Indirect Potable Reuse
in Miramar Reservoir

Jeffery Pasek, Kareem Hannoun, Ira Rackley, Joseph Quicho and Imad Hannoun

Background

Precipitation across the United States vastly exceeds water usage. Water resources, however, are not evenly distributed, leaving many communities in the arid West facing water scarcity as their population grows. Reliable, drought-proof water sources are needed to address current and future water supply needs.

Potable reuse has become a promising option for water resource managers in California and elsewhere, and California has developed a framework for evaluating potable reuse projects. In this article, we explore some of the challenges and lake management implications for a potable reuse project involving Miramar Reservoir in Southern California.

Water reuse – the planned reuse of treated wastewater – is a viable approach to address water shortages and to diversify water supplies. Non-potable reuse, wherein treated wastewater is used for irrigation and industrial supplies, is already practiced throughout the United States. Unplanned, or *de facto*, potable reuse occurs when treated wastewater is discharged into a water body (a river, for example) and then becomes part of the water supply of a downstream user. Not yet common, but important for the future, is the *planned reuse of highly treated wastewater for drinking water supply*. This is called **potable reuse**.

Potable reuse has two basic types (Figure 1). **Indirect potable reuse** (IPR) is the process of intentionally using highly treated wastewater as a source of drinking water supply, using an environmental buffer (a reservoir or groundwater basin) before the water receives final treatment and is distributed as drinking water. For **direct potable reuse** (DPR), treated wastewater is used directly as drinking water without an environmental buffer, although conventional drinking water treatment and artificial storage may still be part of the project. For both IPR and DPR, the wastewater is treated at least to drinking water quality standards. In the case of IPR, an environmental buffer with significant dilution and retention time offers reduction of microbial and chemical contaminants by natural decay and blending. This can improve the consistency of source water quality, provide additional levels of protection, and decrease treatment costs relative to DPR.

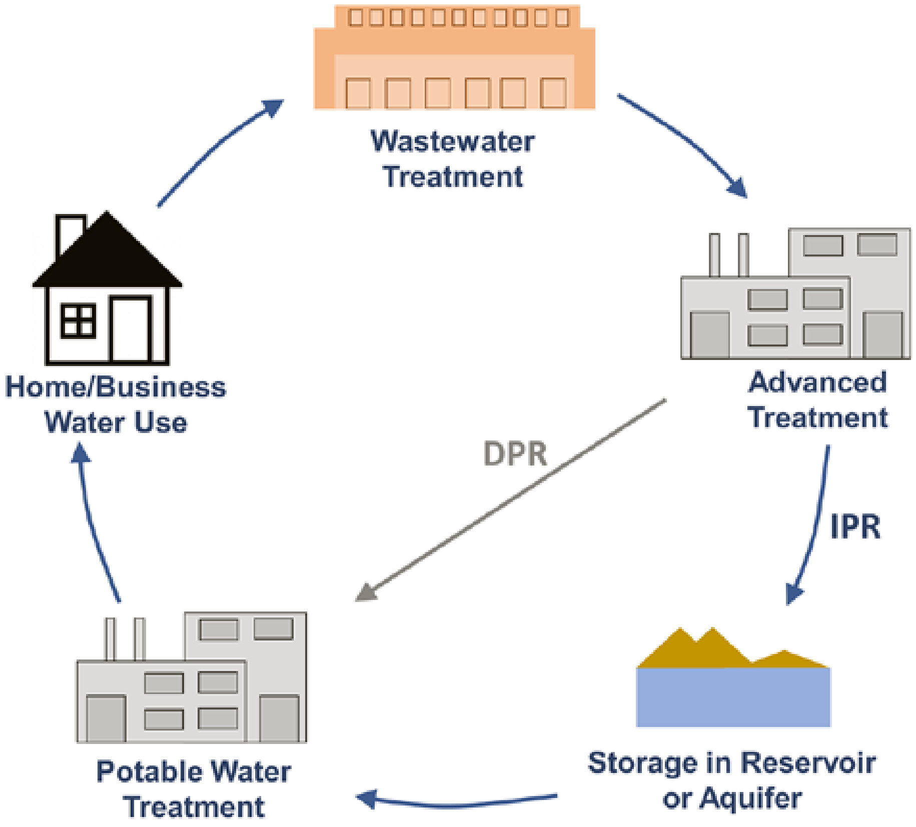


Figure 1. Schematic showing water cycle for indirect potable reuse (IPR) and direct potable reuse (DPR).

The City of San Diego launched the Pure Water San Diego program as part its ongoing efforts to improve water supply reliability and decrease reliance on imported water. San Diego relies on water conveyed hundreds of miles from the Colorado River and northern California (imported water) for 85 percent of its supply. The cost of imported water has risen significantly over several decades, and these imported supplies are increasingly constrained by environmental concerns and competition with other users. With limited local water sources and reliance on imported water, the City's supply is susceptible to drought, climate change, and natural disasters. The Pure Water San Diego program will employ IPR to provide a cost-effective, safe, reliable, and locally controlled source of water. The City uses the name *purified water* for this new source. The Pure Water San Diego program will ultimately produce 83 million gallons per day (mgd) of purified water to meet one-third of San Diego's water needs. Phase 1 will release 30 mgd of purified water into the City's Miramar Reservoir. Construction of Phase 1 has begun, with project startup set for 2025.

History and regulations

IPR has been practiced in the United States for over 50 years, with projects in at least seven states. While a federal permit may be required to discharge treated wastewater, IPR is not otherwise federally regulated and regulatory criteria are developed at the state level. Regulatory guidelines for potable reuse currently exist in Arizona, California, Colorado, Florida, Nevada, Texas, and Washington, with California leading in the number of existing or planned projects. In many other states, potable reuse projects are considered by regulators on a case-by-case basis.

Challenges for IPR projects

IPR provides clear benefits to communities facing water scarcity or insecurity; however, there are a number of challenges to project implementation. These include regulatory barriers, technical challenges, cost, and public perception. Regulatory barriers include stringent treatment criteria, enhanced water quality monitoring requirements, and project requirements such as minimum reservoir retention times. Technical challenges include project feasibility, maintaining high reservoir water quality, delivering treated water to the reservoir, and ensuring adequate mixing within the reservoir or other environmental buffer. High levels of community awareness are needed to gain public support and provide for project funding. In San Diego, where water reuse issues have been debated in community settings and in the media for three decades, water reuse is now widely accepted by the public.

Regulations in California

California has a fully developed regulatory framework for IPR, with detailed regulations applying when a groundwater basin serves as the environmental buffer (groundwater replenishment) and separate regulations for using a surface water body as the environmental buffer (reservoir augmentation). Two key requirements for an IPR reservoir augmentation project in California are (1) an overall water residence time in the reservoir of at least 60 days and (2) that any 24-hour inflow of purified water must be diluted at least 10:1 with ambient reservoir water, measured at the point of withdrawal from the reservoir. The regulations stipulate that three-dimensional hydrodynamic modeling of the reservoir be used to demonstrate that the dilution criteria can be met under all conditions. Further, the regulations require that the hydrodynamic model be calibrated using site-specific datasets; then the modeling must be validated against real-world tracer studies conducted in the reservoir; and finally the entire body of work must be approved by an independent expert panel of scientists and engineers. (California's regulations mandate that a limnologist serve on the expert panel. So far as we know, this is the only occurrence where state or federal regulations require participation of a professional limnologist.) Based on the results of the hydrodynamic modeling, the conditions under which purified water can be released into and withdrawn from the reservoir are specified in a permit from the California Division of Drinking Water.

California regulations also require reservoir water quality monitoring in years prior to augmentation to establish a baseline record of reservoir water quality. Upon project startup, there must be on-going reservoir monitoring in the form of frequent water quality sampling and analysis, real-time data reporting, and annual limnological reports.

Miramar Reservoir background

Miramar Reservoir, a 6,700-acre-foot reservoir owned and operated by the City of San Diego, is a drinking water source for the city. The reservoir has a mean depth of 12 meters, maximum depth of 35 meters, and a four-tier outlet structure that serves the adjacent Miramar Water Treatment Plant. Currently, inflows into Miramar Reservoir consist almost entirely of imported water from the Colorado River and Northern California, and all outflows go to the water treatment plant. The reservoir's catchment is just 650 acres and all residential storm drains are diverted away from the reservoir. Very little local runoff enters the reservoir.

Miramar Reservoir was identified as a promising target for IPR due to its size, elevation, proximity to a water treatment plant and wastewater treatment plant, and small catchment basin. These factors reduce pipeline and pumping costs while ensuring consistent water quality. Purified water will be released into Miramar Reservoir through an underwater diffuser system (Figure 2).

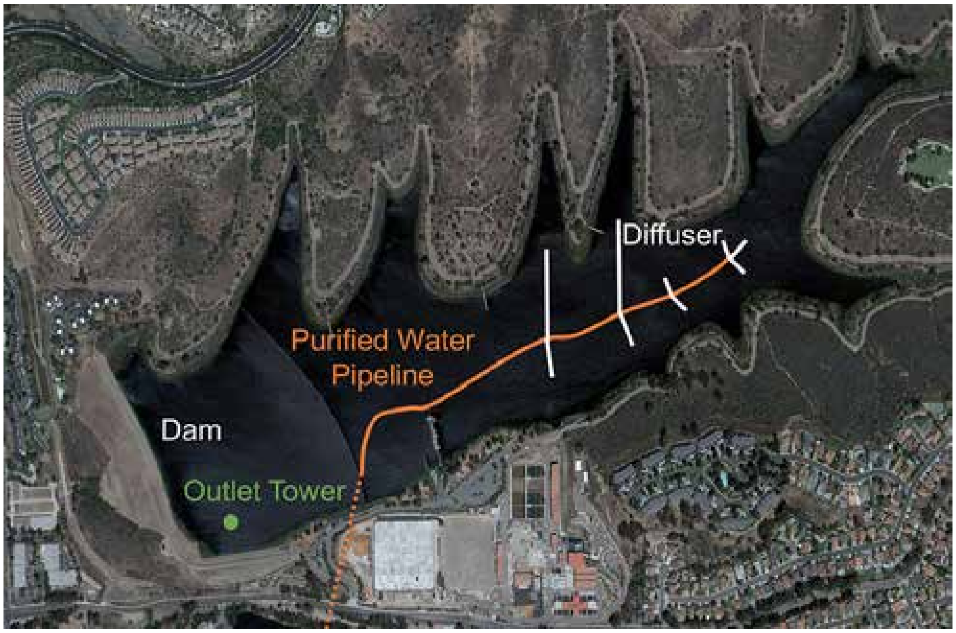


Figure 2. Miramar Reservoir showing the planned locations of the purified water conveyance pipeline (orange), the submerged diffuser system (white), and the reservoir outlet structure. The existing drinking water treatment plant is immediately adjacent to the reservoir at the bottom of the graphic.

Residence time and dilution criteria

With careful management of storage levels and inflow rates, Miramar Reservoir can meet the 60-day residence time requirement.

To demonstrate compliance with the 10:1 dilution criterion of any 24-hour inflow, three-dimensional hydrodynamic modeling was used to understand the complex reservoir dynamics and possible short-circuiting in a stratified reservoir. The AEM3D computational model was used for the 3D modeling, which was calibrated against in-reservoir data (Figure 3). AEM3D is a program that simulates the movement, physical properties, nutrient concentrations, and algal productivity of surface waters over a timescale of days to years.

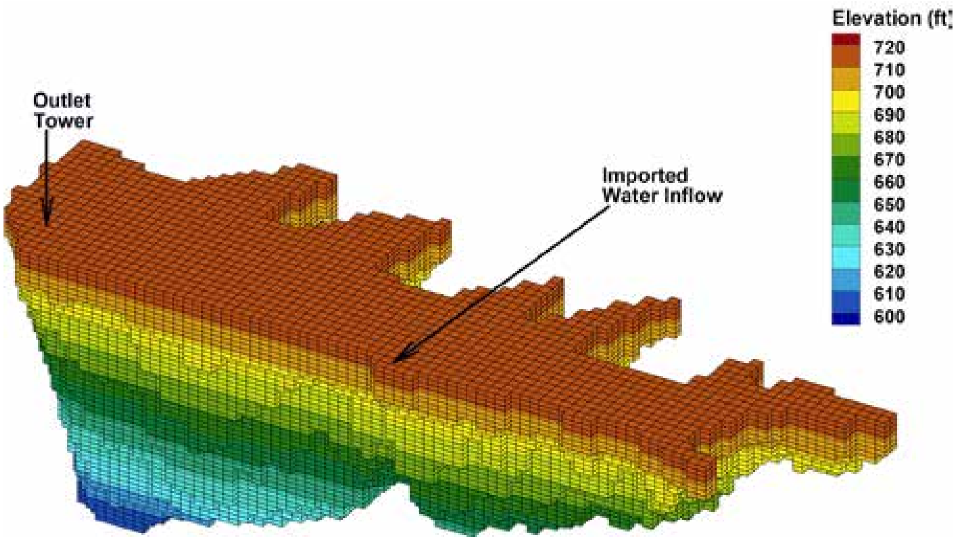


Figure 3. Three-dimensional modeling grid used for hydrodynamic simulations of Miramar Reservoir. Each model cell is 20 by 20 meters in the horizontal and 0.2 to 0.6 meters thick.

Model validation using field tracer study

The performance of the model was validated through a tracer study in Miramar Reservoir. In July 2019, a fluorescent tracer dye (Rhodamine WT) was injected into the reservoir at mid-depth (Figure 4). The distribution and concentration of the tracer was monitored through extensive reservoir-wide sampling over a three-month period. Rhodamine WT concentrations were measured at eleven mid-reservoir stations, with careful attention to horizontal and vertical accuracy of sampling location. Sampling events were concentrated in the beginning of the study, with 11 samplings in the first week, and weekly samplings near the end of the study. The results show that the tracer was confined to a thin layer at the depth of the thermocline for several weeks (Figure 5), then sank to about 17 meters after two months. As stratification weakened in the fall, the tracer mixed to shallower depths and was lost to photolytic decay.

Figure 4. Left, preparation of the Rhodamine WT tracer prior to injection ten meters below the platform. Right, instrument used to measure Rhodamine WT in vertical profiles; the fluorometric sensor can reliably measure Rhodamine WT concentrations to 0.1 ppb.

The tracer concentrations were compared to the results of 3D model simulations, and good agreement was observed between the experimental and simulated results. The model simulations accurately captured both the horizontal and vertical movement of the tracer; thus, the model is considered validated.

Model application

Lakes and reservoirs exhibit great hydrodynamic complexity. Seasonal stratification, inflows and outflows, wind, sunlight, and temperature combine to create a myriad of possible mixing and dilution settings. It is not possible – even in a simple setting like Miramar Reservoir – to use real-world tracer studies to assess dilutions of inflowing purified water under all possible conditions. Thus, the tracer studies are used to validate the performance of the hydrodynamic model, then the model is used to simulate many, varied scenarios to determine compliance with the dilution criteria. Modeling studies at Miramar Reservoir demonstrated that certain combinations of open outlet ports will comply with the dilution criteria under any expected set of conditions. The selection of available combinations of outlet ports depends on seasonal conditions, stratification, and reservoir storage levels. The modeling showed a several-day lag between purified water inflow and first significant detection of purified water at the reservoir outlet, giving reservoir managers time to respond to any problems with purified water quality (Figure 6). Additional modeling work – yet to come – will determine purified water dilutions and time

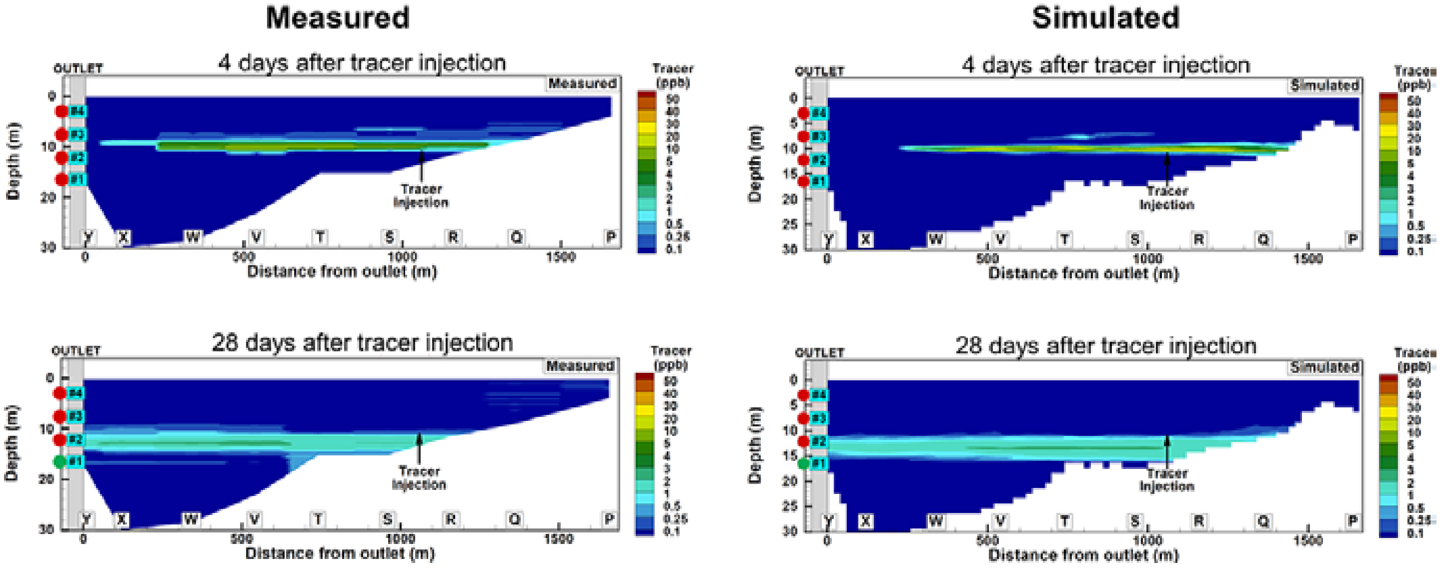


Figure 5. Tracer study in Miramar Reservoir: measured (left) vs simulated (right) Rhodamine WT tracer concentrations four days and 28 days after tracer injection.

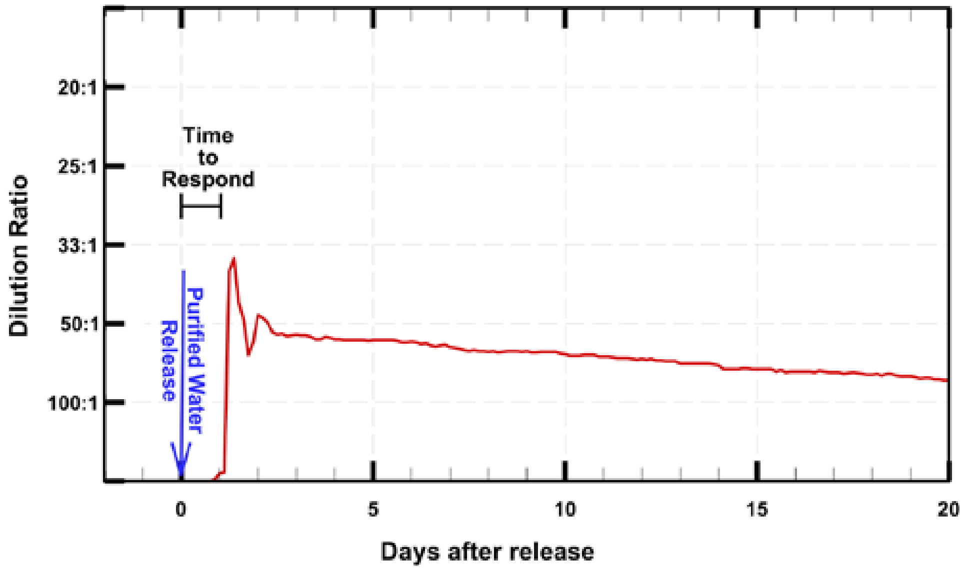


Figure 6. Model simulation of a 24-hour pulse of purified water released into a reservoir, showing dilution of the purified water into ambient reservoir water as measured at the reservoir outlet. The peak of the graph is the minimum dilution, in this case about 30:1. The span along the horizontal axis between release and the peak represents the time to respond, here about 1½ days.

to respond under the full range of conditions and will be used to establish operational rules for reservoir management.

Reservoir water quality

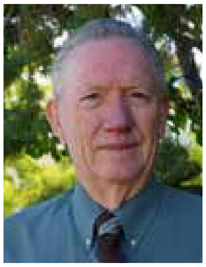
In addition to mandating sufficient residence time and dilution, California's IPR regulations give attention to reservoir water quality. The regulations emphasize managing algal growth in the reservoir, with the desired outcome of limiting nuisance algal blooms, taste and odor events, and algal toxins. Imported water inflows to Miramar Reservoir from the Colorado River and northern California has limited nutrient loading, resulting in a system with low algal productivity. However, replacing imported water with purified water could alter nutrient loadings, causing changes from the current conditions. Historically, with various blends of Colorado River water and northern California water, nutrient concentrations of reservoir inflows have typically been 0.01 to 0.1 mg/L phosphorus and 0.2 to 0.5 mg/L nitrogen. Purified water receives a very high level of treatment (tertiary wastewater treatment followed by five steps of advanced treatment) and water released into the reservoir will have nutrient concentrations of 0.025 mg/L phosphorus and 2 mg/L nitrogen. These nutrient levels will yield a phosphorus-limited system. Modeling with AEM3D using expected purified water phosphorus and nitrogen concentrations predicts continued low algal productivity, at or below current levels. The model's predictions of algal productivity are accepted by regulators, allowing them to approve the project with the proviso that extensive water quality monitoring and reporting, and on-going modeling, show that algal growth continues to be well controlled.

Conclusion

Technological and regulatory advances have led to an increase in water reuse projects in California, and the City of San Diego has identified indirect potable reuse with reservoir augmentation as a viable strategy for increasing water supply reliability and decreasing reliance on imported water. Phase 1 of the Pure Water San Diego program will send 30 MGD of highly treated wastewater – *purified water* – to Miramar Reservoir for use as potable supply. Hydrodynamic and nutrient modeling of the reservoir has been used to demonstrate compliance with state regulations and continued good source water quality, helping to ensure the health and safety of the public water supply.

Jeffery Pasek has managed reservoirs and watersheds in the San Diego region over four decades. As part of the Pure Water San Diego team, he led limnological studies of Miramar, San Vicente, and Otay Reservoirs, and guided the program's regulatory compliance. He previously served as president and southern director of the California Lake Management Society.

Dr. Kareem Hannoun is a scientist at Water Quality Solutions. He works on data and technical analyses of water chemistry of natural water bodies. He also works on one- and three-dimensional hydrodynamic and water quality modeling of reservoirs, with a focus on reservoir water quality improvement.



Ira Rackley has served as principal-in-charge and project manager for numerous municipal and industrial projects and is currently serving as senior engineer with Water Quality Solutions. He has worked within the states of Nevada and California for over 45 years on many projects including municipal water systems, water quality in lakes, municipal storm drainage and flood control, and water quality programs. He was appointed and served for six years on the Nevada State Environmental Commission, and is a founding member of the Wester Coalition of Arid States, where he served as chairman of the Water Science and Technology Committee.

Joseph Quicho is an associate civil engineer with the City of San Diego Public Utilities Department. As part of the Pure Water San Diego team, he is the lead project manager of water and wastewater engineering and applied research projects.

Dr. Imad Hannoun is CEO of Water Quality Solutions. He has acted as project manager for over 170 hydrodynamic and water quality investigations in Southern California and elsewhere. He currently serves as chair of the publications committee for NALMS and as an associate editor of *Lake and Reservoir Management*. He previously served as director of NALMS Region 3 and Region 9, and also as president of the California Lake Management Society.