Section C: San Vicente Reservoir Study

San Vicente Reservoir Study Findings

- The addition of purified water into San Vicente Reservoir would not affect natural hydrologic characteristics of the reservoir, seasonal stratification, or mixing. This finding demonstrates that the addition of purified water would not affect the natural blending and retention in the reservoir.
- Blending and retention of purified water in San Vicente Reservoir would constitute a substantial environmental barrier, sufficient to meet regulatory requirements.
- For all anticipated reservoir operating scenarios and purified water release locations, the reservoir would dilute the purified water by at least a factor of 200 to one at all times.
- The addition of purified water would not substantially affect water quality in San Vicente Reservoir. The dam raise and reservoir expansion, which is independent of the Demonstration Project, will improve overall water quality in the reservoir by reducing nutrients including nitrogen compounds that cause water quality issues, and the addition of purified water will not change these improvements. Addition of purified water would improve some aspects of reservoir water quality, such as reducing salt concentration.

Regulatory agencies require that a substantial environmental buffer, either a groundwater basin or a surface water reservoir, serve as a receptacle for purified water prior to blending into the drinking water system. As recommended as part of the Water Reuse Study, San Vicente Reservoir would provide that environmental buffer if the City were to implement a reservoir augmentation project at San Vicente Reservoir.

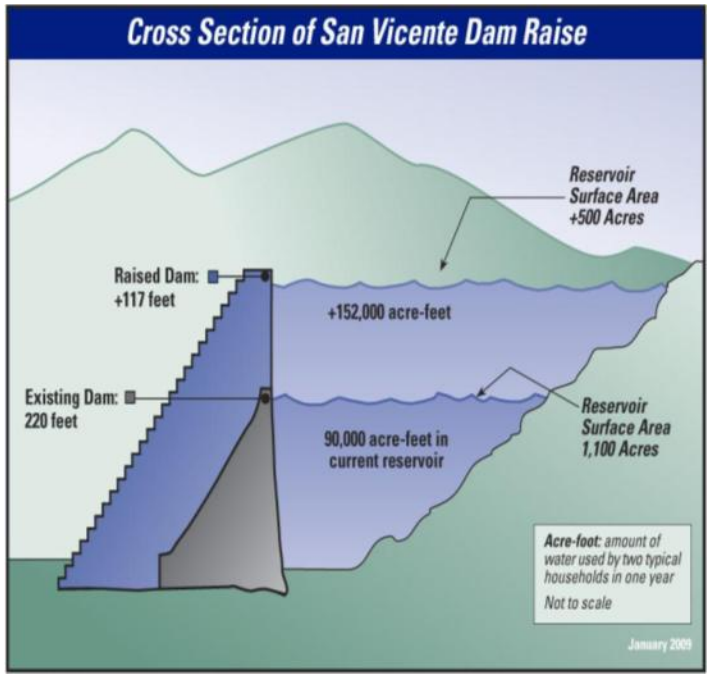
This section describes the San Vicente Reservoir setting, the regulatory considerations for reservoir operation, the reservoir analysis conducted as part of the Demonstration Project, and the results of the reservoir modeling.

The Demonstration Project included an in-depth study of San Vicente Reservoir.

San Vicente Reservoir: A Key Component of San Diego's Water Supply System

San Vicente Reservoir, located near Lakeside, was created by a dam built in

1945 that impounds San Vicente Creek. San Vicente Reservoir is owned and operated by the City's Public Utilities Department and is predominately used for municipal water supply purposes. The reservoir stores imported water, collects local runoff from a 75-square-mile watershed, and stores water transferred from Sutherland Reservoir. San Vicente Reservoir also supports limited recreational activities including boating, fishing, and water skiing.



Historically, San Vicente Reservoir has supplied water to the Alvarado Water Treatment Plant. As part of the Water Authority's Emergency Storage Project, San Vicente Dam is being raised, resulting in an increase in reservoir capacity from 90,000 AF to approximately 247,000 AF. The San Vicente Dam Raise Project will be complete by spring 2013, with refill of the reservoir expected to take three to five years, depending on the availability of imported water. As part of the Emergency Storage Project, new pipelines have been constructed to allow San Vicente Reservoir to receive imported water from the western leg of the regional aqueduct system. San Vicente Reservoir will continue to primarily supply the Alvarado Water Treatment Plant through the City's existing pipelines. The new conveyances of the Emergency Storage Project will also allow water to be sent to other water treatment plants serving all of the City and the entire southern two-thirds of the San Diego region.

San Vicente Reservoir has historically served as an integral component of the City's water supply system. These improvements further solidify the role of San Vicente Reservoir in the region's overall water supply operation, including the ability for the reservoir to play a role in a potential future reservoir augmentation project.

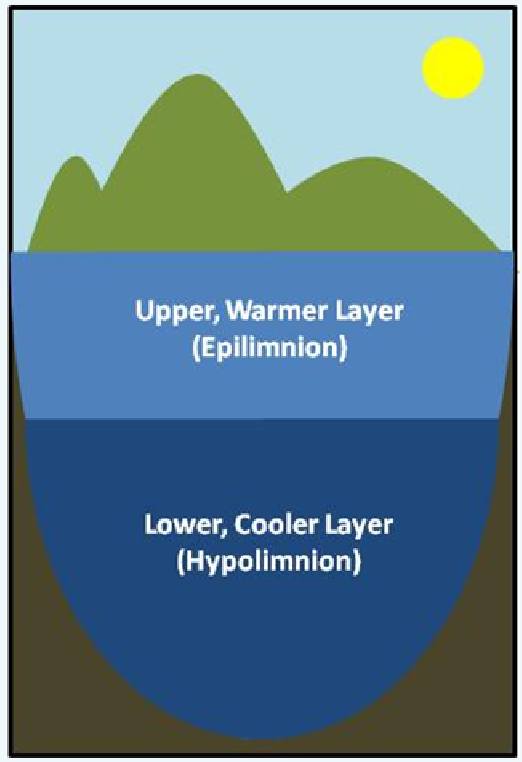
Why Consider San Vicente Reservoir for Reservoir Augmentation?

Purified water produced at the City's AWP Facility has been validated through robust testing as meeting applicable water quality requirements; however, regulatory agencies would require a reservoir augmentation project at San Vicente Reservoir to include an environmental buffer capable of providing adequate retention time and blending of purified water. As described in detail in Section D, Regulatory Coordination, retention time and blending criteria are part of what is known as a multiple barrier approach, which is required by regulatory agencies to ensure that adequate safeguards are in place to protect public health in the event of an unexpected issue with the purified water.

San Vicente Reservoir is an ideal feature for reservoir augmentation because, in addition to having sufficient storage available to accommodate purified water flows throughout the year, it has unique characteristics that assist in meeting regulatory requirements. Specifically, in addition to providing significant blending of purified water with other raw water sources, the reservoir's large capacity and stratification allow it to retain the purified water for a significant period of time before it is delivered for final treatment (refer to the stratification inset below for more information).

A Word About Reservoir Stratification

Reservoir stratification—the formation of "layers" of water within a reservoir—is a natural phenomenon that occurs in essentially all reservoirs in North America, including San Vicente Reservoir. Consistent and predictable stratification has been observed in more than 20 years of monitoring data collected from San Vicente Reservoir. During the period of stratification (approximately 10 months per year), warm water that is naturally heated by the sun is contained within the top-most layer of the reservoir (epilimnion), because warmer water is less dense than cooler water. The more dense, cooler water is contained within the lower layer of the reservoir (hypolimnion). When stratification occurs, the water and any dissolved or suspended constituents contained within the epilimnion do not readily mix with the water and constituents contained within the hypolimnion.



During winter months, the epilimnion cools in response to cooler air temperatures. This causes water temperature in the reservoir to equalize and the epilimnion and hypolimnion mix, causing the reservoir to lose its stratification (destratify). The fully destratified (mixed) condition lasts for a few weeks to a month and typically occurs in January, February, or March. The natural stratification and mixing of the reservoir is an important phenomenon, because it determines the extent and timing of mixing and retention provided by the reservoir.

Characteristics of San Vicente Reservoir that provide adequate retention time and blending features as required by regulatory agencies are described below.

- **Retention time.** The amount of time that purified water is retained in the reservoir, retention time, would provide time needed to monitor the purified water for water quality purposes—a step necessary to demonstrate that the purified water meets applicable water quality standards. San Vicente Reservoir's natural stratification, combined with a purified water release and withdrawal strategy that takes advantage of reservoir stratification (see stratification inset for more information), would provide purified water entering the reservoir with a substantial amount of retention time prior to withdrawal and final processing at a drinking water treatment plant and distribution to the City's drinking water system. Therefore, San Vicente Reservoir would be capable of providing adequate retention time as required by regulatory agencies as part of a multiple barrier approach that ensures the protection of public health.

- **Blending.** In addition to retention, the reservoir would provide significant blending, as a relatively small flow of purified water would be released into a large reservoir and blended with other reservoir water supplies prior to withdrawal. Once the San Vicente Reservoir expansion is complete, the reservoir volume will be 16 times greater than the projected annual purified water inflow of 15,000 AFY simulated.[4] This means that purified water would receive significant blending as it travels through the reservoir prior to being withdrawn and treated at a municipal drinking water treatment plant before flowing to the City's distribution system. Therefore, San Vicente Reservoir would be capable of providing adequate blending as required by regulatory agencies.

Under a reservoir augmentation project at San Vicente Reservoir, the City would augment San Vicente Reservoir with an annual average of 15 mgd of purified water. There would be seasonal variation in the amount of purified water produced at the full-scale AWP facility due to variations in the amount of recycled water available from North City, with winter monthly average inflows nearly twice as great as those seen in summer months. If the City were to implement a reservoir augmentation project at San Vicente Reservoir, the reservoir would continue to receive and store local runoff, water transferred from Sutherland Reservoir, and imported water. These water supplies would be blended with purified water, which is among the highest quality water available, prior to being treated at a drinking water treatment plant for delivery to the City's customers.

A reservoir augmentation project at San Vicente Reservoir would involve releasing purified water into the upper layer of San Vicente Reservoir. Because the purified water would be warm compared to the reservoir water and would flow into the reservoir at the surface, it would tend to remain in the upper layer of the reservoir. San Vicente Reservoir's outlet structure, located near the San Vicente Dam, has multiple ports to provide operators with flexibility when withdrawing water from the reservoir and sending it to a municipal drinking water treatment plant for treatment. Operators typically withdraw water for drinking water treatment and distribution from the deeper ports, where water quality is more consistent. Under stratified conditions, in which the upper and lower layers of the reservoir do not mix, purified water would be prevented from flowing directly to the outlet structure, providing a substantial retention time. During the relatively short period in which reservoir stratification would be lost, the reservoir would experience full and complete blending, so that any

[4] 15,000 AFY was selected as a representative yield for the purposes of reservoir modeling based on previous estimates of project yield, including the Water Reuse Study. This production capacity is approximate to the 15 mgd production capacity now assigned to a full-scale project, and reservoir modeling results obtained during the Demonstration Project are representative of the results expected from a full-scale project.

purified water that were to flow to the outlet would first undergo extensive blending with reservoir water.

San Vicente Reservoir's Role in Assuring Public Health Protection

A reservoir augmentation project at San Vicente Reservoir would protect public health by encompassing multiple barriers to prevent pathogens and chemicals from being introduced into the drinking water supply. While a full-scale AWP facility would provide substantial barriers, and no pathogens or chemicals are expected to be present in the purified water entering San Vicente Reservoir, the reservoir would provide absolute assurance that no target pathogens or chemicals would enter the drinking water supply. This multiple barrier concept is illustrated in Figure C-1.

Figure C - 1: Pathogen and Chemical Removal by Multiple Barriers

		Advanced Water Purification Facility				
Effectively Removes	Secondary/ Tertiary Treatment	Membrane Filtration	Reverse Osmosis	UV Disinfection/ Advanced Oxidation	Reservoir Blending and Retention	Treatment at Drinking Water Treatment Plant
Pathogens	●	●	●	●	●	●
Chemicals	●		●	●		●

Modeling San Vicente Reservoir

To evaluate the potential retention and dilution provided by San Vicente Reservoir, a three-dimensional hydrodynamic computer model of San Vicente Reservoir was set up in order to:

- Determine the effectiveness of San Vicente Reservoir as an environmental buffer capable of providing blending and retention as required by regulatory agencies
- Evaluate any hydrodynamic changes, or changes to movement of water within the reservoir, resulting from introduction of purified water
- Determine whether addition of purified water to San Vicente Reservoir would affect water quality within the reservoir

What is a Three-Dimensional Hydrodynamic Computer Model?

"Hydrodynamics" is the movement of water. The three-dimensional model of San Vicente Reservoir is a computer-based model that simulates and predicts the movement of water in all three directions within the reservoir: up and down, left to right, and forward and back.

The three-dimensional modeling of San Vicente Reservoir used a pair of coupled computer models: the Estuary Lake and Coastal Ocean Model [ELCOM] and the Computational Aquatic Ecosystem

Dynamics Model [CAEDYM]. These models were originally developed at the University of Western Australia. An expert team applied the models for use on the Limnology and Reservoir Detention Study of San Vicente Reservoir. The expert team has experience with similar modeling efforts for Lake Mead in Nevada and for Los Vaqueros Reservoir, Lake Perris, Lake Hodges, and Olivenhain Reservoir in California, plus three previous modeling projects for San Vicente Reservoir.

The computer model was set up, calibrated, and validated using real-world data collected through the Demonstration Project and previous efforts. San Vicente Reservoir modeling initially began in the 1990s when two tracer studies were conducted to establish the reservoir's retention and blending characteristics. During these tracer studies, an inert material (referred to as a tracer) was released into the reservoir, and its movement was monitored to simulate how water particles move and travel throughout San Vicente Reservoir. The three-dimensional hydrodynamic modeling was validated with data from the tracer studies to determine how well the model analyzed known conditions of San Vicente Reservoir. Three-dimensional hydrodynamic modeling was conducted for a variety of reservoir operation conditions and climatic cycles, including wet years, droughts, varying inflows and outflows, and other factors. By comparing data collected during the tracer studies to model predictions, the model was refined to accurately predict the movement of water through the reservoir.

The model was used to focus on hydrodynamic characteristics such as retention time and blending, but included a water quality component, or subroutine. The hydrodynamic modeling analysis consisted of the following steps:

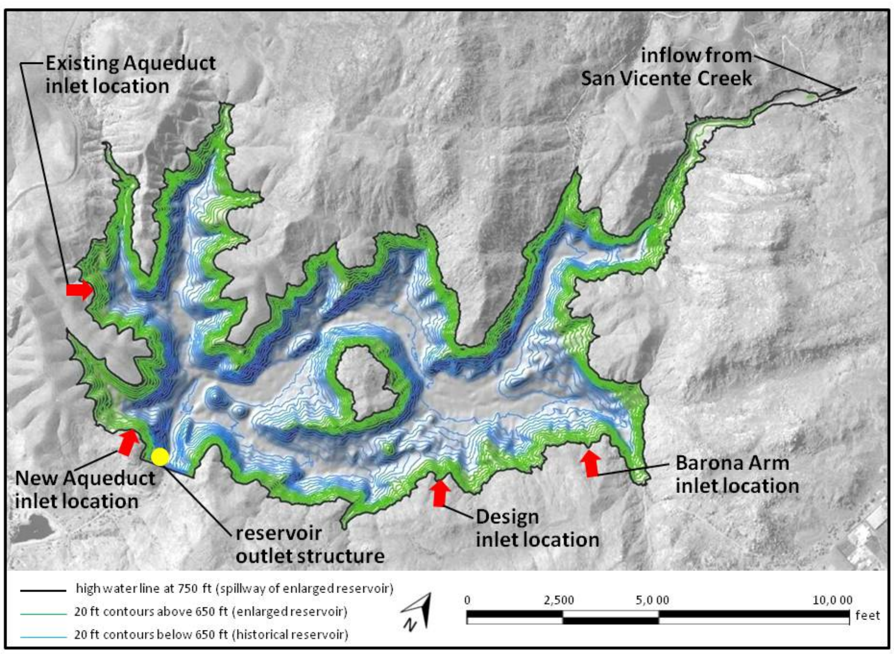
- Prepare a three-dimensional hydrodynamic model to simulate conditions in the old (90,000 AF-capacity) San Vicente Reservoir
- Use extensive historical reservoir water quality data and results from two tracer studies conducted in the late 1990s to calibrate and verify the accuracy of the three-dimensional hydrodynamic model
- Adjust the model to represent the expanded (247,000 AF-capacity) San Vicente Reservoir
- Conduct additional modeling to:
    - Assess the impact of adding purified water on the movement of water in the reservoir, including any potential implications on the formation and duration of the stratified layers
    - Assess the retention time and blending of purified water at various times of the year
    - Assess the impact of alternative purified water release locations on each of the above

The water quality component of the model was designed to simulate the potential effects of purified water on water quality in San Vicente Reservoir, specifically focusing on algae growth in the reservoir (Flow Science, 2010, Flow Science, 2012a, Flow Science, 2012b). Algal growth is the most important water quality factor affecting the use of the reservoir as a potable water supply, and also the most important water quality consideration for recreational uses. The water quality modeling analysis consisted of the following steps:

- Apply a water quality component to the three-dimensional hydrodynamic model
- Calibrate and verify the accuracy of the water quality component of the model using extensive historic reservoir water quality data
- Conduct model scenarios to compare water quality for three cases: 1) historic reservoir (90,000 AF), 2) expanded reservoir (247,000 AF), and 3) expanded reservoir with purified water added, compare physical parameters such as temperature and clarity, and nutrients for each case

Another key consideration in the reservoir modeling was the location where purified water would enter San Vicente Reservoir. The modeling effort involved testing four different potential locations to determine if the location of purified water entering the reservoir had an impact on water quality, retention, or blending. Figure C-2 illustrates these locations.

Figure C - 2: Potential Purified Water Inlet Locations



For the San Vicente Reservoir Study, Flow Science performed 18 separate runs of the three-dimensional hydrodynamic model. From these model runs, the project team–with input from the IAP–selected eight modeling scenarios for further assessment and analysis. Table C-1 summarizes the eight modeling scenarios. These modeling scenarios were selected because they represent the full range of purified water inlet locations and operational conditions that a reservoir augmentation project at San Vicente Reservoir could encounter. As such, the modeling effort captured the expected result of adding purified water to San Vicente Reservoir under all anticipated operating conditions. This modeling approach was a necessary step in the Demonstration Project to validate that San Vicente Reservoir will be able to meet regulatory requirements for retention time and blending under all conditions.

Table C- 1: Summary of Model Scenarios Completed

Model Scenario	Operating Scenario Simulated
1	**Base Case – Design Inlet Location:** reservoir under median expected storage and normal expected operations. Initial reservoir volume was 155,000 AF. Annual flow rates for Aqueduct inflow, runoff, purified water inflow, and dam withdrawal were 3,000, 4,500, 15,000, and 19,000 AFY, respectively. There were no water transfers from Sutherland Reservoir into San Vicente Reservoir. Purified water inlet was simulated at the Design Inlet Location, shown on Figure C-2.
2	**Base Case – Existing Aqueduct Inlet Location:** reservoir under median expected storage and normal expected operations. Initial reservoir volume was 155,000 AF. Annual flow rates for Aqueduct inflow, runoff, purified water inflow, and dam withdrawal were 3,000, 4,500, 15,000, and 19,000 AFY, respectively. There were no water transfers from Sutherland Reservoir into San Vicente Reservoir. Purified water inlet was simulated at the Existing Aqueduct Inlet Location, shown on Figure C-2.
3	**Base Case – New Aqueduct Inlet Location:** reservoir under median expected storage and normal expected operations. Initial reservoir volume was 155,000 AF. Annual flow rates for Aqueduct inflow, runoff, purified water inflow, and dam withdrawal were 3,000, 4,500, 15,000, and 19,000 AFY, respectively. There were no water transfers from Sutherland Reservoir into San Vicente Reservoir. Purified water inlet was simulated at the New Aqueduct Inlet Location, shown on Figure C-2.
4	**Base Case – Barona Arm Inlet Location:** reservoir under median expected storage and normal expected operations. Initial reservoir volume was 155,000 AF. Annual flow rates for Aqueduct inflow, runoff, purified water inflow, and dam withdrawal were 3,000, 4,500, 15,000, and 19,000 AFY, respectively. There were no water transfers from Sutherland Reservoir into San Vicente Reservoir. Purified water inlet was simulated at the Existing Barona Arm Inlet Location, shown on Figure C-2.
5	**No Purified Water Additions:** similar to Base Case, except there are no purified water additions and an equal reduction in reservoir outflow. Initial reservoir volume was 155,000 AF. Annual flow rates for Aqueduct inflow, runoff, and dam withdrawal were 3,000, 4,500, and 4,000 AFY, respectively. There were no water transfers from Sutherland Reservoir into San Vicente Reservoir.
6	**Extended Drought – Design Location:** hypothetical two-year drought where a large and constant volume of water is withdrawn monthly from the reservoir without importing additional water to refill the reservoir. Initial reservoir volume was 155,000 AF. Annual flow rates for Aqueduct inflow, runoff, purified water inflow, and dam withdrawal were 3,000, 4,500, 15,000, and 48,000 AFY, respectively. There were no water transfers from Sutherland Reservoir into San Vicente Reservoir. The volume of water stored in San Vicente Reservoir at the end of the simulation period was about 100,000 AF. Purified water inlet was simulated at the Design Inlet Location, shown on Figure C-2.
7	**Extended Drought – New Aqueduct Inlet Location:** hypothetical two-year drought

Model Scenario	Operating Scenario Simulated
	where a large and constant volume of water is withdrawn monthly from the reservoir without importing additional water to refill the reservoir. Initial reservoir volume was 155,000 AF. Annual flow rates for Aqueduct inflow, runoff, purified water inflow, and dam withdrawal were 3,000, 4,500, 15,000, and 48,000 AFY, respectively. There were no water transfers from Sutherland Reservoir into San Vicente Reservoir. The volume of water stored in San Vicente Reservoir at the end of the simulation period was about 100,000 AF. Purified water inlet was simulated at the New Aqueduct Inlet Location, shown on Figure C-2.
8	**Emergency Drawdown:** simulates a situation in which 66,000 AF of water is withdrawn from the reservoir in January and February of Year 2 and the reservoir is then refilled by adding 66,000 AF of water from the Aqueduct between March and July of Year 2. The rest of the flow rates are the same as the Base Case. Initial reservoir volume was 200,000 AF.

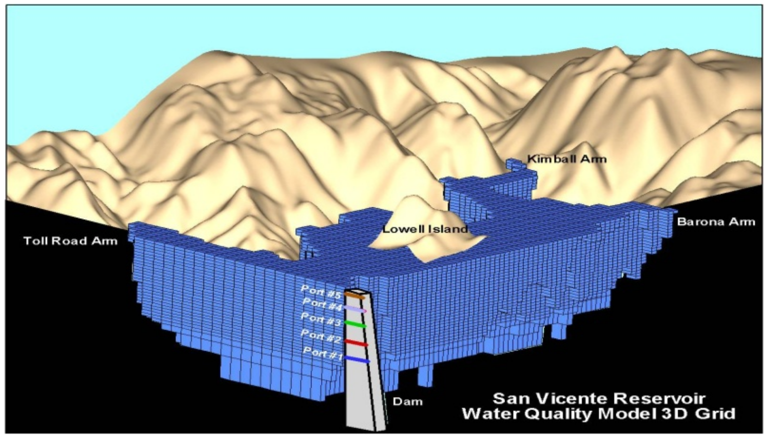
The reservoir model was set up in conjunction with regulatory entities including the Regional Board and CDPH, whose feedback was important to this process due to regulatory requirements for blending, retention, and water quality conditions. Model development and validation were also reviewed by the IAP. A dedicated subcommittee of the IAP was convened to review the model and associated data, and to provide comments to the City's reservoir modeling team throughout the reservoir modeling process. The IAP concluded that the model provides "an effective and robust tool" for assessing the effects of purified water on San Vicente Reservoir (NWRI 2010).

> ***"The Subcommittee (IAP Subcommittee for the San Vicente Reservoir Study) believes that the modeling is sufficiently predictive for purposes of evaluating the input of advanced treated recycled water (purified water)."***
>
> Findings and Recommendations of the Limnology and Reservoir Subcommittee (NWRI 2010)

San Vicente Reservoir Study Findings

Key findings of the San Vicente Reservoir modeling effort are:

- The addition of purified water into San Vicente Reservoir would not affect natural hydrologic characteristics of the reservoir, seasonal stratification, or mixing. This finding demonstrates that the addition of purified water would not affect the natural blending and retention in the reservoir.



The three-dimensional hydrodynamic model allowed the City to simulate potential effects of purified water on San Vicente Reservoir.

- Blending and retention of purified water in San Vicente Reservoir would constitute a substantial environmental barrier, sufficient to meet regulatory requirements.
- For all anticipated reservoir operating scenarios and purified water release locations, the reservoir would dilute the purified water by at least a factor of 200 to one at all times.
- As discussed in Section B: Advanced Water Purification Facility, the purified water produced at the AWP Facility was found to be very pure, approaching distilled water purity. The addition of purified water would not affect any aspect of water quality in San Vicente Reservoir. The dam raise and reservoir expansion, which is independent of the Demonstration Project, will improve overall water quality in the reservoir by reducing nutrients including nitrogen compounds that can stimulate algae growth and cause water quality issues, and the addition of purified water will not change these improvements. Addition of purified water would improve some aspects of reservoir water quality, such as reducing salt concentration.