Potable Reuse: Surface Water Augmentation

White Paper on Alternatives Clause – Final Version

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Prepared for:

WateReuse California

Prepared by:

Trussell Technologies, Inc.
Shane Trussell, Ph.D., P.E., BCEE
Rhodes Trussell, Ph.D., P.E., BCEE
Brian Pecson, Ph.D., P.E.
Sarah Triolo

Consultants
Imad Hannoun, Ph.D., P.E. (VA)
President, Water Quality Solutions, Inc.
George Tchobanoglous, Ph.D., P.E., BCEE
Professor Emeritus, U.C. Davis

Advisors and Reviewers

Shivaji Deshmukh, Assistant General Manager, West Basin MWD
Brian Olney, System Operations Manager, Helix Water District
Jeffery Pasek, Watershed Manager, City of San Diego
Mike Wehner, Assistant General Manager, Orange County Water District

Executive Summary

Surface Water Augmentation has the potential to greatly expand the scope of potable reuse in California, further advancing the State towards it recycled water goals. Unlike the decades of project experience that preceded the Groundwater Recharge regulations, surface water augmentation regulations will be developed without the benefit of actual project experience. This fact is relevant for the following reason: understanding of public health risks and the ability to control them has evolved continuously over California's 50-year potable reuse history. Cognizant of this fact, the groundwater recharge regulations provide adaptability in the form of an "alternatives clause," offering permitting pathways for innovative projects that build off of the expanding knowledge base. The same degree of adaptability should be included in future potable reuse regulations, including surface water augmentation. The goal of this document is to show that an alternatives clause for the reservoir criteria can be enacted safely, allowing the State to protect public health, maximize potable reuse, and maintain the benefits that initially drove the creation of the reservoirs near the State's drinking water treatment facilities.

Surface water augmentation is distinct within the potable reuse spectrum for its use of a reservoir between the advanced water treatment facility and the drinking water treatment facility. The Division of Drinking Water has identified three benefits of the reservoir in protecting public health: retention time, response time, and dilution. The draft surface water augmentation regulations have specific requirements to ensure these elements are included (Figure ES.1).

Theoretical Retention Time

"An augmented reservoir shall have a theoretical retention time of no less than six months."

Response Time **Dilution**

The ~~total~~ volume of water withdrawn from the augmented reservoir to be ultimately supplied as a drinking water ~~during a 24-hour period~~ contains no more than:
(1) **one percent, by volume**, of recycled municipal wastewater that was delivered to the reservoir **during any ~~preceding~~ 24-hour period**, or
(2**)** **ten percent, by volume**, of recycled municipal wastewater that was delivered to the reservoir **during any ~~the preceding~~ 24-hour period**...with an additional **process producing no less than a 1-log reduction**

Figure ES.1. Time and dilution requirements for reservoir operation in draft surface water augmentation regulations. Requirements related to retention time, response time and dilution requirements are shown in blue, red and green, respectively. Expert panel edits to the Division of Drinking Water draft have been preserved.

The regulations specify that the dilution requirements be provided to protect against a 24-hour input of off-spec water, with the implication that any failures in treatment must be detected and corrected within this time period.

In line with the Division of Drinking Water's perspective, the primary function of the reservoir in potable reuse is to promote reliability in public health protection. The reservoir accomplishes this objective by means of three primary functions: (1) dilution and (2) a 24-hour response time, as described in the draft regulations, but also a third benefit, which is (3) the uncoupling of the advanced water treatment facility from the drinking water treatment facility. Although uncoupling is not mentioned in the draft surface water augmentation regulations, the reservoir offers significant public health protection from potential treatment and monitoring anomalies with the ability to independently regulate flow into and out of the reservoir. A project that can provide all three elements offers significant public health protection; these are what ultimately distinguish surface water augmentation from other forms of reuse (Figure ES.2).

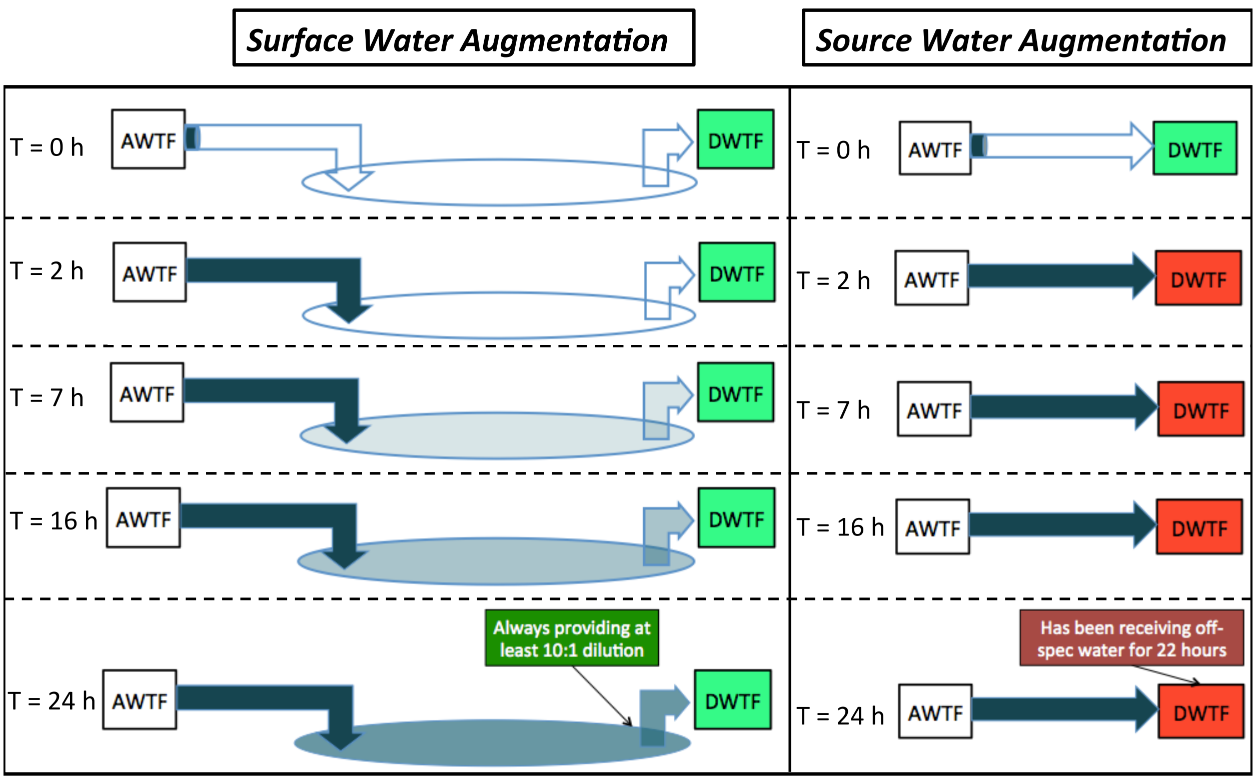


Figure ES.2. The benefits of dilution and response time in Surface Water Augmentation projects. Figures show the fate of a 24-hour production of off-spec water (dark blue color). Surface water augmentation requires a minimum dilution of at least 10:1 of this 24-h production, providing a response time during which failures can be detected and addressed. Source water augmentation projects receive the undiluted slug of off-spec water throughout the majority of the same time period.

The theoretical retention time requirement (V/Q) is intended to ensure a minimum reservoir residence time, so that if a treatment failure were to occur, a project sponsor would have sufficient time to prevent the contaminant from impacting the drinking water treatment facility (i.e., response time). Put another way, V/Q is intended to serve as a *surrogate* for response time, but does not necessarily provide a direct benefit in and of itself. As a screening tool, the V/Q surrogate has important value. The Expert Panel showed the value of specifying a minimum retention time in order to provide "time to react", and that a 4-6 month V/Q requirement would "essentially assure" that the dilution and response time were also met. In summary, a reservoir meeting the 6-month retention time should easily meet the dilution and response time requirements.

It is incorrect, however, to assume that a project that fails to meet V/Q will necessarily fail to meet the response time and dilution requirements. The example in Figure ES.3 illustrates that smaller reservoirs can provide as much protection as large reservoirs. Similar conditions have already been demonstrated in California reservoirs. In short, the *actual* operation of the reservoir may outweigh the importance of the *theoretical* V/Q in protecting public health. Incorporating advancements in the science and technology of reservoir management, therefore, allows projects to enhance public health protection.

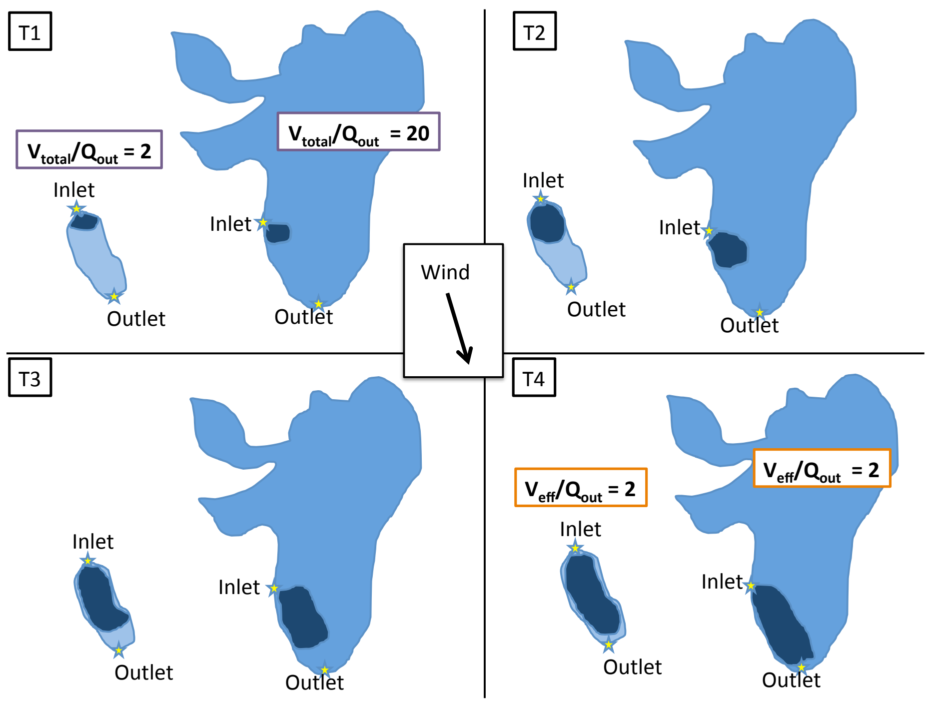


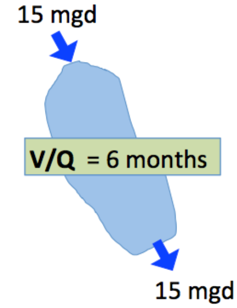
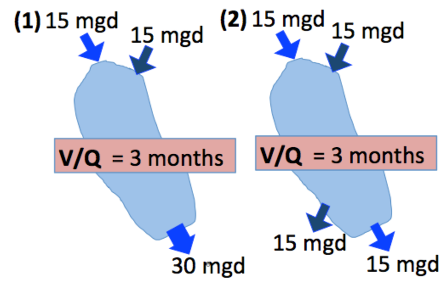
Figure ES.3. Evaluation of public health protections provided by two hypothetical reservoirs of varying sizes. The reservoirs utilize the same effective volume (V_{eff}) to provide dilution and response time, resulting in equivalent V_{eff}/Q in both cases. This example illustrates that reservoirs with higher V_{total}/Q do not necessarily provide a higher degree of public health protection. Dark blue represents the passage of purified water over four time periods (T1 to T4).

Ultimately, this ambiguity in the predictive value of V/Q is overcome by other surface water augmentation requirements. Namely, all projects must demonstrate through tracer tests and modeling that they can meet the dilution and response time requirements. **This mandatory *demonstration of public health protection* should supersede the need for an additional *theoretical* time requirement**. A clause that allows alternatives to the V/Q requirement would expand the use of surface water augmentation in California by allowing a wider range of projects, all of which would be equally demonstrative of public health protection.

This document proposes an expansion of Article 9 to make allowance for alternatives *if they can demonstrate equal public health protection*. The analysis provides perspective on an alternate grouping of elements that could be used to assess public health protection: (1) dilution, (2) response time, and (3) uncoupling. This new set of requirements, which builds on the core criteria from the existing regulations, could serve as a foundation for a path to safe alternatives.

An alternatives clause in Article 9 will lead to more successful surface water augmentation projects for several reasons:

1) **Expanding understanding of public health protection**: dilution and response time provide demonstrable benefits for public health protection in the reservoir; however, there may be other benefits that the reservoir can provide that are not yet fully understood. As full-scale projects are planned and implemented, a wealth of new information will be gained. The inclusion of an alternatives clause in Article 9 will facilitate consideration of advancements in science and technology to enhance strategies for design and operation.
2) **Raw water reservoirs need to maintain their original functions**: many raw water reservoirs upstream of drinking water plants were originally built for flood control and to be a source of water supply during maintenance, unscheduled downtime, and emergencies. These abilities may be compromised by a strict V/Q requirement, and may lessen the degree of public health protection provided (Figure ES.4)
3) **Drinking water treatment facilities must maintain the ability to operate independently of the surface water augmentation reservoir**: operators routinely use reservoirs to increase the flexibility of drinking water treatment facility operation—choosing to take or not to take water from the reservoir to suit operations. This option allows operators the "freedom to be cautious" if there are concerns about the quality of one source or another. The V/Q requirement would limit the ability to go off the reservoir, and decrease this operational flexibility.

<table>
<tr><th>Scenario Description</th><th>Operational Benefits</th><th>Retention Time Impact</th></tr>
<tr><td colspan="2">Normal Operations</td><td rowspan="2">
</td></tr>
<tr><td>Normal operations – flow into reservoir equals flow out of reservoir. AWTF is only flow into reservoir, and only outflow is to DWTF.</td><td></td></tr>
<tr><td colspan="2">Blending with Additional Sources</td><td rowspan="2">
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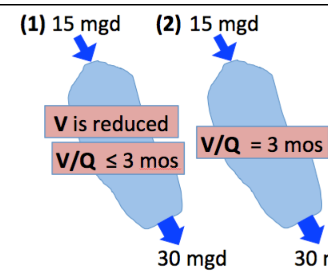
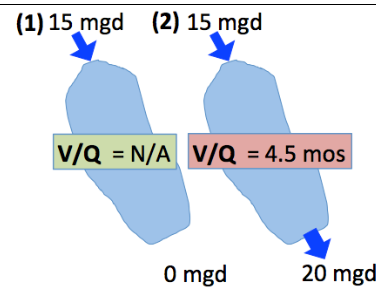
<tr><td>(1) Operation with 1:1 aqueduct to AWTF water, and (2) operation with additional water flowing through (e.g. streamflow, aqueduct water)</td><td>Improves dilution and treatability of AWTF water May be necessary to meet downstream needs</td></tr>
<tr><td colspan="2">Runoff Collection & Flood Control</td><td rowspan="2">
</td></tr>
<tr><td>(1) Reducing reservoir volume to prepare for wet season, and (2) operation during wet season</td><td>Makes room in reservoir to collect local runoff, which is a low-cost water source. Also provides flood control.</td></tr>
<tr><td colspan="2">Precautionary Operation</td><td rowspan="2">
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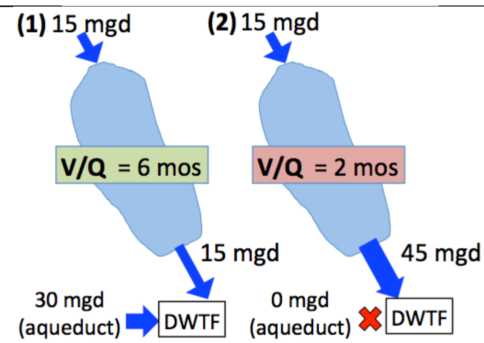
<tr><td>(1) DWTF not taking reservoir water as precautionary measure, and (2) DWTF catching up to return to normal reservoir level</td><td>DWTF has freedom to be cautious by switching to alternate supply for significant period of time</td></tr>
<tr><td colspan="2">Operation During Aqueduct Downtime or Emergency</td><td rowspan="2">
</td></tr>
<tr><td>Operation with additional draw from reservoir during aqueduct downtime</td><td>Reservoir provides supply during emergencies and scheduled aqueduct maintenance</td></tr>
</table>

Figure ES.4. Historic reservoir roles impacted by V/Q requirement.

Another option is to permit reservoir projects that fail to meet the V/Q requirement as direct potable reuse projects. This document demonstrates why it is in the State's best interest not to take this approach, but to learn from a broad range of surface water augmentation projects and apply this understanding to strengthen the creation of future direct potable reuse regulations (Figure ES.5).

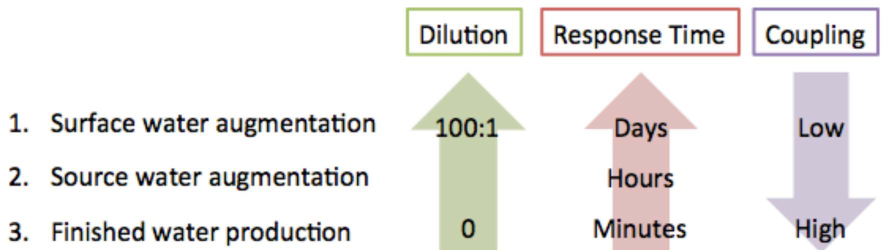


Figure ES.5 Surface water augmentation experience will offer insight into issues relevant for direct potable reuse, including dilution, response time, and coupling

In conclusion, an alternatives clause will benefit the State in the following ways:

- Ensure public health protection and allow more projects to be permitted and constructed
- Provide an opportunity to incorporate an expanding body of knowledge from a larger set of operating projects
- Prevent the misclassification of surface water augmentation projects—with their unique public health protections—as a form of direct potable reuse
- Inform the development of future direct potable reuse regulations
- Maintain the ability to provide a secure, safe, and reliable water supply by preserving the original uses of the reservoirs (flood control, emergencies, etc.)

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Acronyms

AWTF	Advanced water treatment facility
DDW	Division of Drinking Water
DPR	Direct potable reuse
DWTF	Drinking water treatment facility
GWR	Groundwater recharge
LRV	Log removal value
OCWD	Orange County Water District
SWA	Surface water augmentation
SWRCB	State Water Resources Control Board
SWSAP	Surface Water Source Augmentation Project
V/Q	Theoretical retention time, defined as volume (V) divided by flow (Q)

1 Introduction

Severe drought, climate change, population growth—California faces an unprecedented set of challenges with regard to water management. Many approaches have been proposed to maintain a clean, affordable drinking water supply, including seawater desalination, recovery of impaired groundwater, and potable reuse of wastewater. Of these, potable reuse is an attractive and cost-effective option—it enables year-round availability of potable supply, avoids the need for new distribution infrastructure, and can be safely accomplished with today's technologies (Tchobanoglous et al., 2015). It also has the potential to provide up to a quarter of the country's drinking water needs with a dependable new source of supply (NRC, 2012). For this reason, the recycled water policy put forth by the State Water Resources Control Board (SWRCB) includes a goal to "**increase the use of recycled water over 2002 levels by at least one million acre-feet per year (afy) by 2020 and by at least two million afy by 2030**" (SWRCB, 2013). Furthermore, SWRCB has a goal of the "**substitution of as much recycled water for potable reuse water as possible by 2030.**" These goals envision a safe but unprecedented expansion of *potable* reuse practice in California.

The term "potable reuse" presumes the treatment of recycled water for potable consumption, but it should be stressed that the potable reuse spectrum spans a wide diversity of project types. This breadth of types is shown schematically in Figure 1. This diversity is bookended by groundwater recharge (GWR) at one end to direct potable reuse (DPR) at the other, with each offering different benefits and challenges. All of the existing projects in California engage in groundwater recharge.

California is a worldwide leader in potable reuse, utilizing approximately 200 million gallons of recycled water each day for potable purposes. California' s experience began in the 1960s with the spreading of recycled water by the Los Angeles County Sanitation Districts at Montebello Forebay, and expanded in the 1970s with groundwater injection of advanced treated water at Orange County Water District's (OCWD) Water Factory 21. Both of these GWR projects were made possible by the significant environmental barrier offered by the groundwater basins where the projects were located.

Over the years, GWR projects have provided invaluable experience that advanced the industry's understanding of potable reuse. Real-world experience from operating projects also allowed the regulatory community to evolve their understanding of the factors required for public health protection. As this body of knowledge grew, the regulations adapted to include an expanded range of projects, while always maintaining their focus on the protection of public health.

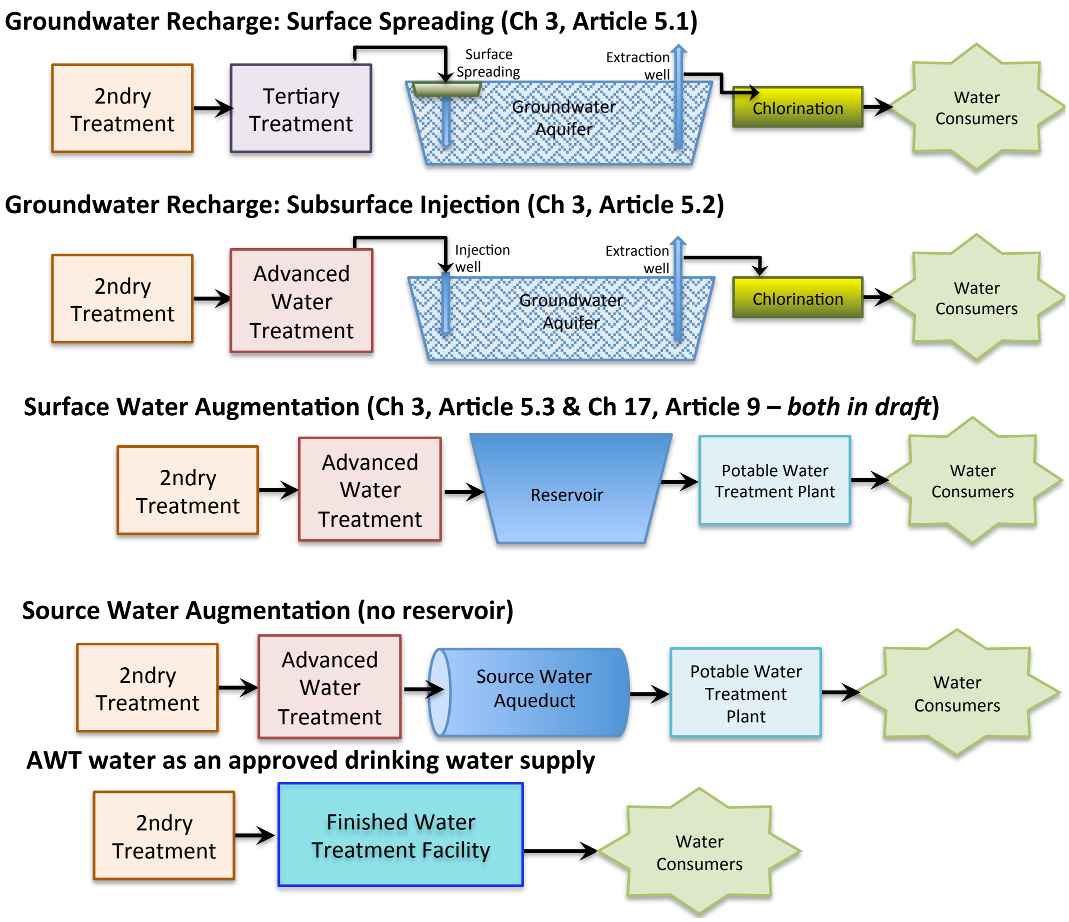

Figure 1: Types of potable reuse projects being discussed in California today

Major advancements have occurred over the last 50 years in treatment and monitoring technology, and in the understanding of environmental processes. These advancements were incorporated in interim drafts throughout the regulatory development period (1976 to 2014). Recognizing that such advancements would likely continue at a rapid pace, the regulators included an alternatives clause enabling a project to propose an alternative to any requirement if it "assures at least the same level of protection to public health" (DDW, 2014). This clause provides flexibility in the GWR permitting process, allowing projects to adapt to advances in science and technology, site-specific circumstances, and other factors. This clause requires a rigorous examination of the evidence to assure the Division of Drinking Water (DDW) that the alternative provides at least an equivalent level of protection to public health.

DDW is currently facing the challenge of developing uniform water recycling criteria for surface water augmentation (SWA) in a much more condensed timeline. Unlike with GWR, these regulations will be developed without the benefit of full-scale project experience. DDW, with the advice of the State Expert Panel, has developed draft regulations governing both the treatment requirements and reservoir criteria for SWA. The GWR regulations are exclusively contained in Title 22, Division 4, Chapter 3 of the California Code of Regulations; the proposed SWA regulations are split between two chapters (see the structure illustrated in Figure 2). Chapter 3, Article 5.3 contains requirements for treatment, source control, pathogen and chemical control, and monitoring, while Chapter 17, Article 9 contains the criteria for the reservoir. Under these draft regulations, Article 5.3 contains an alternatives clause similar to that found in the GWR regulations, but Article 9 does not.

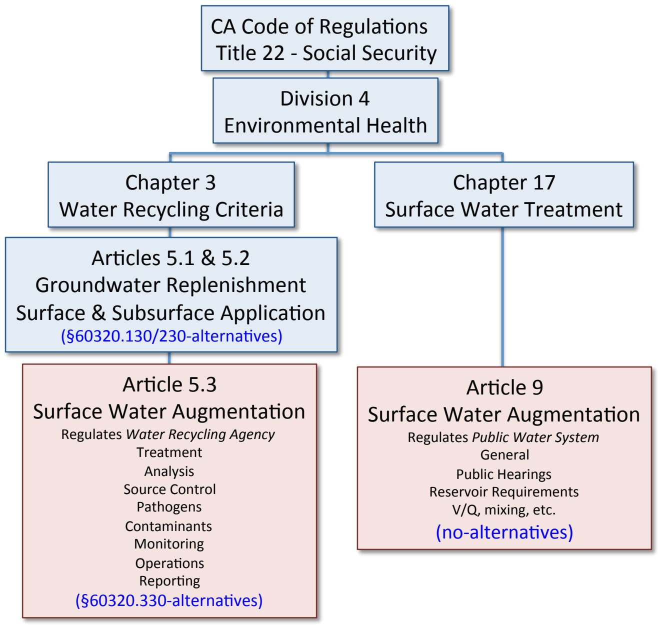

Figure 2: Regulatory structure for GWR and draft SWA regulations

If the process for evaluating and approving alternatives is robust, projects can ensure a firm foundation of safety. The goal of this document is to show that an alternatives clause for the reservoir criteria can be enacted safely, allowing the State to protect public health, maximize potable reuse, and maintain the benefits that initially drove the creation of the reservoirs near the State's drinking water treatment facilities. The document is divided into the following sections:

- Section 1: Introduction
- Section 2: Public health benefits of the reservoir
- Section 3: Evaluation of reservoir criteria
- Section 4: The need for an alternatives clause
- Section 5: Permitting as direct potable reuse
- Section 6: Draft Alternatives Clause
- Section 7: Conclusions

2 Public Health Benefits of the Reservoir

In evaluating the potable reuse spectrum (Figure 1), the distinguishing characteristic of surface water augmentation projects is the reservoir itself. The State Water Code is unambiguous, defining SWA as "the planned placement of recycled water into a surface water reservoir used as a source of domestic drinking water supply" (CA Water Code 13561(d)). The focus on the reservoir stems from its distinct potential to enhance public health protection. Insight into the nature of these benefits can be found in key documents from the State Expert Panel as well as in the draft SWA regulations.

2.1 Insight from the draft regulations

Displayed in Figure 3 are excerpts from the latest, publicly available edits to the draft SWA regulations related to Reservoir Requirements in §64668.30 (NWRI, 2015c). These excerpts capture some of the most important criteria where public health protection is concerned.

Theoretical Retention Time

"An augmented reservoir shall have a theoretical retention time of no less than six months."

Response Time

Dilution

The ~~total~~ volume of water withdrawn from the augmented reservoir to be ultimately supplied as a drinking water ~~during a 24-hour period~~ contains no more than:
(1) **one percent, by volume,** of recycled municipal wastewater that was delivered to the reservoir **during any ~~preceding~~ 24-hour period**, or
(2**)** **ten percent, by volume**, of recycled municipal wastewater that was delivered to the reservoir **during any ~~the preceding~~ 24-hour period**...with an additional **process producing no less than a 1-log reduction**

Figure 3. Time and dilution requirements for reservoir operation in draft SWA regulations. Requirements related to retention time, response time and dilution requirements are shown in blue, red and green, respectively. Expert panel edits to the DDW draft have been preserved.

The three elements identified in the reservoir requirements are (1) retention time, (2) dilution, and (3) response time. The retention time and dilution requirements in the draft regulations are relatively straightforward. Projects must provide a theoretical retention time (V/Q)[1] of no less than six months. They must also provide either 100:1 dilution of the

[1] The retention time requirements are based on a monthly calculation using the volume of the reservoir at the end of the month divided by the total flow rate out of the reservoir during that month (V/Q_{out}).

advanced treated water, or 10:1 dilution plus an additional log of removal through treatment[2]. In essence, these options show that either (a) dilution or (b) a combination of dilution and treatment are equally protective, as both serve to reduce the concentration of contaminants within the reservoir. Yet, a reservoir receiving a continuous stream of off-spec water would eventually lose its ability to dilute that stream over time. In other words, a reservoir's dilution capacity is finite.

How long must the reservoir provide this "protection-through-dilution"? The regulations specify dilution requirements to protect against a 24-h input of off-spec water. In specifying this period, the regulations tacitly require that projects be able to detect and respond to any failures within this time period. The implication is that the 24-h time period would be sufficient to detect and respond to any failure in treatment. **This 24-hour period is the response time** described above.

By providing dilution and response time, the regulations protect the quality of the water in the reservoir, ensuring it remains a consistent and safe source of supply for the DWTF.

2.2 Insight from the Expert Panel

In their December 2014 Final Panel Report, the Expert Panel offered several assumptions used to develop and support the criteria in DDW's draft SWA regulations. Below are excerpts from some of the assumptions that address the public health protection important in Chapter 17, Article 9 (NWRI, 2015b):

- Assumption No. 1: *"The primary benefit of the reservoir is to ensure improved treatment scheme **reliability**."*

- Assumption No. 2: *"Improved reliability is defined as the provision of **residence time** of the advanced treated water in the reservoir, allowing for a **response time** to mitigate potential treatment failures."*

Thus, the first path to reliability is to provide a response time to detect and respond to failures. Residence time in the reservoir enters this discussion, but its importance seems to reside in its ability to provide the project with response time, which is vital to protecting public health should a failure occur. Assumptions about minimum response times for the project are also included in the Panel's discussion:

- Assumption No. 6: *"All [reservoir] options are based on the assumption that an advanced treatment plant failure producing inadequately-treated water will occur and be detected and corrected within 24 hours."*

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[2] To qualify for the lower 10:1 dilution requirements, an additional log must be provided at the AWTF for the three pathogen groups of interest—virus, *Giardia* cysts, and *Cryptosporidium* oocysts.

The Panel also highlights a third main benefit of the reservoir as dilution.

- Assumption No. 4: *"The reservoir dilution requirement is also included to mitigate potential advanced treatment plant failures."*

In summary, the Expert Panel report shows that the main benefits of the reservoir are (1) response time and (2) dilution, with the two mitigation mechanisms working together to prevent off-spec water from jeopardizing the quality of water in the reservoir.

2.3 Insight from the evolution of the SWA regulations

Insight into the relative significance of all three parameters—theoretical retention time, response time, and dilution—can also be gained by examining the evolution of the reservoir requirements as set forth in the Panel's reports. The criteria proposed by DDW, as written in Expert Panel Report for the second meeting (NWRI, 2015a), included a theoretical retention time of 12 months along with four alternate requirements including: 24-hour dilutions of 100:1 or 10:1 (the latter with extra treatment), as well as either a retention time of 60 days or 30 days (the latter with a 24-hour dilution of 10:1).

In these original criteria, two different forms of the retention time concept were used. The first retention time, t_2, was defined as the time to abstract two percent of the recycled water. The second, the theoretical retention time (V/Q) was calculated as the volume of the reservoir at the end of a month (V_{total}) divided by all outflows from the reservoir during the preceding month (Q_{out}).

The Expert Panel performed an analysis examining the implications of these criteria. As a simplification, they used the continuous-flow stirred tank reactor (CFSTR) model and demonstrated that t_2, V/Q, and dilution are not independent parameters. Based on their analysis, the proposed t_2 requirements would preclude all but the largest reservoirs. As a result, the Panel recommended eliminating the t_2 requirement, while maintaining the use of V/Q.

Nonetheless, the discussion of theoretical hydraulic retention time was complex. On the one hand, the Panel pointed out that, "…[V/Q] values can obscure important hydrodynamic, design, and operational factors that ultimately govern the true dilution and travel time/time to react...." On the other hand they also argued, "there is possible value in retaining a minimum [V/Q] value as a way to set some bounds on the transport time/time to react ... and on the size of potential SWA projects." In the end the Panel proposed "a general requirement for a minimum theoretical hydraulic retention time… as an alternative to ... t_2 ..." They concluded that 4 to 6 months might be a reasonable compromise because requiring SWA reservoirs to be that large would essentially assure that they have abundant dilution and adequate retention time. Hearing this, DDW decided to require that V_{total}/Q_{out} be greater than six months.

3 Evaluation of Reservoir Criteria

The goal of this section is to look more deeply into the current reservoir criteria, and understand how each element can be used to promote public health. Insight from both the Expert Panel and DDW will be used in this assessment. Ultimately this analysis shows that the current requirements are protective of public health, but provides perspective on an alternate grouping of elements that could provide equal public health protection. This new set of requirements, which builds on the core criteria from the existing regulations, could be used as a foundation for a path to safe alternatives.

3.1 Theoretical Retention Time

The theoretical retention time requirement, as discussed previously, is intended to ensure a minimum reservoir residence time, so that if a treatment failure were to occur, a project sponsor would have sufficient time to prevent the contaminant from entering the drinking water treatment plant (i.e., response time). Put another way, V/Q is intended to serve as a *surrogate* for response time, but does not necessarily provide a direct benefit in and of itself. As a screening tool, the V/Q surrogate has important value. As discussed, the Panel showed the value of specifying a minimum retention time in order to provide "time to react," and that a 4-6 month requirement would "essentially assure" that the dilution and response time were also met. In summary, a reservoir providing a 6-month retention time should easily meet the dilution and response time requirements.

Nonetheless, the Expert Panel was upfront about the limitations of this screen, in that the theoretical retention time values "can obscure important hydrodynamic, design, and operational factors that ultimately govern the true dilution and travel time/time to react [response time, ed.]." Factors that might undermine the screening tool's usefulness include "wind-forcing, convection, and other processes that can allow for short-circuiting in which recycled water is quickly transported from the discharge point to intake" (NWRI, 2015b).

Despite these limitations, sufficient conservatism is present in the 6-month retention time requirement such that the impact of these issues is negligible. In fact, modeling results from actual reservoirs help to support this claim. Figure 4 displays the modeling results from the Otay Reservoir, a large surface water source that would comply with all of the criteria in the draft regulations including the V/Q requirement. Under certain conditions, however, the complete volume of the reservoir is not involved in the mixing and dilution of the advanced water treatment facility (AWTF) input. Despite the fact that only a fraction of the volume participates, the reservoir still meets the dilution and response time requirements.

Another way of looking at this is that the volume that is effectively involved (V_{eff}) is only a fraction of the reservoir's total volume (V_{tot}), and yet the reservoir still meets the dilution and response time requirements. Efforts could be made to bring the V_{eff} closer to V_{tot}—e.g., through improved design of reservoir inlet and outlet, mixing, and baffling—but are not required.

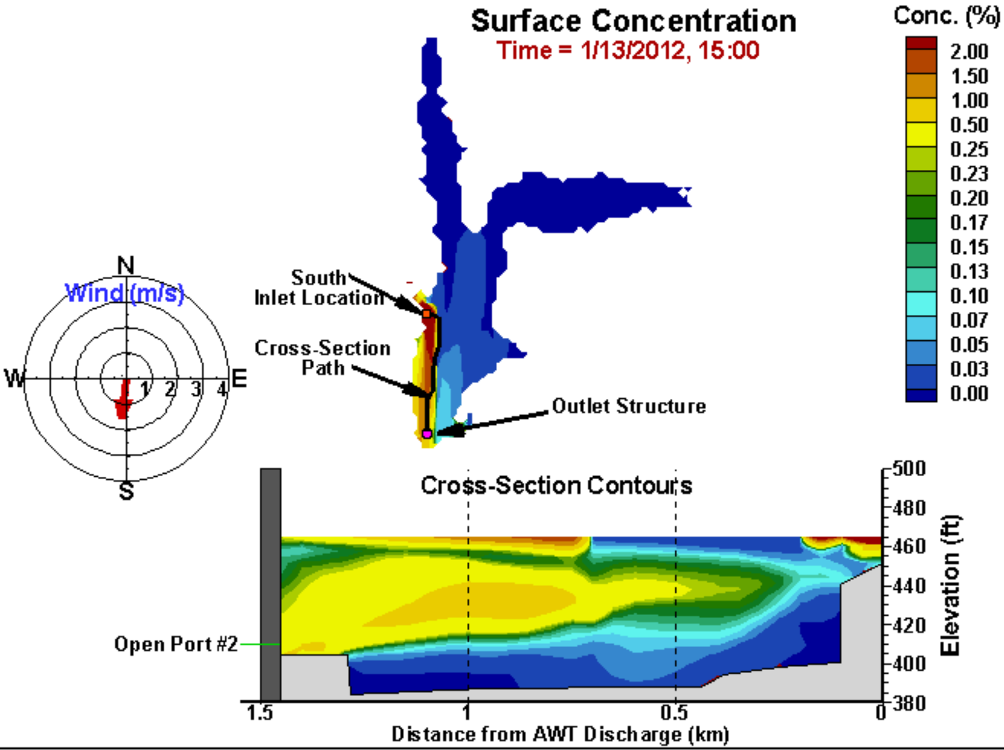


Figure 4: Modeling results from Otay Reservoir in which effective volume is approximately 10% of total volume. (ELCOM/CAEDYM Model, calibrated via tracer studies: Time=1/12/2012, 15:00)

Now imagine a smaller reservoir that has a V_{tot} equal to the V_{eff} of the larger reservoir (Figure 5). Using engineered solutions (e.g., outlet design, mixing, baffling, etc.) at the reservoir, its V_{eff} is actually equivalent to the V_{eff} of the larger reservoir. *The smaller reservoir would fail to meet the V/Q requirements, but would provide identical protection under the key reservoir parameters: dilution and response time.*

While the V/Q requirement is a useful screen to assess the safety of projects, it is incorrect to assume that a project that fails to meet V/Q will also fail to meet the response time and dilution requirements. As illustrated, the use of existing reservoir science and technology offers an alternative pathway to provide equal levels of protection in smaller reservoirs. In the absence of a V/Q "landmark," however, other elements must be specified to ensure public health protection. The following sections present the three elements that define SWA projects; these elements could be used as alternative criteria to the V/Q requirement.

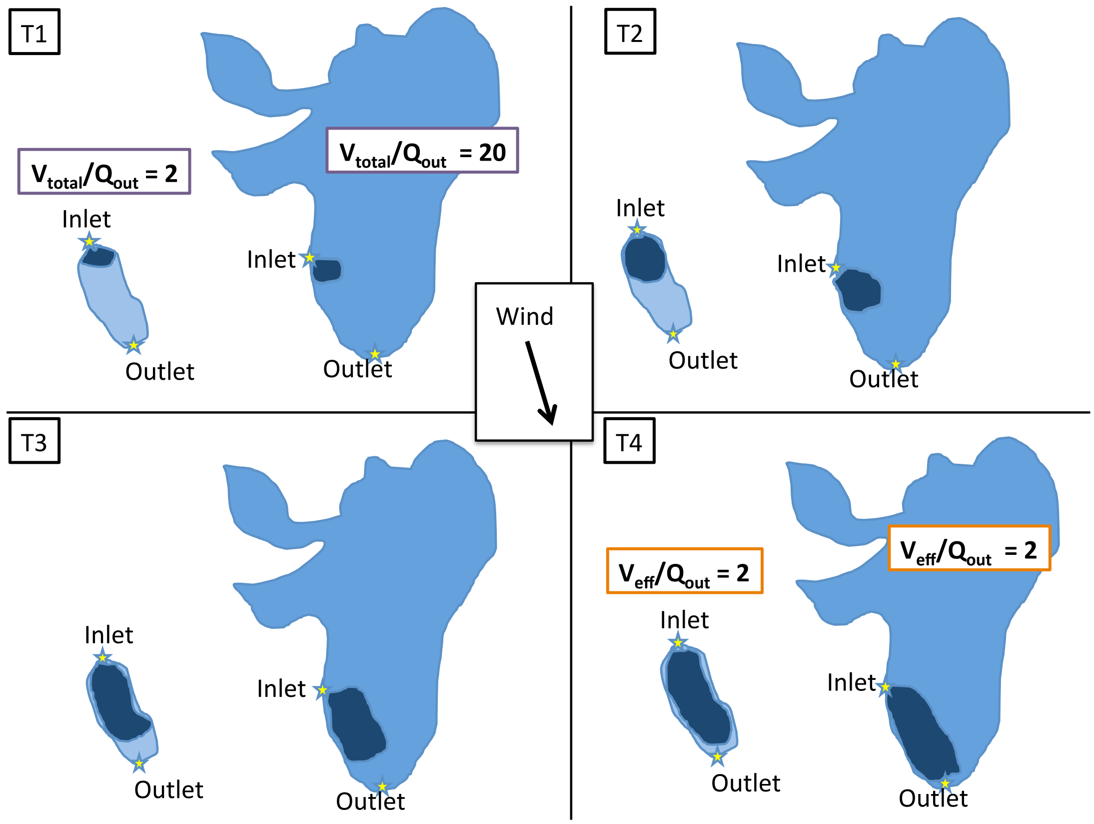


Figure 5: Evaluation of public health protections provided by two hypothetical reservoirs of varying sizes. The reservoirs utilize the same effective volume (V_{eff}) to provide dilution and response time, resulting in equivalent V/Q in both cases. This example illustrates that reservoirs with higher V_{total}/Q_{out} do not necessarily provide a higher degree of public health protection. Dark blue represents the passage of purified water over four time periods (T1 to T4).

3.2 24-hour Response Time

As discussed previously, the goal of the theoretical retention time requirement is ultimately to provide response time to mitigate failures. In the words of the Expert Panel, "to serve as an effective environmental buffer, the reservoir should provide ample time to implement corrective actions and prevent off-spec water from being delivered to a downstream surface water treatment plant" (NWRI, 2015b). Based on the preceding discussion, however, it is clear that V/Q alone cannot ensure this benefit. An effective way to guarantee adequate failure response is to define a minimum response time, and require that each project demonstrate that it is achievable.

The draft regulations currently include this requirement: the 24-hour time requirement, which essentially defines the minimum response time. Evidence from multiple sources support this requirement, beginning with the assumption that "an advanced treatment plant failure producing inadequately-treated water will occur and be detected and corrected within 24 hours" (NWRI, 2015b). This fact is further supported by the draft regulations, which allow for on-spec water delivered to the reservoir during any preceding 24-hour period to be used as diluent water for future inputs of recycled water. In other words, once suitable advanced treated water has been in the reservoir for 24 hours, the reservoir is suitable to dilute out any future contaminants. This situation can only be true if the water has been verified as meeting specifications at least every 24 hours.

One might ask if it is even reasonable to achieve a 24-hour response time. The assumption has been that failure response occurs only at the AWTF—in order to ensure no more than 24 hours worth of off-spec water enters the reservoir, any treatment failure must be detected *and corrected* within 24 hours. Another approach to failure response is to recognize that the drinking water treatment facility (DWTF) can play a role in meeting the 24-hour response time. The goal of failure response is to prevent off-spec water from reaching the DWTF; this can be accomplished by correcting a failure at the AWTF, *or by having the DWTF cease intake of reservoir water and switch to an alternate supply*.

To evaluate the benefit of using the DWTF as part of a failure response scheme, consider the following timeline for identifying a failure and switching to an alternate supply for a DWTF (Table 1). A key assumption of this timeline is that the AWTF has continuous monitoring (i.e., every 15 minutes) of pathogen surrogates that would allow a failure to be detected immediately[3]. Based on this estimate, 24 hours is actually a conservative response time, and a response could be enacted as quickly as within 2 hours. Given the uncertainty in the amount of time required to correct a failure at the AWTF, taking advantage of the DWTF for failure response provides further assurance that the 24-hour response time criterion can be met. The 24-hour response time criterion is therefore reasonable for SWA projects.

Table 1: Failure response timeline for surface water augmentation

Action	Time Required
Detect failure	15 minutes
Confirm failure	1 hour
Request alternate supply	30 minutes
Receive alternate supply	15 minutes (minimum) to 12 hours (maximum)
Implement DWTF modifications to adapt to new water source	Immediate
Total	2 hours (minimum) to ~15 hours (maximum)

[3] Current monitoring technology is capable of achieving this degree of information.

3.3 Dilution

The 24-hour response time requirement is reasonable to achieve, as shown above, allowing projects sufficient time to identify failures and provide alternate sources of supply. The flipside of this operational approach, however, is that it allows up to 24 hours of off-spec water to enter a reservoir before a failure response is enacted. During this time, the DWTF may continue to extract, treat, and serve the water to the public. Therefore, the 24-h response time must work in concert with another strategy to ensure public health protection. This complementary strategy is dilution, the second main benefit of the reservoir. Dilution within the reservoir can be used to ensure the water entering the DWTF remains suitable as source water, even in the event of a treatment failure. The coupling of these two elements—response time and dilution—is a key benefit provided by the reservoir, and further distinguishes SWA from more direct forms of reuse, including source water augmentation.

The power of the reservoir in protecting public health is illustrated in Figure 6, through a comparison with source water augmentation. Source water augmentation is differentiated from SWA for its notable exclusion of a reservoir. Advanced treated water is instead piped directly upstream of a DWTF. The series of figures is meant to illustrate the distinct benefits of the reservoir in protecting against a 24-h production of off-spec water.

In both hypothetical cases, it takes two hours for the off-spec water to reach either the reservoir (SWA) or the DWTF (source water augmentation). Even with the input of off-spec water into the reservoir, the DWTF extracts diluted reservoir water that remains suitable as a source water over the 24-hour period. The suitability of this water stems from dilution, which maintains the quality of the water at specified levels. Conversely, the source water augmentation project provides no dilution between the AWTF and DWTF. Consequently, the water provided to the DWTF from the AWTF is off-spec starting two hours after the failure occurs and continuing on through the end of the 24-hour period, i.e. during 22 of the 24 hours of production.

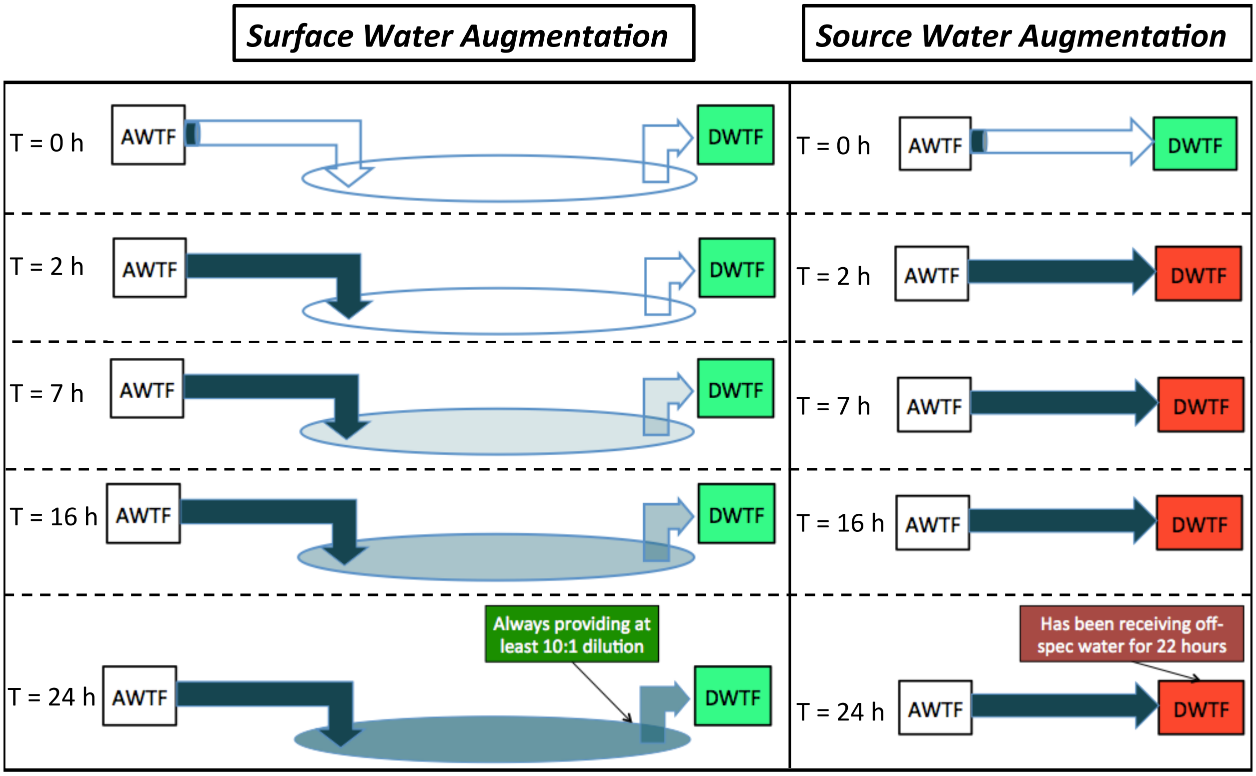


Figure 6: The benefits of dilution and response time in Surface Water Augmentation projects. Figures show the fate of a 24-hour production of off-spec water (dark blue color). Surface water augmentation requires a minimum dilution of at least 10:1 of this 24-h production, providing a response time during which failures can be detected and addressed. Source water projects receive the undiluted slug of off-spec water throughout the majority of the same time period.

In conclusion, the dilution of a 24-hour input of recycled water maintains safety while providing time to respond to failures. These unique benefits of the reservoir work together to control contaminant risk, and are therefore key elements to ensure public health protection. *Dilution and response time are the first two reservoir elements that must be ensured for safe reservoir operation.*

3.4 Uncoupling

By providing a "wide spot in the road," the reservoir provides both dilution and response time, but its benefits do not end there. Another public health protection provided by the reservoir is the uncoupling it provides between the AWTF and DWTF. Research has identified the importance of minimizing highly coupled and complex systems in potable reuse schemes (Salveson et al., 2014). Although uncoupling is not mentioned in the draft SWA regulations, the reservoir offers significant public health protection from potential treatment and monitoring anomalies if a project maintains the ability to independently regulate flow into and out of the reservoir. This benefit is another significant element that differentiates SWA from source water augmentation. As shown in Figure 7, there are effectively two "switches" that separate the production of advanced treated water from the production of drinking water. It is important to realize that each switch plays a significant and unique role in public health protection.

Switch 2 operates the reservoir withdrawal pumps and valves and the uncoupling provided by the reservoir allows the DWTF to shut these valves off to enter a "safe mode" at the first sign of concern at the AWTF. This uncoupling is an important and relevant advantage because many DWTFs are already permitted to treat multiple supply waters, routinely making changes in source water (e.g., from reservoir to aqueduct water). Using this reservoir "switch" provides time for the AWTF to be verified—in terms of treatment, monitoring, and water quality—without forcing the AWTF to cease production. As shown above, it also ensures the 24-hour response time can be met. Once a significant risk to public health has been confirmed or the reservoir level has risen to the point where a spill may occur, Switch 1 can be initiated to halt the production of purified water from the AWTF. This tool is important for public health protection, as reservoirs will provide days to weeks of storage, during which the AWTF can continue operating prior to achieving the spillway elevation. Most importantly, it allows the DWTF to decide to move off the reservoir without shutting down the entire project.

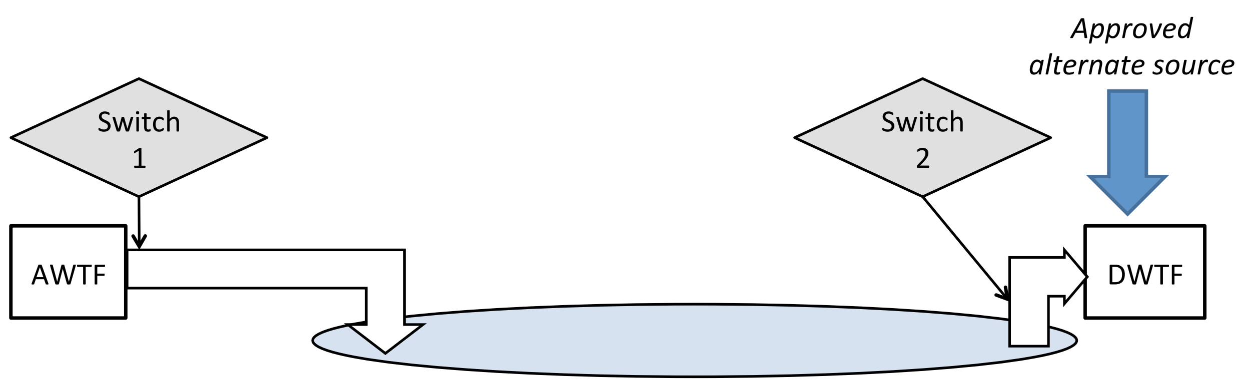


Figure 7: Illustration of "two switches" concept for surface water augmentation. AWTF: advanced water treatment facility; DWTF: drinking water treatment facility.

The reservoir allows the DWTF operations staff the freedom to be cautious because they can switch to the alternate supply without immediately halting the AWTF production. This uncoupling of the AWTF and DWTF ensures that the SWA project will maintain public health protection as the priority while eliminating the need to halt AWTF production until or unless a treatment or monitoring anomaly is confirmed as a potential public health concern. These two switches allow for a high degree of conservatism in operation, which, when paired with an advanced control system at the AWTF, effectively eliminates the possibility that off-spec water will enter the DWTF.

In summary, three elements emerge as the key protectors of public health: (1) dilution, (2) response time, and (3) uncoupling. Projects complying with the V/Q requirement are very likely to also meet these three key criteria. It is possible, however, that projects not meeting V/Q could provide equal protection under these three key criteria. Thus, a broader framework for assessing the viability of SWA projects is recommended. *An alternatives clause allows consideration of projects that use innovative technology to provide equal protection to the existing regulations.*

4 Need for Alternatives Clause

As stated, public health protection is paramount for all potable reuse projects. Section 3 illustrates that an alternatives clause can be developed without sacrificing public health. In this section, the other benefits of an alternatives clause are developed. An alternatives clause in Article 9 will lead to more successful SWA projects for several reasons, among them:

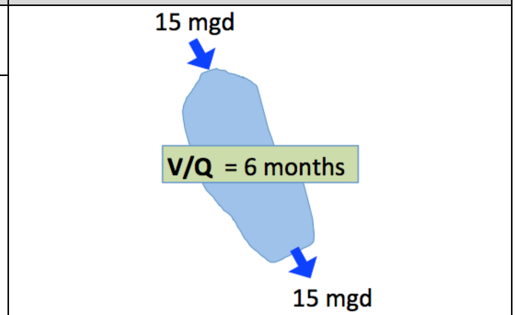
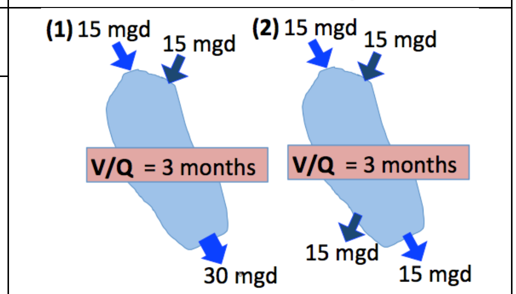
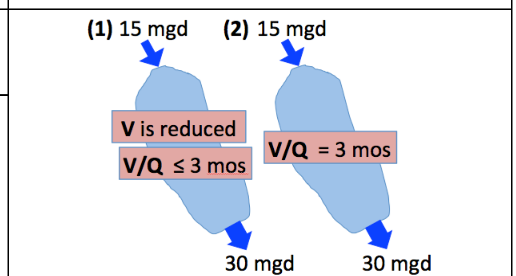
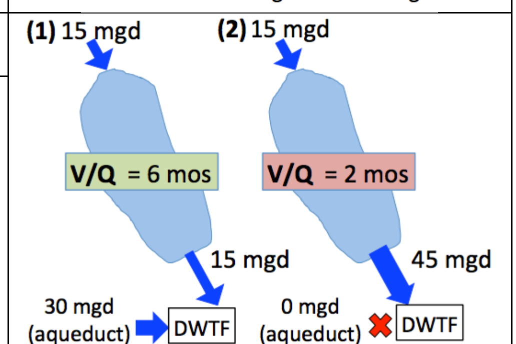
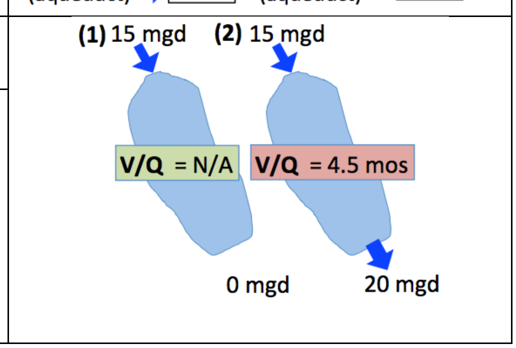
1) The raw water reservoirs near drinking water plants were originally built for important functions that must be preserved
2) Precedent from existing regulations illustrates how the inclusion of alternatives provisions can improve the adaptive capability of regulations in a rapidly changing technological environment
3) An alternatives clause in Article 9 will accommodate innovative technologies and techniques related to reservoir operation and management

4.1 Impact of Current Reservoir Criteria on Historic Reservoir Functions

California's reservoirs serve numerous functions, many in support of improved public health. Many raw water reservoirs upstream of drinking water plants were originally built for flood control and to be a source of water supply during maintenance, unscheduled downtime, and emergencies. The strict V/Q requirements may cause undue tension between wanting to maximize the capacity and economics of future projects, and the sacrificing of these historical reservoir uses. For example, the V/Q requirement drives projects to minimize any additional flows into and out of the reservoir, as these flows make it more difficult to achieve the minimum retention time requirements. The examples in Table 2 illustrate how the functions may be compromised by the V/Q requirement.

Ideally, the historical uses of the reservoir would be maintained without undue constraint on project capacity and viability. An alternatives clause would offer a much-needed middle ground that could allow continued use of these functions without jeopardizing public health. In fact, preserving these historical functions will likely improve the overall protections provided by a SWA project.

Table 2: Historic reservoir roles impacted by V/Q requirement

Scenario Description	*Operational Benefits*	*Retention Time Impact*
Normal Operations		
Normal operations – flow into reservoir equals flow out of reservoir. AWTF is only flow into reservoir, and only outflow is to DWTF.		
Blending with Additional Sources		
(1) Operation with 1:1 aqueduct to AWTF water, and **(2)** operation with additional water flowing through (e.g. streamflow, aqueduct water)	**Improves dilution and treatability** of AWTF water May be necessary to meet downstream needs	
Runoff Collection & Flood Control		
(1) Reducing reservoir volume to prepare for wet season, and **(2)** operation during wet season	Makes room in reservoir to **collect local runoff**, which is a low-cost water source. Also provides **flood control**.	
Operation During Aqueduct Downtime or Emergency		
Operation with additional draw from reservoir during aqueduct	Reservoir provides **supply during emergencies** and scheduled aqueduct maintenance	
Precautionary Operation		
(1) DWTF not taking reservoir water as precautionary measure, and **(2)** DWTF catching up to return to normal reservoir level downtime	DWTF has **freedom to be cautious** by switching to alternate supply for significant period of time	

4.2 Precedent from Existing Regulations

The pace of advancement in science and technology has greatly accelerated in recent decades, whereas regulatory frameworks often are built based on the technologies available at the time when the regulation is written. This creates a situation where regulations can become increasingly out-of-date as the gap between contemporary technology and the past technology grows. As slowing the pace of science and technology is neither achievable nor desirable, the only way to remedy the situation is to increase the adaptive capability of regulations themselves.

Regulators at both the Federal and State level have been struggling with this for several years. An early example of a DDW regulation that included this adaptive capability is in Title 22, Division 4, Chapter 3 Water Recycling, §60301.230 (a)(2), which expanded the requirements for disinfected tertiary recycled water to allow alternatives beyond chlorination. Since that time several similar alternative provisions have been included in Title 22, Division 4, Chapter 17 Surface Water. These include:

- §64653 (a), (e), (f), (g), (h), and (i) on alternative filtration processes
- Addendum B §141.719 (b) allowing approval of alternative monitoring parameters for direct integrity monitoring
- Addendum B §141.720(c) & (d) on alternative CT values for chlorine dioxide and ozone and alternative validation for UV

Most of these provisions are designed to accommodate new technologies, but none are as comprehensive as the alternatives clause DDW has included in Chapter 3, Article 5.1 & 5.2 governing groundwater recharge. To understand the intention of this clause, it is worth examining the development of those regulations.

California's regulations on groundwater recharge remained in draft form for almost four decades beginning with an early draft on spreading in June 1976 (CDH, 1976), followed by several more comprehensive drafts on both spreading and injection beginning in 1988 (CDHS 1988) and concluding in 2008 (CDHS, 2008). Formal regulations were promulgated in June 2014 (DDW, 2014), almost exactly 38 years after the first draft was created.

The use of draft regulations provided important guidance to the practice of potable reuse as it developed in California. During that time, several full-scale projects were built and operated[4]. As a result of the experience gained in these full-scale operating projects,

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[4] The Montebello Forebay project; the Orange County Water District projects—Water Factory 21 and Groundwater Replenishment System; West Basin Municipal Water District's West Coast Barrier Project; Los Angeles Department of Water and Power's Dominguez Gap Project; Water Replenishment District's Alamitos Gap project; and several projects in Inland Empire Utilities Agency's recycled water program

understanding of what makes for a successful project improved significantly throughout this period. Examples of areas where understanding improved include: treatment requirements, monitoring requirements, the ability to characterize the aquifer and prescribe how the project should fit in its hydrogeological setting, how monitoring should be structured, the requirements necessary to ensure effective response to failure, and goals for pathogens and other contaminants that are protective of public health. This improved understanding was reflected in each of the different versions of the draft regulations as they evolved. Recognizing that these dynamic circumstances would continue even after the regulations were finalized, the inclusion of the alternatives clauses lays a path forward for consideration of project proposals based on new information about how public health can be protected.

4.3 Development of New Technology in the Context of SWA

The alternatives clause in Articles 5.1, 5.2, and 5.3 reflects an appreciation for the fact that understanding of all aspects of how a project might be structured to maximize public health protection continues to improve. The concept that there are trade-offs between different aspects of public health protection is not a novel one; the 2012 National Research Council committee on potable reuse stated, "retention and blending requirements for quality assurance are expected to become less significant as monitoring and attenuation technologies improve" (NRC, 2012). Including an alternatives clause recognizes that surface water augmentation will encompass a spectrum of projects in which different combinations of treatment, monitoring, dilution, response time, and other key project components can be used to achieve the same goal of public health protection. The alternatives clause creates an environment in which guidance from independent scientific experts, input from the public, and approval from the State Board will be provided in such a way that the exploration of this spectrum proceeds safely.

It could be argued that because there is an alternatives clause in 5.3, the regulations already allow a spectrum of projects. However, as it stands now, Article 9 is one of the areas where there is significant potential for future innovations and developments in understanding, and where no experience with full-scale operating projects is available. The field of reservoir science and technology is one in which many advancements are ongoing and anticipated in the near future; some of these are presented in Table 3.

Table 3: Anticipated advancements in reservoir science and technology[5]

Automated in-reservoir monitoring
Engineered mixing
Inlet diffusers
Multiple level inlets and outlets
Management of stratification
Management of hypolimnetic oxygenation
Better quantification of natural treatment
Enhancement of natural treatment
Real-time forecasting and modeling of recycled water dilution
Measures to enhance uncoupling
Enhanced communication between AWTF, DWTF, and reservoir management
Improved reservoir modeling

The Expert Panel and DDW have already recognized many of the strategies shown in Table 3 as being relevant for public health protection. For example, the original proposed regulations from DDW included 1-log virus reduction credit for every month the recycled water is retained in the reservoir. The Panel response was that "the complexity of demonstrating LRVs under all circumstances… for all possible pathogens would make this pathway to compliance a difficult one with a high burden of proof" (NWRI, 2015b). DDW also originally included a provision enabling projects to take advantage of reservoir stratification. The Panel response was "reliance on the thermocline to achieve dilution and/or t_2 retention time requirements is thought to be a difficult operational strategy and one that imposes severe constraints for use in SWA" (NWRI, 2015b). In neither of these examples does the Panel refer to these strategies as not useful or impossible; rather, they use the words "difficult" and "complex." Given the current state of industry knowledge, to remove these provisions as defined aspects of the regulations makes sense. However, these are protections that can be made real in specific projects. As full-scale SWA projects are planned and come into being, a wealth of new information will be gained. An alternatives clause in Article 9 will facilitate consideration of new strategies for design and operation based on new knowledge.

Today the State of California faces a more uncertain future where water is concerned than it did nearly four decades ago, and the strategy of using draft regulations is no longer available—the Water Code calls for the adoption of regulations for SWA by the end of this year. Given these circumstances, the best approach is to promulgate regulations that include an alternatives clause like those used in the groundwater recharge regulations. Just as the key requirements for an aquifer in groundwater projects continue to change, understanding of the key requirements for reservoirs for SWA will change as well.

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[5] A more detailed discussion of these advancements is included in Appendix A.

5 Permitting as Direct Potable Reuse

DDW has the legal authority to permit any potable reuse project on a case-by-case basis, even direct potable reuse. However, per the Water Code §13563, DDW must report to the Legislature on the feasibility of developing criteria for direct potable reuse by the end of 2016 and regulations for source water augmentation and finished water production will need to be developed in the future. With SWA regulations scheduled for completion at the end of 2016, it is suggested that any project that does not meet the reservoir requirements set forth in Chapter 17 must seek permitting on a case-by-case basis as a direct potable reuse project.

It may be argued, however, that it is in the best interest of the State to include an alternatives clause that will allow more projects to be permitted under the SWA regulations. Four arguments in favor of this position are:

1) Surface water augmentation is *not* direct potable reuse
2) Permitting SWA as DPR misleads the public
3) Experience with SWA projects will enhance future DPR implementation
4) Greater progress toward State Board's recycling goals will be achieved

Each of these reasons is considered briefly below.

5.1 Surface Water Augmentation is Not Direct Potable Reuse

As described in this document, the multiple benefits provided by a reservoir in a potable reuse scheme enhances the overall project reliability. The reservoir provides significant dilution and response time, and uncouples the AWTF from the DWTF with multiple switches. The benefits provided by the reservoir will, as illustrated in Figure 8, change as the move is made from SWA to source water augmentation and ultimately finished water production. Dilution will decrease significantly in source water augmentation. While summer demands may require the use of multiple supply sources, winter demands may be met solely by water produced at the AWTF, i.e., with no dilution. Dilution will not exist at the finished water production facility as drinking water will be distributed to the distribution system immediately from the AWTF.

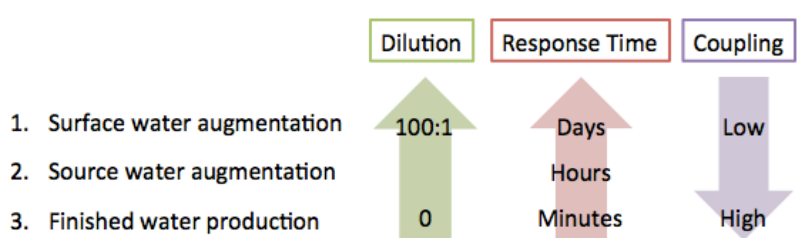

Figure 8: Surface water augmentation experience will offer insight into issues relevant for direct potable reuse, including dilution, response time, and coupling

Similarly, in source water augmentation, response time will be reduced without the reservoir, and the time provided in the conveyance pipeline and DWTF will be the only response time available. A finished water treatment facility does not benefit from the conveyance time and the only response time available will be provided at the AWTF. As the transition is made from SWA to finished water production, the potable reuse system becomes more closely coupled and the need to address all anomalies at the AWTF with rapid automation will increase. The reservoir, with its dilution and response time requirements, provides significant reliability that differentiates SWA from more direct forms of potable reuse.

5.2 Permitting SWA as DPR is Misleading

When the public hears the term "Direct Potable Reuse," they envision an AWTF serving as a final water production facility immediately delivering drinking water to the distribution system. This was evident in the Bill Analysis of Senate Bill 918, where direct potable reuse was assumed to be "the introduction of recycled water directly into the drinking water system" (Senate Bill 918 Bill Analysis, 2010). But with today's technology, SWA provides significantly more protection than a finished water production facility using recycled water. The public will not only be confused by this improper classification of SWA projects, but it will further complicate public acceptance of potable reuse projects in the future. It is important to describe each potable reuse scheme properly so that the public can remain informed and engaged as the State proceeds with the expansion of potable reuse facilities to meet the goals defined in the SWRCB recycled water policy.

5.3 Experience with SWA will Enhance DPR Implementation

The evolution of the GWR regulations was informed by operating projects and this insight has resulted in regulations that have supported the expansion of potable reuse to 200 MGD while maintaining public health protection. Industry and regulators will learn important lessons from operating SWA projects. In fact, putting more projects into operation with different source control programs, different AWTF equipment and controls, varying reservoir sizes, inlet and outlet designs, as well as varying approaches to achieving the dilution requirements will strengthen industry understanding of potable reuse and will support the development of comprehensive regulations for the more direct forms of potable reuse. The SWA regulations should allow alternatives that can achieve the public health protections established by the proposed criteria and encourage new technological developments based on improved understanding of risk management alternatives as the water industry makes an important transition to more direct forms of potable reuse in the near future.

5.4 Maximizing SWA will Quicken Progress toward the State Goals

The SWRCB recycled water policy goal to expand recycled water production by 2 million acre-feet by 2030 requires an expansion of potable reuse practice that is unprecedented. The SWA regulations should allow alternatives that are equally protective of public health to maximize the number of projects that can be permitted and constructed under the SWA regulations. The availability of such regulations will eliminate delay and promote the necessary trajectory to hasten the expansion of potable reuse schemes that are equally protective of public health.

6 Draft Alternatives Clause

Provided below is a draft alternatives clause for Article 9 for DDW's consideration.

§64668.XXX. Alternatives.

(a) A SWSAP PWS may use an alternative to a requirement in this Article if the SWSAP PWS:

(1) demonstrates to the State Board that the proposed alternative provides an equivalent or better level of performance with respect to the efficacy and reliability of the removal of contaminants of concern to public health, and ensures at least the same level of protection to public health;
(2) receives written approval from the State Board prior to implementation of the alternative; and
(3) if required by the State Board or Regional Board, conducts a public hearing on the proposed alternative, disseminates information to the public, and receives public comments.

(b) The demonstration in subsection (a)(1) shall include the results of a review of the proposed alternative by an independent scientific advisory panel, whose membership is approved by the State Board, that includes, but is not limited to, a toxicologist, a limnologist, an engineer licensed in California with at least three years of experience in wastewater treatment, an engineer licensed in California with at least three years of experience in public drinking water supply, a microbiologist, and a chemist.

7 Conclusions

The recycled water policy established by the State Water Resources Control Board contains an ambitious goal of expanding recycled water production in California by 2 million acre-feet that will require the construction of many new potable reuse projects throughout the State. The Division of Drinking Water is working closely with an appointed Expert Panel to develop, review and consider regulations for surface water augmentation to promulgate regulations by the end of 2016. These regulations will govern potable reuse practice in existing reservoirs throughout the State.

Surface water augmentation is fundamentally different than more direct forms of potable reuse because of the presence of the reservoir. The primary function of the reservoir is to ensure reliability through a combination of dilution, a 24-hour response time, and uncoupling. Although the current reservoir criteria are protective of public health, they also preclude many projects that could achieve these benefits, and thus limit the statewide potential for implementation of safe surface water augmentation. In this document it is proposed to maintain the current criteria, but to also add an alternatives clause in Chapter 17, Article 9. There is currently an alternatives clause in Chapter 3, Article 5.3, but this clause will not be able to accommodate the many ongoing advancements in reservoir science and technology that are anticipated in the near future.

The inclusion of an alternatives clause in Chapter 17, Article 9 will benefit the state in many ways. It will:

- Ensure public health protection and allow more projects to be permitted and constructed sooner
- Provide an opportunity to incorporate lessons learned from more operating projects
- Prevent the regulations from determining that projects with the protections offered by a reservoir are a form of direct potable reuse
- Inform the development of future direct potable reuse regulations for source water augmentation and finished water production
- Maintain a reservoir's ability to provide a secure, safe, and reliable water supply by allowing the reservoirs to be used for mixing, confirming treatment and monitoring anomalies, as well as for flood control, emergency supply, and routine maintenance on existing infrastructure

The water management challenges facing California today are unprecedented. With the tools that are available today, potable reuse can be used to improve the security of existing drinking water supplies. Further, the available toolbox will only continue to grow in the future. Maximizing the adaptive capability of the surface water augmentations regulations will propel the State toward safely meeting its recycled water goals.

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9 Appendix A: Detailed Discussion of Future Reservoir Advancements

Automated in-reservoir monitoring: Installation of various sensors within a reservoir can provide real-time data that can be used to "finger-print" the purified water (for example, elevated temperatures or different levels of a chemical constituent). Coupled with meteorological monitoring and real-time forecasting (see below), "black swan" events can be identified before they occur. Accurate sensors for temperature, EC, DO, and turbidity and robust telemetry systems are now commonly deployed in reservoir and lakes.
Engineered mixing: A reservoir can be mechanically mixed using air bubble diffusers or propeller mixers to enlarge the effective volume of a reservoir used for dilution. Air curtains [linear arrays of rising air bubbles] can be used to slow the movement of water from one part of the reservoir to another.
Inlet diffusers: Multi-port inlet diffusers provide a passive means for mixing the inflow with ambient reservoir water. Also, inlet diffusers can be used to disperse the inflow over a large reservoir area, both vertically and horizontally, increasing dilution. An inlet diffuser uses the energy of the inflowing water to achieve a desired mixing.
Multiple level outlets: Selective withdrawal from a multiple level outlet can be used to withdraw reservoir water with the best water quality and highest dilution levels.
Multiple level inlet: An inlet structure with multiple-level ports allows inserting the purified water at a specific level. Coupled with stratification and selective level withdrawal, this can increase the separation [time and dilution] between inflow and outflow.
Management of stratification: Coupled with selective withdrawal, stratification can be used to increase the uncoupling between the inlet and outlet, thus providing more time to respond.
Management of hypolimnetic oxygenation: oxygenation of anoxic reservoir water enhances water quality. Oxygenated water is suitable habitat for organisms that prey on pathogens; e.g zooplankton that eat bacteria.
Better quantification of natural treatment: Sun exposure and residence time generally result in pathogen attenuation, but the amount of attenuation is not well understood. Research can be performed to better quantify such attenuation.
Enhancement of natural treatment: Natural treatment could possibly be enhanced by spreading the purified water over a large surface area of the reservoir, thus enhancing exposure to UV light.
Real-time forecasting and modeling of recycled water dilution: A real-time three-dimensional hydrodynamic model, coupled to a meteorological model and automated in-reservoir monitoring, can be continuously used in real-time to forecast the dilution and mixing patterns, providing an early warning system that could help better manage the reservoir operations (for example, change tier levels, invoke engineered mixing, cease water withdrawals, etc.)
Measures to enhance uncoupling: Real-time forecasting and modeling could be used as a decision tool for uncoupling. For example, operational rules could be established such that a certain model result directs that the reservoir be shut off as a source of supply to the DWTP.
Enhanced communication between AWTF, DWTF, and reservoir management: Integrating the reservoir automated data and real-time forecasting systems to the AWTF and DWTF could produce a robust algorithm that can provide early warning and better response to system failures.