 to December 2021).

The mapping of flows to fill the BCM flows from 2017 to 2022 was done so that Russian River flow conditions (which can impact MMWD imported water) would not be disconnected from MMWD reservoir inflow conditions.

Ideally, the MarinDSM would also use BCM time series for the MMWD reservoirs whenever measured inflows are not available and for climate projection scenarios. The addition of BCM results for the MMWD area might be one future model update, however, in early 2021 this dataset was not available. It was then necessary to establish a correlation between Russian River flows and MMWD reservoir inflows so that the climate projection flows could be translated into MMWD reservoir inflows. Although the MMWD reservoirs are not located within the Russian River watershed, the MMWD's inflows to reservoirs still present a strong monthly correlation with Russian River. Figure B-5 presents the monthly correlation of flows between inflows to all MMWD's reservoirs versus Russian River at the confluence between Dry Creek and Russian River with an R-Square value of 0.89, indicating strong correlation on a monthly basis.

Figure B-5. Monthly correlation of flows between inflows to all MMWD's reservoirs versus Russian River confluence between Dry Creek and Russian River



Once a strong correlation was verified between the Russian River and Marin County watersheds, the next step was to develop specific correlations between each MMWD reservoir inflows and flows from the USGS's BCM model.

The correlation between BCM model and MMWD reservoir inflows was developed from monthly linear regression equations developed between Russian River Flow station Guerneville (Flows from USGS BCM model) and each MMWD's reservoir inflows. Once the correlation was developed, MarinDSM can estimate reservoir inflows for the period between 1910 and 1927 and could also run with climate inflows developed for the Russian River. These are the main two reasons why establishing and validating a correlation between MMWD reservoir inflows and Russian River flows is important. First, once the correlation between MMWD reservoir inflows and Russian River flows is established and validated the model can also run with flows from 1910 to 1927 (period when MMWD historical inflows is not available), second, climate flow projections (from 20 different climate models) available for the Russian River can be translated to MMWD reservoir inflows.

A total of twelve different BCM flow locations were available for Russian River. Monthly correlations between each of these twelve locations and each of the seven MMWD reservoirs were generated so that a Russian River BCM flow location with the best correlation to the MMWD reservoir inflows could be selected for MMWD reservoir flow estimates. It was determined that:

- Nicasio and Soulajule reservoir inflows have the best correlation with the Russian River's Hildenberg BCM flow location (R-square coefficient of 0.87)
- Alpine, Bon Tempe, Kent, and Phoenix reservoir inflows have the best correlation with the Russian River's Guerneville BCM flow location (R-square coefficient of 0.81)
- Lagunitas reservoir inflows have the best correlation with the Russian River's Clovis BCM flow location (R-square coefficient of 0.55)

Figure B-6 shows the monthly correlation of flows between inflows to groups of MMWD's reservoirs versus Russian River's BCM flow locations. Nicasio, Soulajule, and Kent are the reservoirs that account for most of the storage in the system, these reservoirs present a strong correlation with Russian River Flows (Hildenberg and Guerneville BCM locations) with correlations showing R-squared values of 0.87 and 0.81. The lowest correlation observed was for Lagunitas inflows, however Lagunitas inflows represent less than 4% of the average annual inflow to MMWD reservoirs. These correlations are used only when historical flows were not available, from 1910 to 1928, and on model runs that use climate projections as inflows, although model users can choose to run the entire simulation with correlated flows (which was done as a test and presented under Section B.5 Model Validation).

Figure B-6. Monthly correlation of flows between inflows MMWD's reservoirs versus Russian River BCM flow locations

The average historical reservoir inflow for the seven MMWD's reservoirs between 1929 and 2021 was 82,835 AFY. The average reservoir inflow based on correlated inflows with Russian river is 81,577 AFY.

The model also estimates the evaporation from the reservoirs. A fixed monthly evaporation rate (mm/month) set of lookup tables for the MMWD reservoirs. The evaporation rates were obtained from the same logic implemented in the WaterSim model simulation (RMC 2017).

Each reservoir has its own monthly average evaporation rate (mm/month), the final daily evaporation is obtained by the product of the monthly evaporation rate and the current storage area of the reservoirs. Annual total evaporation from reservoirs in the MMWD area can vary from less than 1,500 AFY to a little over 4,000 AFY due to reservoir water surface area variations.

Once all inflow gaps were filled for the Russian River and for MMWD's reservoirs, for the time window extending from October 1910 to September 2022 (112 years), the inflow time series were added to the model for simulations. For example, for running the model with projected demands from 2022 to 2045, the model user might want then to test the system by running some of the driest past years and evaluate the impact in the system.

B.4.2 Demands

The system demand will drive the use of multiple water supplies in the system. The model has two main different modes for demand inputs:

- Historical Demands from January 2009 to January 2021
- User Input annual demands from the end of Historical demands on.

Historical system demands are represented by the actual system deliveries for past years. The model always runs with historical demands if the simulation starts before 2021.

The user Input demands are meant to accommodate potential future system demands and are flexible to be changed. The model converts the annual demand table into monthly average demands based on historical monthly demand patterns (high demands during summer, low demands in winter), therefore the model assumes there will be no major shift in the District's demand pattern for the foreseeing future. The basic demands' scenario in the system is based on the latest demands published in Urban Water Management Plans (UWMP) extending from 2020 to 2045. Individual agency demands can be adjusted in the model depending on the scenario that the user wants to run. The adjustment can be directly on tables or by multipliers and constants added to the demands.

MMWD has a demand adjustment that is a function of storage levels. The adjustment was programmed in the model to mimic the Water Shortage Allocation Levels (WSAL) developed by MMWD. The WSAL are estimated levels of conservation that the agency believes is possible to achieve in the case of a drought. The levels of conservation are a function of storage volumes in April first and are presented in Table B-4. The model assumes that once an April first storage goes back to be above 70,000 AF the conservation levels drop to zero, an assumption that might be conservative, since some of the conservation practices adopted during the drought might have a longer time period impact and in reality. Although Table B-4 includes several levels of conservation, model simulations for project alternatives never assumed expected conservation to be achieved to be more than 25%.

Table B-4. Water Shortage Allocation Levels

Storage Range in April 1st (AF)	Expected Conservation to be achieved
70000-65000	10%
65000-55000	20%
55000-45000	25%
45000-35000	40%
35000-25000	50%
25000-10000	60%
10000-0	>60%

B.4.3 System Operation Logic

The general system (entire model domain from Eel River to MMWD system) operates by providing supplies (Russian River flows and local supplies) to the system demands (Sonoma Water contractors and MMWD) at daily time step. Some of the model inputs are not available in daily time step, and for that reason, most of the results are analyzed on a monthly or annual time step.

Each demand of the system, represented by each one of the Sonoma Contractors plus MMWD, can be fulfilled by different supplies, and each supply has a priority to be used in fulfilling demands. The priority of supply usage is a user specified input and cannot be changed in the middle of a simulation except if programed to do so in some specific cases. For example, under normal conditions (average or wet years) MMWD gives priority to receive local supply from its reservoirs over imported water, however, that priority changes if MMWD reservoirs drop below a certain threshold storage value, giving higher priority to imported water to save local storage volume.

MMWD water supplies available to be selected in model include: local surface storage from seven reservoirs, imported water, reuse water and future potential desalination water (only for model alternatives evaluating this option since currently this supply is not available in the system). Baseline local supplies are limited by the existing total reservoir storage capacity and the volume available in storage, ability to pump from storage to the two existing water treatment facilities (Bon Tempe and San Geronimo), and the treatment capacity of the treatment plants. Baseline imported supplies are limited by pipes and pump stations that convey imported water from Russian River to the Ignacio Pumping plant. In general, there is enough capacity in the Sonoma Water transmission lines from Sonoma Water’s collectors at the Russian River to Ely booster in the Petaluma aqueduct. From Ely booster until Ignacio Pump station the system can be limited by conveyance capacity and the sharing of conveyance capacity with Petaluma and North Marin demands. The model takes into account the Petaluma and North Marin usage of the aqueduct shared with MMWD, which at times could limit the imported water amount being delivered to MMWD. All the water management alternatives including the conveyance capacities can be adjusted in the MarinDSM to account for different scenario assumptions.

The current model version has more the 5,000 different input elements when all Sonoma contractors and Sonoma River operations are considered. The following subsections describe model inputs that are relevant to the MMWD operation of the system. Most of the input variables necessary to create model scenarios are concentrated in the MarinDSM model dashboard (Figure B-1).

B.4.3.1 Recycled Water

The general assumption for all Sonoma Water contractors is that recycled water supplies are delivered all years, therefore, the total demands are reduced or satisfied by the recycled water supplies (that is equal to the demands). The baseline assumption for recycled water production for MMWD is consistent with the latest UWMP and set at 750 AFY (MMWD 2021).

The Recycled water options available for MMWD includes, in addition to the general assumption, options of recycled water production that is sent to Kent and to Bon Tempe reservoirs plus a Direct Potable Recycled alternative that reduces the total system demands. The specific inputs for the recycled water options to MMWD have additional logic that reduces recycled water production if system demands drops below 30%. This additional logic prevents or reduces recycled water production in an extreme shortage condition when wastewater flows would be reduced.

B.4.3.2 Desalination

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

The baseline assumption for desalination is no production. For MMWD model scenarios the MarinDSM user can specify the desalination production of a plant that will feed the system demands or specify the capacity of the Petaluma desalter. The Petaluma desalter could technically provide water to Petaluma, North Marin and MMWD. The model assumes that Petaluma brackish will be shared between North Marin and MMWD. If the user wants to evaluate an option that only MMWD takes brackish water from Petaluma desalter, the user can use the regular model input for desalination that has a priority of utilization.

B.4.3.3 Baseline Local Storage

Stored surface reservoir water is released to the two treatment plants, Bon Tempe and San Geronimo.

Bon Tempe reservoir feeds the Bon Tempe Water treatment plant. The model pumps water from Alpine to Bon Tempe as long as Bon Tempe has storage available to receive the flows from

Alpine. Storage from Alpine can also be released to Kent, however only if Kent usable storage is below 2,000 AF (less than 10% of its maximum storage).

San Geronimo Water Treatment Plant is fed by Nicasio and Kent reservoirs. Kent receives overflows from Alpine, Bon Tempe and Lagunitas but pumping from Kent to Alpine can also occur although has not occurred in many years.

Ignacio Water Treatment Plant receives only imported water from Sonoma Water, not from any of the MMWD reservoirs. MarinDSM assumes that once the water reaches one of the three water treatment plants, it can reach all final costumers but subjected to water treatment capacity. In the case of Ignacio water treatment plant, an additional limitation of 14.8 MGD was added based on a recent study that evaluated bottlenecks withing the MMWD transmission system (W&C, 2022).

Soulajule is a storage reservoir that hasn't been fully connected to the MMWD's system. The reservoir does not have permanent power to supply pumps. The last pumping operation in 2021 relied on diesel generators to move water from Soulajule to Nicasio. The model assumes that the Soulajule to Nicasio pump operation will commence anytime Nicasio storage drops below 50% of its maximum storage and Soulajule storage is above 10% of its maximum storage capacity (1,072 AF). The 50% value is a user defined value that can be changed. Soulajule/Nicasio pumping is constrained by pump capacity (max 13,000 gpm with capacity also affected by reservoir elevation). Pumping rates in 2021 were kept below 8,000 GPM to avoid erosion and potential for flooding in natural channels that had been filled in over the years since the prior use of Soulajule in 1991.

Imported Water (Sonoma Water)

The baseline assumption for imported water consists in requesting imported supplies after other (local) supplies that have higher priority are delivered to demands. Imported water will be limited by aqueduct capacities, including booster pumps and pipes, and share of the aqueduct with other agency demands. Imported water is also subjected to Russian River conditions, Lake Sonoma and Lake Mendocino storage, and Sonoma water collectors' capacity. Baseline also assumes that MMWD will give priority to aqueduct imported water over its local storage when total local storage drops below 55,000 AF.

For the modeling of other imported potential supplies (not baseline conditions) that would not reach MMWD system via Petaluma aqueduct and have its origins in the Russian River, the model user can use a reduction in demands or use model inputs that provide water direct to the MMWD transmission system like some of the desalination and recycled water alternatives.

B.4.3.4 Environmental Releases

Environmental releases account for approximately 10,000 AFY of releases from Soulajule and Kent. The model includes dynamic logic that estimates the environmental releases for Soulajule initially based on MarinSim calculations but updated in the MarinDSM. Releases from Soulajule are meant to complement local unimpaired watershed flows at Walker Creek. The MarinDSM logic includes estimates of unimpaired flows at the downstream Walker Creek as a function of Soulajule reservoir inflows.

The environment releases from Kent relies on the logic initially developed in the MarinSim model (RMC 2017) and updated in the current MarinDSM model. The District controls releases from Kent Lake to implement the minimum instream flow schedules in Lagunitas Creek in accordance with its water rights permits and Order 95-17. Order 95-17 specifies minimum flows in Lagunitas Creek, measured at a USGS flow gage (USGS11460400, see Figure B-3) located approximately three miles downstream of Peters Dam (Kent Reservoir). These minimum flow requirements vary based on hydrologic conditions in the Lagunitas Creek watershed, as specified in Order 95-17. The model estimates inflows between Kent and the USGS flow gage using a rainfall/flow correlation developed in the MarinSim model (RMC 2017). The difference between minimum flow requirements and the estimated by correlation flows between Kent and the USGS gage is released from Kent reservoir. Climate hydrology projections runs assume that no flow is generated between Kent and the USGS gage resulting in maximum environmental releases from Kent (conservative approach). It is recommended that the District develops a more robust estimate of flows between Kent and the USGS gage. The development of such dataset will represent Kent reservoir releases for instream requirements more accurately.

B.5 Model Validation

A previous version of the MarinDSM (version developed for Sonoma Water) had the validation of the Russian River system done by comparison of model results versus historical data of Lake Sonoma and Lake Mendocino storages, Russian River diversion at the collectors, and deliveries to Sonoma water contractors and MMWD. The validation time window extended from October 2009 to September 2017 and was limited by inflows to the system that matched historical inflows. An exact match with historical operations was challenging given that the operation of storage for supply releases and environmental purposes is not always consistent and not easily translated in a set of rules that reflect all nuances of operation. Despite the challenges, the model offered good matching between model results and measured data validating the Russian River operations with adequate accuracy and general operation needed for the model goals. It is also important the future conditions are well characterized in terms of assumptions since future operation will not necessarily match past operation. This validation step is important to acknowledge because the MarinDSM relies upon and build upon this work.

The MarinDSM results were validated by comparing model versus historical measured flows and storage for past operation, from 2009 to 2020. Although the historical Russian River inflows end in September 2017, MMWD reservoir inflows were available until December 2020. The lack of Russian River historical flows from 2017 to 2020 can impact the accuracy in representing imported water flows, but for the most part, MMWD's operations is more impacted by its own storage and inflows.

Validation of the MMWD model logic was limited by the amount of historical time series available for comparison. This appendix presents model versus measured historical comparisons for the available historical time series, that includes, all seven MMWD's local surface storage reservoirs, two flow locations along the Lagunitas Creek, imported water that MMWD received from Sonoma Water, and water treatment flows for San Geronimo and Bon Tempe Water Treatment Plants.

The model validation period chosen was from October 2009 to December 2020. This time window was chosen because actual MMWD system demands could be input in the model (assuming historical demands equal to historical deliveries) and historical reservoir inflows were also available. The model would not replicate historical conditions if the input model demands did not represent actual historical demands. The availability of MMWD system demands up to December 2020 is the current limitation for the calibration extent.

Figure B-7 shows the comparison of total MMWD system storage between MarinDSM and measured values. It is noteworthy mention that MarinDSM can the latest bathymetric information available from 2017, which states that the maximum system storage is 78,384 AF, but can also use the historical maximum storage pre 2017 survey, which estimated maximum storage at 79,566 AF (Table B-2). The model validation was executed with pre-2017 survey capacity so that model storage could be compared against historical storage. Model presented excellent correlation with storage filling (as a function of time series inputs) and storage releases (as a function of model rules to provide flows to demands, environmental requirements, and spills). The good comparison between total model versus historical storage, including the good replication of the most recent 2020 drought period, indicates that the rules programmed in the MarinDSM capture the main system operation of the reservoirs, and that these rules could be tested under different reservoir inflow conditions. The model simulations extending beyond 2022 use the most current 2017 storage capacity values.

Figure B-7. MMWD total storage comparison between model results and measured storage for the model validation period

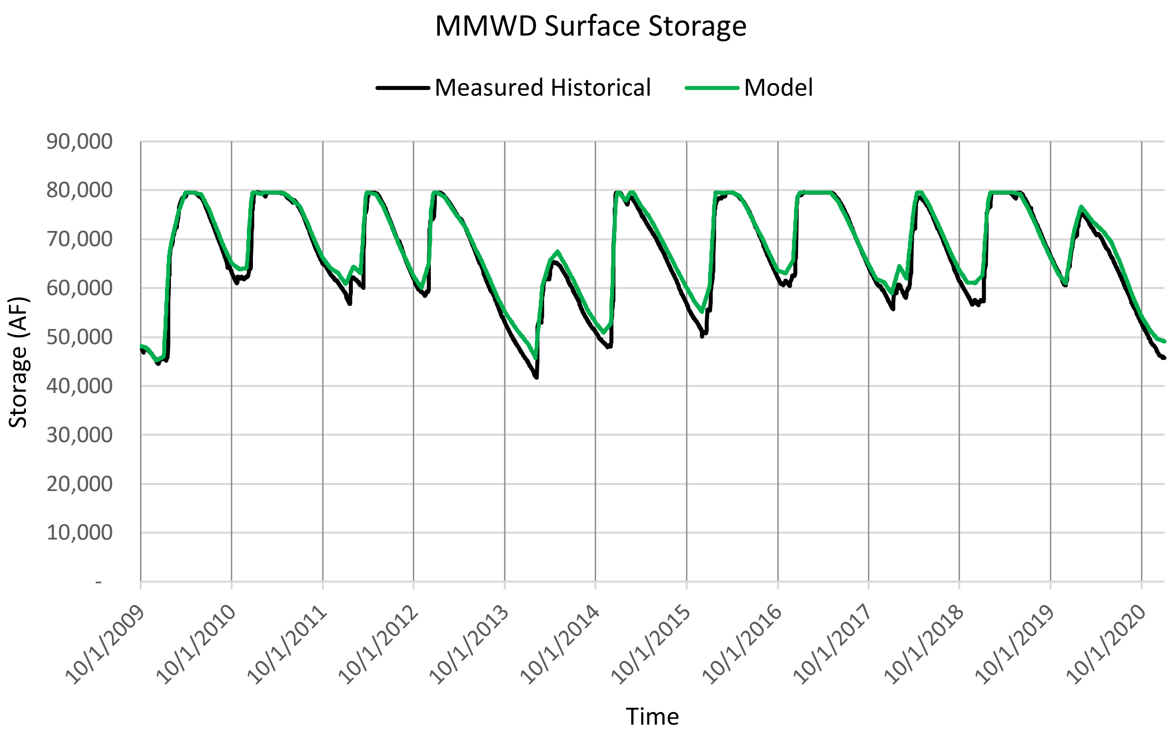
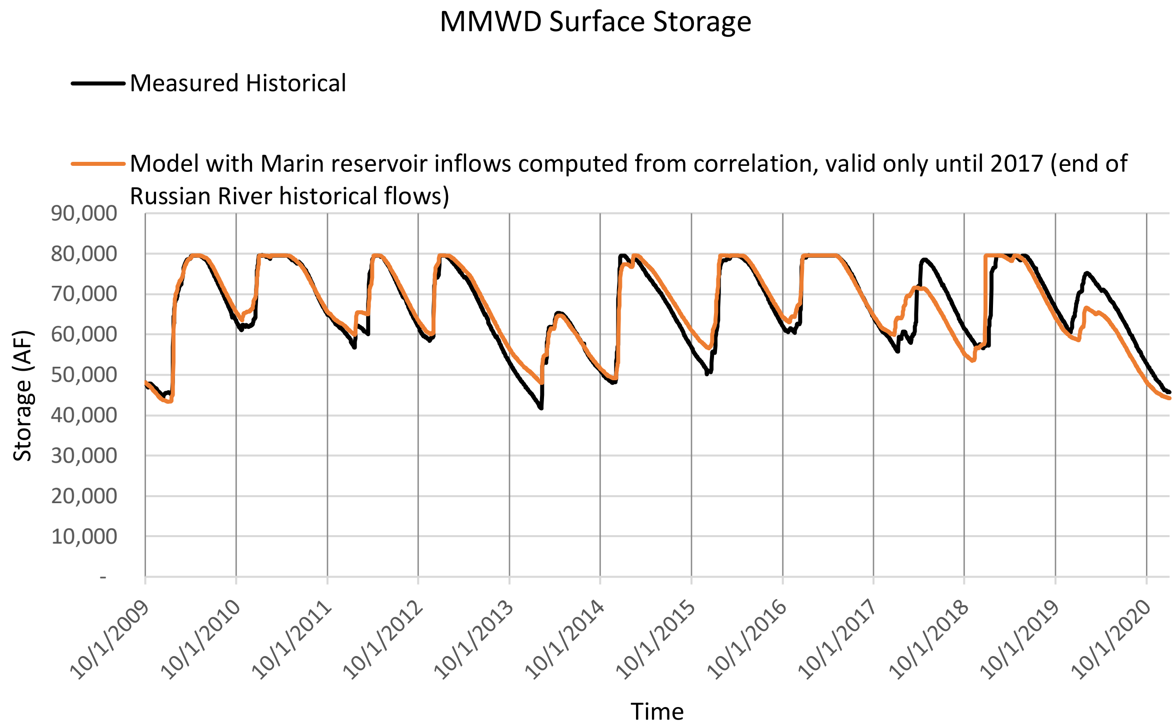


Figure B-8 is a variation of the validation simulation. In that run, MMWD's inflows to reservoirs were exchanged from measured monthly values to daily flows estimated as a function of Russian River flows. Results from this run shows that the years previous to 2017 offer a very good match, indicating the strong correlation developed between Russian River and MMWD's reservoir inflows and validating the assumption to use this correlation for climate inflow projections and the MMWD's reservoir inflow data gap between 1910 and 1927. For years after 2017, the lack of Russian River historical flows impacts the MMWD's inflow to reservoirs and the match between model and historical results.

Figure B-8. MMWD total storage comparison between model results and measured storage for the model validation period using MMWD reservoir inflows from correlation with Russian River flows



The following Figures B-9 to B-15 show the comparisons between model and historical measured storage values for the seven MMWD's reservoirs. The historical volumes were derived from rating curves prior to 2017. Model results for the individual storages have a good correlation with historical storage volumes. Some differences are observed and are mainly related to the fact that the MarinDSM does not have documented operations for each reservoir to replicate day to day variations in reservoir operations within the model.

Figure B-9. Kent reservoir storage comparison, model versus historical measured volume

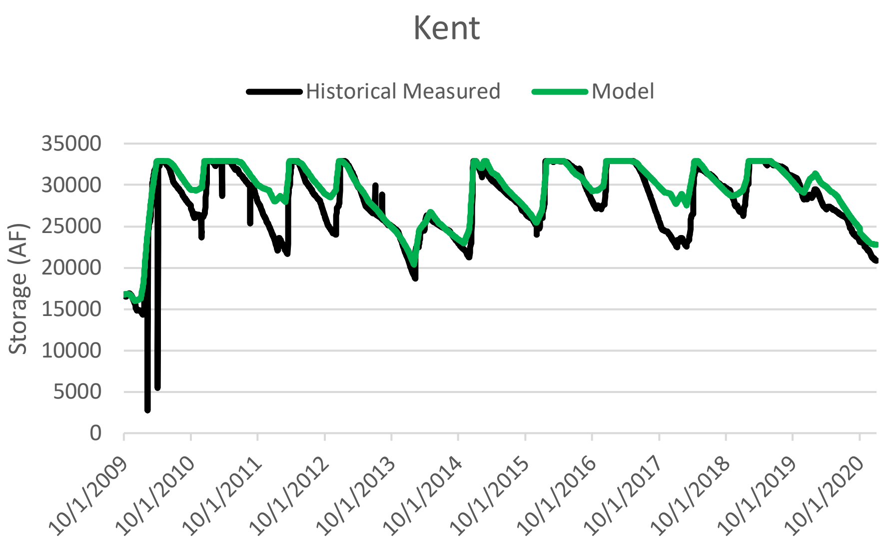


Figure B-10. Nicasio reservoir storage comparison, model versus historical measured volume

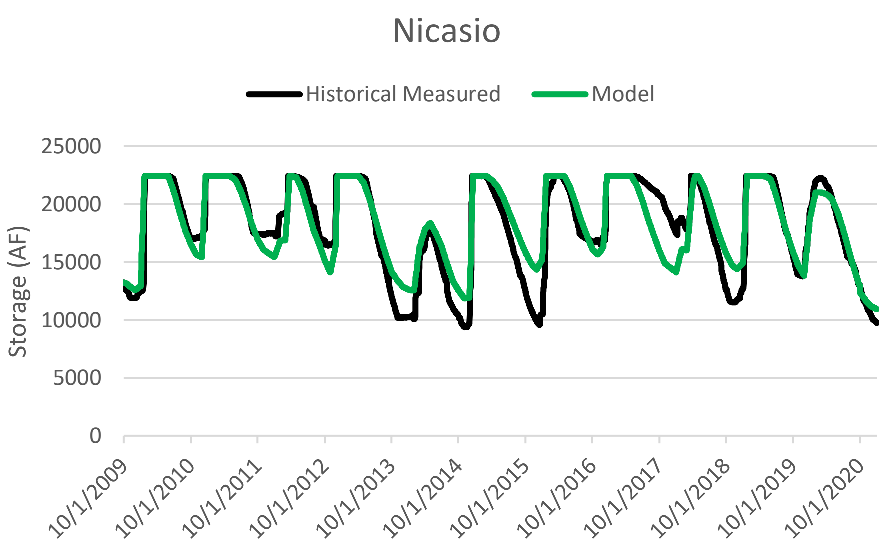


Figure B-11. Soulajule reservoir storage comparison, model versus historical measured volume

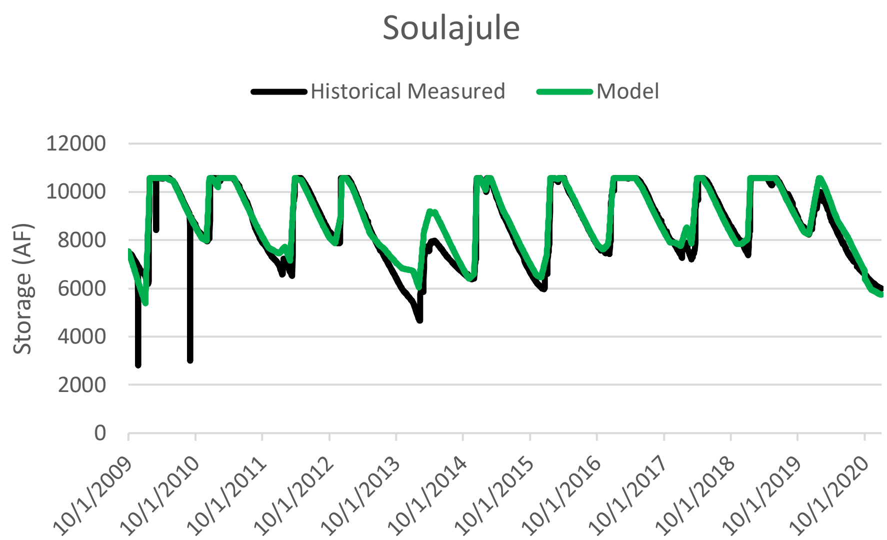


Figure B-12. Alpine reservoir storage comparison, model versus historical measured volume

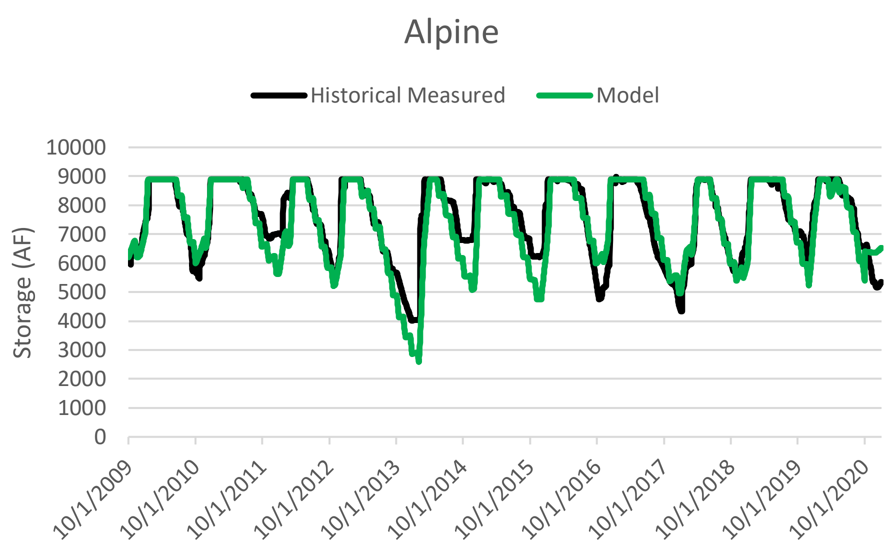


Figure B-13. Bon Tempe reservoir storage comparison, model versus historical measured volume

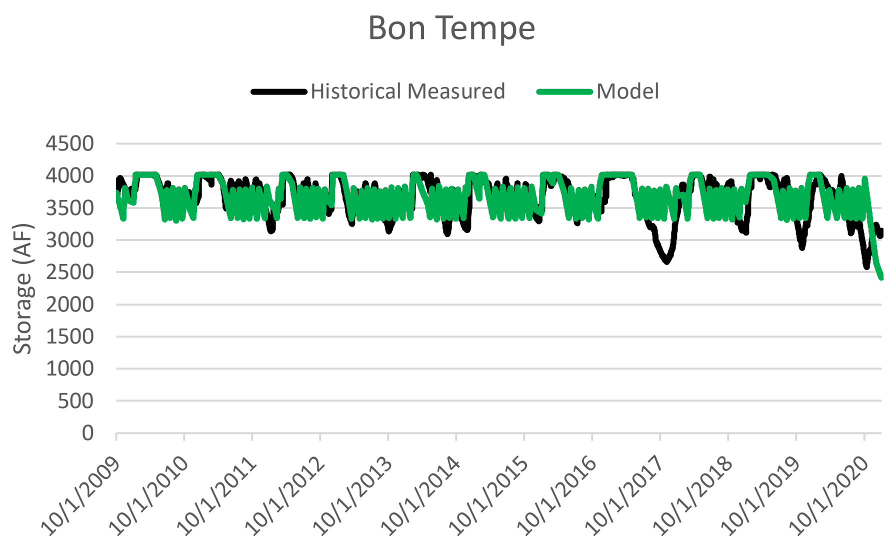


Figure B-14. Phoenix reservoir storage comparison, model versus historical measured volume

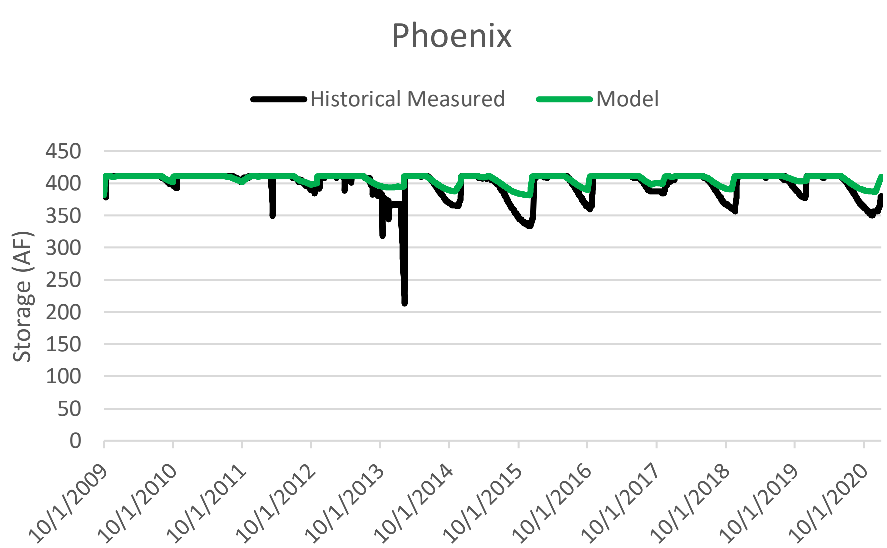


Figure B-15. Lagunitas reservoir storage comparison, model versus historical measured volume

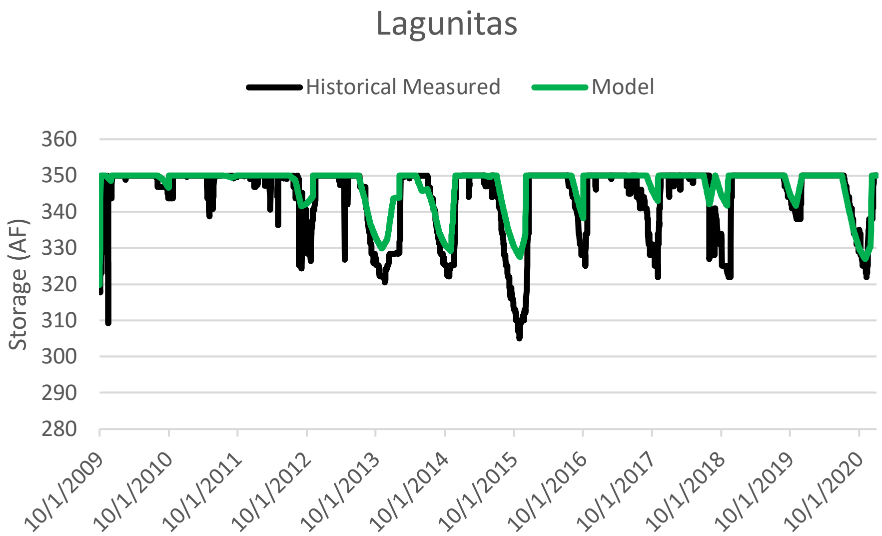
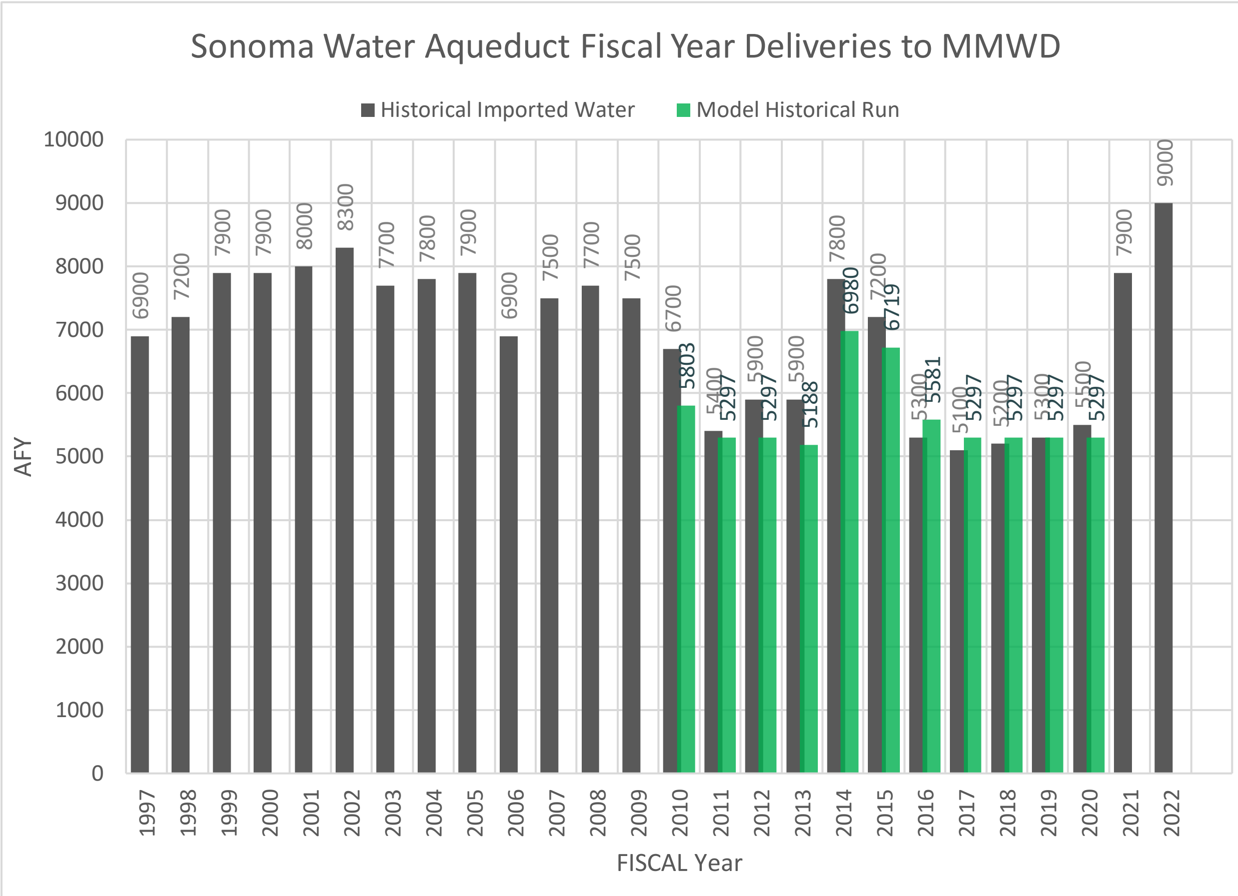


Figure B-16 shows the comparison between the model estimates of imported water to MMWD versus actual imported water for the fiscal years that data were available, and a comparison could be done. The average historical imported water consumption by MMWD between 2010 and 2020 is 5,936 AFY while model results report 5,641 AFY, a difference of 295 AFY (0.3 mgd).

Although there wasn't a strict fixed historical rule followed by MMWD to import water from Sonoma Water, the rules established by the Fourth Amended Offpeak Water Supply Agreement, (2015) were included in the model, plus the general rule that MMWD will request additional imported water if MMWD's total surface storage drops below 55,000 AF, offer a good correlation with the historical imported water volumes. The 55,000 AF is an empirical rule based on past imported water patterns, MMWD requested more than the minimum take and pay mostly on years that MMWD's storage reach volumes below 55,000 AF. Currently the district does not have a written rule that specifies how much should be imported every year. MMWD can currently import a maximum of 14,300 AFY and minimum 5,300 AFY (take or pay) from Sonoma Water based on current agreement (Fourth Amended Offpeak Water Supply Agreement, 2015). A test was done where a rule would trigger imported water if the total MMWD storage was below the monthly average storage. This rule did not improve the match between model and historical values.

Figure B-16. Imported water comparison between model and historical import volumes



Figures B-17 and B-18 show the monthly average time series comparison between historical measured water treatment production and model production flow for the two treatment plants that receive stored water from MMWD reservoirs, Bon Tempe and San Geronimo.

The average historical Bon Tempe water treatment production between 2012 and 2020 is 4.8 mgd while model results report 5.9 mgd. The average historical San Geronimo water treatment production between 2012 and 2020 is 12.1 mgd while model results report 10.4 mgd. Model shows slightly more production at Bon Tempe which is compensated by slightly less production at San Geronimo. The goal of the MarinDSM model was not to replicate and be accurate on the monthly production of individual plants, but to assure that enough water was being delivered from the right sources to meet demands assuming that there is a capacity limitation on the plants.

Figure B-17. Bon Tempe monthly average water treatment production

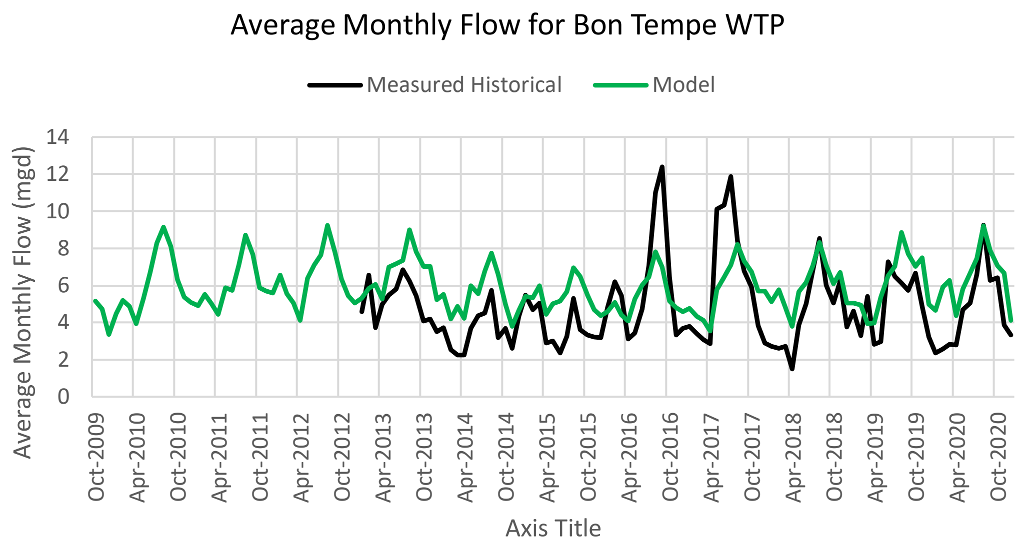
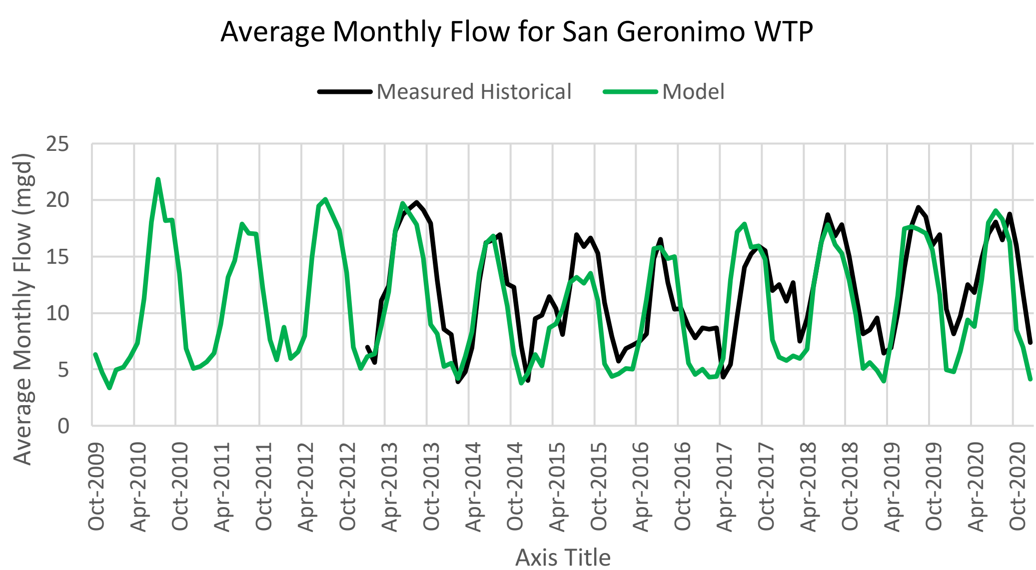


Figure B-18. San Geronimo monthly average water treatment plant production



Th USGS offers two locations along the Lagunitas Creek with historical flow records:

- USGS 11460400 LAGUNITAS C A SAMUEL P TAYLOR STATE PARK CA
- USGS 11460600 LAGUNITAS C NR PT REYES STATION CA

Both stations are presented in Figure B-3 (model schematic). LAGUNITAS C A SAMUEL P TAYLOR STATE PARK CA is located downstream of Kent reservoir and LAGUNITAS C NR PT REYES STATION CA is located downstream of the confluence of Lagunitas creek and Nicasio Creek. The model estimate watershed flows downstream of Kent and Nicasio as a function of precipitation developed in the 2017 MarinSim model (RMC 2017). Flows for the two USGS locations in Lagunitas Creek are presented in Figures B-19 and B-20. Model versus historical flow records (in a monthly average time step) have a good correlation and present the same magnitude of flows and seasons for both locations, indicating that reservoir inflows and rules for reservoir releases to the creek are accurate.

Figure B-19. MMWD total storage comparison between model results and measured storage for the model validation period

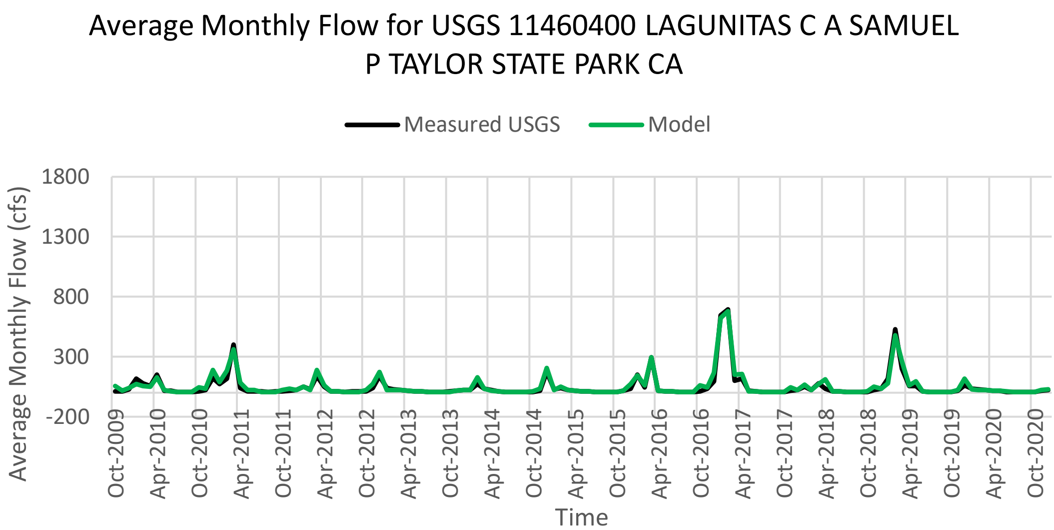
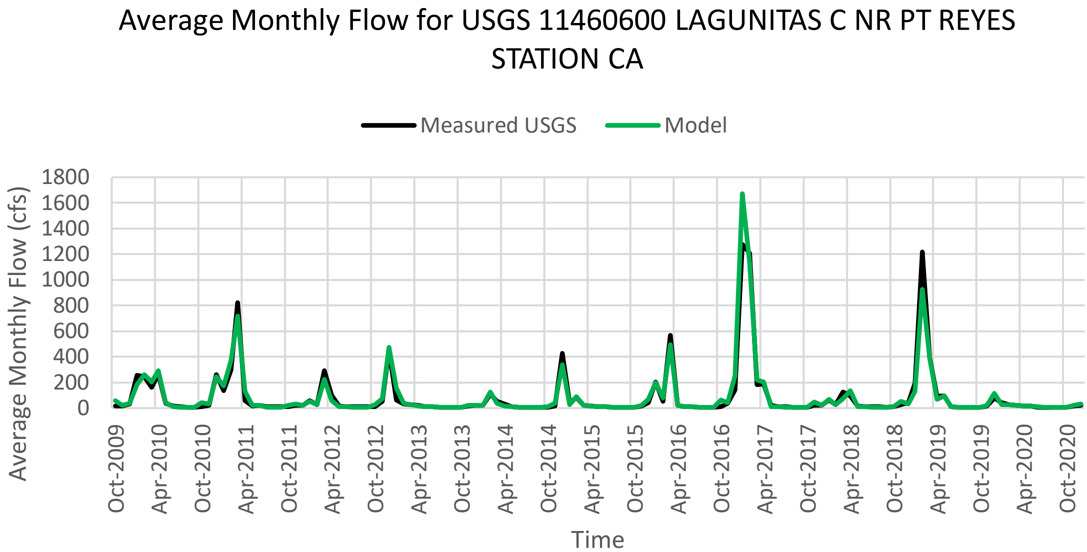


Figure B-20. MMWD total storage comparison between model results and measured storage for the model validation period



B.5.1.1 Mass Balance

In addition to validation simulation checks, where model results are compared with measured flows and storages, MarinDSM also includes an overall mass balance check, assuring that all system inflows and outflows are accounted for. The mass balance check takes into account all inflows, outflows and changes into storage on a daily time step. Table B-5 presents a summary of MMWD water balance components for the MMWD area on annual basis for the model validation simulation. The overall Mass Balance is represented by:

$$\Delta Storage = \Sigma Inflow - \Sigma Outflow$$

Where DStorage is the change in storage for the period, SInflow represents the sum of all inflows, and SOutflow represents the sum of all outflows within the MMWD system. Table B-5 columns show the different components of the water balance. The SInflow term includes all reservoir inflows plus imported water plus recycled water production within MMWD system (Columns D, L and M), the SOutflow term includes evaporation from all reservoirs (column E), reservoir spills (column F), environmental releases (column H), and total system deliveries (column N).

Table B-5 has additional items besides the ones that comprise the water balance calculations. Column A shows the model year and column B shows the water year for flows used in the simulation. For the model validation, column A equals column B, but for simulations that estimate future flows (e.g simulation of 2022 to 2045) the model reports which years were used for flows. Column C shows total water year Lagunitas precipitation, column G shows the environmental demands to maintain minimum instream flows downstream of Kent and Soulajule reservoirs, column I shows the potable plus recycled water demands for MMWD, column J reports is there was any adjustments on the demands due to low storage conditions, column O shows the storage at the end of September (end of water year), column P reports any shortages (if the system supplies did not meet system demands), and column Q reports any unmet environmental demands (if low storage at Kent or Soulajule could not meet instream flow requirements).

Table B-5 can be generated for any model scenario run in MarinDSM.

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Table B-5. MMWD annual water balance – Model Validation Scenario

A: Simulation Year	B: Water Year used for Hydrology	C: Lagunitas Rainfall	D: Reservoir Inflow	E: Reservoir Evaporation	F: Reservoir Spills	G: Env. Demand	H: Environmental Releases	I: Water Demand	J: Adjusted Water Demand	K: Reservoir Deliveries to Treatment Plants	L: Sonoma Water Imports	M: Recycled Water Production	N: Total Deliveries	O: End of Year Reservoir Storage	P: Shortage	Q: Unmet Environmental Demand
WY	WY	IN	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF
2009														48,173		
2010	2010	57.89	111,039	4,062	61,962	9,606	9,606	25,822	25,822	18,510	6,810	502	25,822	65,073	0	-
2011	2011	70.23	136,928	4,167	103,423	8,916	8,916	25,055	25,055	19,276	5,299	480	25,055	66,219	0	-
2012	2012	40.85	43,516	4,037	11,431	10,894	10,894	26,796	26,796	21,031	5,299	466	26,796	62,342	0	-
2013	2013	41.4	71,499	3,891	41,070	12,300	12,300	27,285	27,285	21,348	5,299	638	27,285	55,232	0	-
2014	2014	31.33	31,178	3,613	990	10,920	10,920	25,520	25,520	18,977	5,938	605	25,520	51,911	0	-
2015	2015	39.83	61,299	3,947	20,260	12,126	12,126	23,022	23,022	16,806	5,681	535	23,022	60,071	0	-
2016	2016	49.56	86,613	4,060	50,893	10,424	10,424	23,295	23,295	17,728	5,041	526	23,295	63,579	0	-
2017	2017	94.82	243,388	4,132	212,789	7,613	7,613	23,432	23,432	17,662	5,298	472	23,432	64,770	0	-
2018	2018	39.06	44,502	4,035	11,670	10,795	10,795	25,043	25,043	19,188	5,298	557	25,043	63,586	0	-
2019	2019	72.45	143,550	4,138	110,056	7,135	7,135	24,960	24,960	19,608	5,298	54	24,960	66,199	0	-
2020	2020	35.77	26,551	3,849	1,709	11,228	11,228	27,044	27,044	21,674	5,370	-	27,044	54,290	0	-

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B.6 Model Simulations

The MarinDSM model runs are set up in a way that future demands, future system operations and future project configurations are tested under different hydrological conditions. The hydrological conditions test how the system would behave under different water availability conditions, it tests, for example, how the system would behave if past droughts would happen in the future.

Figure B-21 helps illustrate how the simulations test the system for potential droughts. The Figure show measured historical MMWD storage versus model results. The two lines (model and measured storage) matches from 2009 to 9/30/2021, when measured reservoir inflows are not available to be used as input to model equations. Beyond 9/30/2021 the model can run using inflows from:

- Repeated past hydrological years
- Synthetic hydrological sequences
- Climate projections

Figure B-21 shows as an example what would happen to MMWD storage if the same hydrological conditions of water year 1976 repeated itself after 9/30/2021. The model uses historical reservoir inflow sequence starting at October 1976 to continue the simulation from 9/30/2021 to the end of simulation. In this case, assuming that the 1976 hydrological sequence would repeat after the 2020/2021 drought, MMWD storage levels would drop below 10,000 AF (assuming no dead pool reserves). The hydrology of 1978 had significant flows, which recovered the storage to levels above 60,000 AF.

One of the most important uncertainties that needs to be understood in water resources analysis is the uncertainty related to future flows that will be observed in the basin. This istudy relies upon GoldSim capability to run Monte Carlo simulations to understand how different inflow sequences will impact the MMWD water system.

The model stochastic capabilities are based on GoldSim's Monte Carlo simulation option. The Monte Carlo method is a computational approach that can run the same set of algorithms (model for this study) multiple times, each time using a random set of inputs. The Monte Carlo approach used for this study selects the multiple sequences of flows available for each model run. The result of a Monte Carlo simulation is not a single deterministic value but a range with probabilities based on the results of all runs.

A Monte Carlo analysis can tell, for example, the probability of MMWD reservoir storage end up above certain level if all available historical years of flows are considered for the next year. For example, it is unknown how much inflows MMWD reservoirs will have next year, but the system can be tested for all previous years of flows, providing the user with statistics of likelihood of reservoirs end up next year above certain value.

If only historical flows are used in a Monte Carlo analysis the assumption is that future flow ranges will stay within the historical range, which is not true. For example, it is possible that next year the basin experiences record inflows or no flows at all, for that reason, a long-term historical dataset is desirable but in conjunction with climate change flow projections, which could have a range greater than historical values.

MarinDSM can also run multiple hydrological sequences instead of the water year 1976. A stochastic simulation can use all possible and available historical water years as hydrology after 9/30/2021. The results of a stochastic simulation can be presented in the form of probabilistic ranges. Figure B-22 shows that the median of 112 model realizations (112 hydrologic sequences) would result in storage above 50,000 AF. In this example, about 1% of the realizations had storage dropping below 20,000 AF, however the baseline assumptions include water conservation targets that are triggered as a function of storage. Figure B-22 Also shows that the system storage can drop between 30,000 AF approximately 5% of the time or more.

Figure B-21. Example of model run using water year 1976 after 9/30/2021 period to test system storage

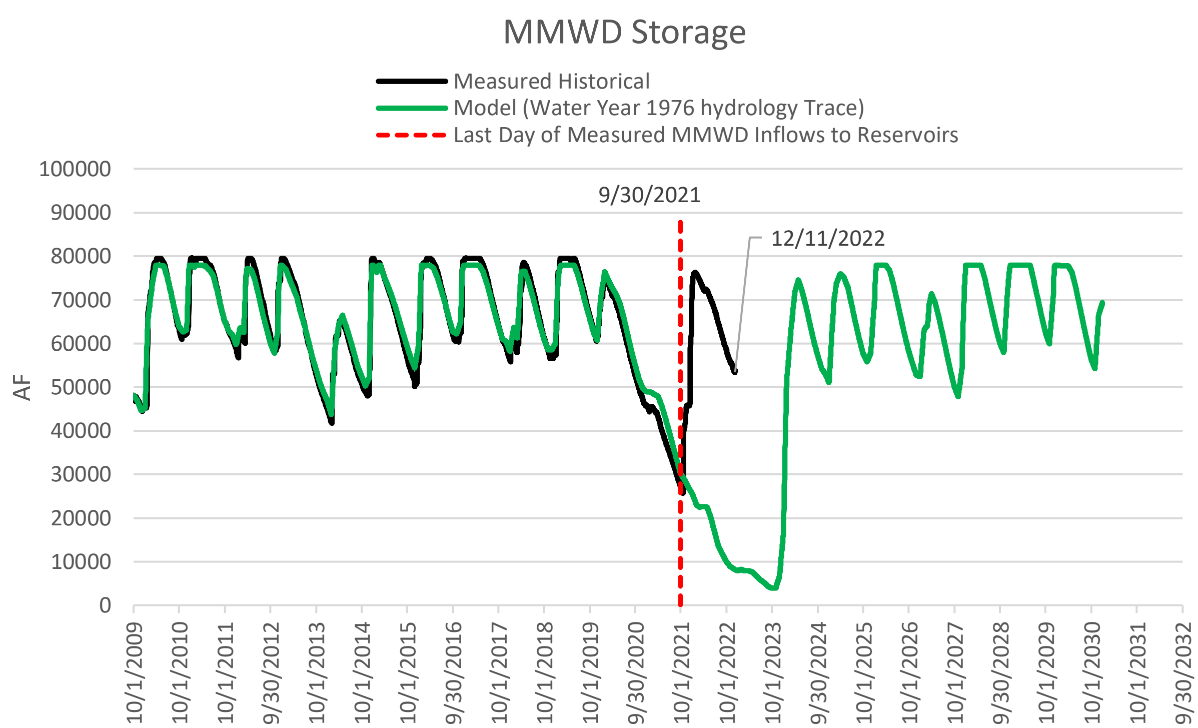
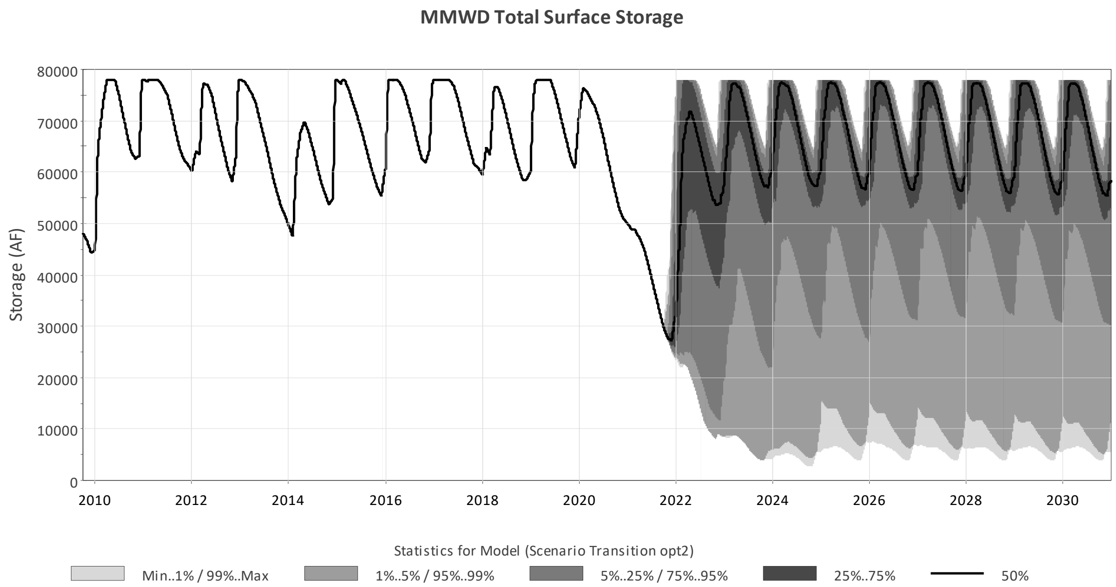


Figure B-22. Example of results from ana stochastic model simulation



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