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CHAPTER TWO

California water reuse—Past, present and future perspectives

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Abstract

The State of California has a long history of water reclamation and reuse and in 1918 developed the first regulations in the United States to address the use of recycled water for agricultural irrigation. In California, as well as in many water-scarce areas, water reclamation, recycling, and reuse are integral components of water resource planning and management. Historically, the driving motivation for water recycling was to supplement scarce resources and to provide alternatives to effluent disposal into surface waters. The California State Water Resources Control Board (State Water Board) adopted a Recycled Water Policy that moves towards the sustainable management of surface waters and groundwater, together with enhanced water conservation, water reuse, and the use of stormwater. In California, the practice of planned potable reuse has occurred in the form of indirect potable reuse (IPR), including an environmental buffer, for over 50 years. California’s experience has demonstrated that planned potable reuse using IPR can be practiced without having any apparent detrimental effects on public health.
In 2018 the State Water Board adopted surface water augmentation regulations\(^1\) that establish *minimum* uniform water recycling criteria for the planned placement of recycled water into a surface water reservoir that is used as a source of domestic drinking water supply. The transition from IPR to direct potable reuse has the potential to modify conventional public health practices by removing the environmental buffer between wastewater disposal and water supply. California is currently developing regulations that would govern potable reuse situations that have either no environmental buffer and/or a reduced buffer.

**Keywords:** California reuse regulations, Indirect potable reuse, Direct potable reuse, Non-potable reuse, Pathogens, CECs, Environmental buffer, Surface water augmentation, Groundwater recharge

- Brief history of water reuse in California.
- Difference between indirect potable reuse and direct potable reuse (including the environmental buffer).
- Critical public health considerations for direct potable reuse.
- California Framework for Direct Potable Reuse.
- Water Research Foundation (WRF) Investigations.

## 1. Introduction

The State of California has a long history of water reclamation and reuse and in 1918 developed the first regulations in the United States to address the use of recycled water for agricultural irrigation. The regulations have been modified over the years and additional information on California history is provided in Crook et al. 1994 paper\(^1\) and Harris-Lovett and Sedlak.\(^2\)

In California, as well as in many water-scarce areas, water reclamation, recycling, and reuse are integral components of water resource planning and management. Historically, the driving motivation for water recycling was to supplement scarce resources and to provide alternatives to effluent disposal into surface waters. With periods of severe drought and a growing population, recycled water is now considered an important water resource. Engaging in non-potable and potable water reuse can enable communities to maximize and extend the use of limited freshwater resources.

### 1.1 Overview of water reuse in California

Water supplies in the State of California rely largely on runoff associated with melting snowpack. Over the next few decades, supplies are likely to diminish because climate change is predicted to cause more precipitation
to fall as rain rather than as snow, with runoff occurring earlier in the season. In response to the challenges of climate change and population growth, the California State Water Resources Control Board (State Water Board) adopted a Recycled Water Policy that declared independence from relying on the vagaries of annual precipitation and moved towards the sustainable management of surface waters and groundwater, together with enhanced water conservation, water reuse, and the use of stormwater. The policy of the State Water Board includes the following goals related to water recycling:

- Increase the use of recycled water from $881 \times 10^3$ m$^3$ per year in 2015 to $1850 \times 106$ m$^3$ per year in 2020 and to $3083 \times 10^6$ m$^3$ per year by 2030 (714 acre-feet per year (AFY) in 2015 to 1.5 million AFY by 2020 and to 2.5 million AFY by 2030).
- Reuse all dry weather direct discharges of treated wastewater to enclosed bays, estuaries and costal lagoons, and ocean waters that can be viably put to a beneficial use. For the purpose of this goal, treated wastewater does not include discharges necessary to maintain beneficial uses and brine discharges from recycled water facilities or desalination facilities.
- Maximize the use of recycled water in areas where groundwater supplies are in a state of overdraft, to the extent that downstream water rights, instream flow requirements, and public trust resources are protected.

The main drivers for water recycling include the following:

- Manage or alleviate water stress (i.e., the need for water).
- Replace the use of existing supplies of potable water (i.e., reduce the use of freshwater).
- Abate pollution.
- Address the need for reliable supplies of water.
- Address the need for cost-effective alternative supplies of water.
- Use wastewater as a source of new water.
- Respond to or comply with regulatory policies and regulations

1.2 The state water board’s recycled water policy

The California State Water Resource Control Boards are composed of the State Water Board, along with the nine Regional Water Quality Control Boards (Regional Water Boards). The State Water Board mission is.

To preserve, enhance, and restore the quality of California’s water resources and drinking water for the protection of the environment, public health, and all beneficial uses, and to ensure proper water resource allocation and efficient use, for the benefit of present and future generations.
The State Water Board develops statewide policy and regulations for water quality control and allocates water rights. The Regional Water Boards provide local implementation of policy and regulations, develop long-range plans for their areas, issue waste discharge permits (including water recycling permits) and take enforcement actions against violators. The State Water Board establishes general policies governing the permitting of recycled water projects consistent with its role of protecting water quality and sustaining water supplies. The State Water Board exercises general oversight over recycled water projects, including review of Regional Water Board permitting practices, and leads the effort to meet the State Water Board’s recycled water use goals. Since July 1, 2014, when the California Department of Public Health Drinking Water Program was transferred to the State Water Board, the State Water Board has been charged with the development and adoption of uniform water recycling criteria appropriate for specific uses of recycled water. The State Water Board (Health & Safety Code, div. 104, pt. 12, ch. 4, §116,270 et seq.) also is charged with the responsibility to enforce the Clean Water and the Safe Drinking Water Acts (42 U.S.C. §300f et seq.), thus requiring the melding of state and federal processes together. In addition, the State Water Board’s Division of Drinking Water (DDW) and the Regional Water Boards coordinate efforts as part of the review and development of permit requirements for permitting water recycling projects.

In 2009, the State Water Board developed a Recycled Water Policy (“Policy”) (adopted under Resolution No. 2009-0011). In 2013, the Recycled Water Policy was amended (adopted under Resolution No. 2013-003) to include monitoring requirements for contaminants of emerging concern (CECs) based on the recommendations of the Science Advisory Panel and amended again in 2018. The Policy was adopted to promote the use of recycled water in a manner that is protective of public health and water quality by providing streamlined permitting criteria for recycled water projects. The Policy also includes goals and mandates for recycled water use and guidance for the collaborative development of salt and nutrient management plans for groundwater basins or sub-basins in California.

Several key modifications made as part of the 2018 amendment include: (1) removal of the statewide recycled water mandates; (2) establishing narrative goals for the production and use of recycled water; (3) establishing treated wastewater and recycled water reporting requirements statewide; (4) improving consistency in permitting of recycled water projects by encouraging the use of statewide water reclamation requirements for
non-potable recycled water use, and adding permitting guidance for reservoir augmentation projects; (5) updating monitoring requirements for CECs in recycled water used for groundwater recharge and reservoir water augmentation, and (6) provision to reconvene a Science Advisory Panel every five years to update recommendations for CEC monitoring in recycled water.

In addition to the above topics, the expansion of the Policy to address new potable water sources (both raw and finished drinking water sources), and the approach for permitting and enforcement of the new sources needs to be clarified and made consistent with the current State Water Board findings and regulations regarding such new potable water sources. There are several State and Federal regulations that have bearing on planned potable water reuse projects. For example:

- The Clean Water Act (CWA) with regard to water quality for discharge to receiving waters
- The CWA relative to the regulation of discharges to publicly owned treatment works (POTWs) (e.g., source control and pretreatment regulations)
- The Safe Drinking Water Act (SDWA) relative to the protection of water supply sources [e.g., source assessments and risk reduction barriers as part of the source water protection program (SWPP)]
- The SDWA relative to drinking water treatment requirements for different source waters (e.g., the Long-Term 2 Enhanced Surface Water Treatment Rule)

Treatment technologies (i.e., advanced water treatment (AWT)) capable of producing high-quality potable water from wastewater for supplementing drinking water supplies have been demonstrated in a number of full-scale AWT facilities (AWTFs). In California, water recycling “constitutes the development of new basic water supplies”.

California maintains primacy for Federal regulations relative to permitting POTWs, drinking water sources, and associated water treatment facilities. Consideration should be given to integrating regulatory programs that implement the provisions of the CWA and SDWA as they relate to potable reuse to allow for more efficient and effective management of the growing demand for potable reuse.

2. Regulatory developments for recycled water applications

There are two main water reuse types, non-potable and planned potable reuse.
Non-potable reuse: The planned use of recycled water for non-potable reuse applications has been practiced for many decades in California, several other areas of the United States, and in other countries. In non-potable reuse, recycled water is used for purposes other than drinking, provides water for agricultural and landscape irrigation, as well as water for industrial processes, toilet flushing, construction, artificial lakes, and other non-drinking applications. The reuse guidelines and regulations that existed in the 1960s and early 1970s, which addressed only non-potable reuse, reflected the state-of-the-art at that time and the conservative approach taken by public health officials. California Water Recycling Criteria governing the production and use of recycled water are contained in Title 22, Division 4, of the California Code of Regulations.

Planned indirect potable reuse (IPR): Planned IPR involves the introduction of recycled water either into an environmental buffer such as a groundwater aquifer or a reservoir before the blended water is subject to conventional water treatment and/or disinfection and introduced into a water supply system. The relevant forms of IPR covered include:

- **Indirect potable reuse for groundwater recharge (IPR-GWR):** planned use of recycled water for replenishment of a groundwater basin or an aquifer that has been designated as a source water supply for a public water system (CWC section 13561c).
- **Surface water augmentation (SWA):** planned placement of recycled water into a surface water reservoir used as a source of domestic drinking water supply for a public water system (CWC section 13561d). On October 6, 2017 amendments to Sections 13560 and 13,561 of Chapter 7.3 (commencing with Section 13560) of Division 7 of the Water Code and to Sections 13560.5 and 13,561.2 were added to the Water Code relating to potable reuse that modify terminology. For example, Surface Water Augmentation (SWA) is now titled Reservoir Water Augmentation (RWA).

Section 2.2 includes a more detailed discussion of the State Water Board regulations for the various reuse categories and also includes the revised definitions for potable reuse.

2.1 Non-potable reuse

The planned use of recycled water for non-potable reuse applications was first practiced on a large scale shortly after cities began using flush toilets and sewers. In coastal areas, pipes transported sewage to the sea, where it
was discharged far enough offshore to prevent aesthetic problems; however, surface water discharges presented problems for many inland communities. An alternative to dilution was needed for managing sewage. One such alternative was planned non-potable reuse of municipal wastewater, first implemented in the late nineteenth century with the development of sewer farms in England, Australia, Germany, France, and Italy. By 1900, sewer farms were numerous in these countries with 10 located in California of the 12 or so in the United States.\(^9\) For example, one of the first sewer farms in California was established when the City of Pasadena purchased a 120-ha (300-acre) plot of land outside the city, named it the Pasadena Sewer Farm, and piped in raw sewage to irrigate crops. This sewer farm produced walnuts, pumpkins, hay, and corn, and became a profitable business for the City.\(^10\) Other Southern California cities also turned to sewer farms as a means to profit from human waste while sending it away from homes. For example, in 1909, residents of the coastal city of Redondo Beach voted down a proposed sewer outflow to the ocean and instead insisted the City adopt the sewer farm model for reuse.\(^11\) To the City, sewage was a source of water and nutrients that could make the dry landscape of Southern California produce useful crops.

By 1910, as many as 35 communities in California were using sewage for irrigation without any treatment and 24 after septic tank treatment.\(^9\) The sewage farms gave way to wastewater treatment plants (WWTPs) when the land area required for the treatment of wastes grew too large to be feasible, urban areas began to encroach on sewer farms, and concerns grew about odors and health risks associated with putting raw sewage on farm fields.\(^2\) Biological waste treatment—developed in the early twentieth century—required much less land and permitted the discharge of wastewater effluents to bays, rivers, and streams. Until the early twentieth century, there were no significant regulations or restrictions on the use of wastewater for agricultural irrigation. As the scientific basis of disease became more widely understood, concerns grew among public health officials about the possible health risks associated with irrigation using wastewater and other non-potable uses of recycled water. This concern led to the establishment of guidelines and regulations to control the use of wastewater for agricultural irrigation, the first application of recycled water to be regulated in California.

Water reuse began to increase in both the number of projects and types of recycled water applications as wastewater treatment, disinfection processes,
and microbiological analytical techniques became more sophisticated during the first half of the twentieth century. Similarly, water reuse standards evolved to regulate the use of recycled water for irrigation. During this time, water resources generally were adequate to meet all potable and non-potable needs, and the use of recycled water often was based on opportunity, convenience, and economics. In general, projects were implemented when water reuse constituted the most economical method of sewage disposal; however, burgeoning population growth in the second half of the twentieth century began to strain available freshwater resources and increased water demands in certain areas in California to the point where natural freshwater was no longer readily available and the development of additional supplies became necessary. It was in these water-stressed areas that recycled water first came to be viewed as a beneficial resource. The development of non-potable water recycling practices in California includes the milestones listed in Table 1.

| Year  | Description of milestone |
|-------|--------------------------|
| 1890  | Sewer farms in use in several California communities |
| 1909  | The City of Redondo Beach votes down a proposed sewer outflow to the ocean and instead insists that the City adopt the sewer farm model for reuse |
| 1929  | The City of Pomona begins using recycled water for the irrigation of lawns and gardens in a suburban, semi-rural home development area |
| 1932  | Golden Gate Park initiates recycling for filling ornamental lakes and landscape irrigation from a specially constructed water reclamation plant (which was terminated in 1981) |
| 1943  | Recycled water is first used at military installations to irrigate landscape in recreational areas |
| 1961  | The City of Santee uses recycled water to develop recreational lakes for fishing and boating, and studies an experimental swimming operation |
| 1965  | The City of Burbank begins using recycled water for power plant cooling |
| 1977  | The Irvine Ranch Water District initiates the first major residential landscape irrigation project with a dual water system delivering recycled water |
| 1998  | Monterey Regional Water Pollution Control Agency initiates the first project in California using tertiary-treated recycled water to irrigate food crops eaten raw |
The reuse guidelines and regulations that existed in the 1960s and early 1970s, which addressed only non-potable reuse, reflected the state-of-the-art at that time and the conservative approach taken by public health officials. As the need grew for more water, additional recycled water applications (for both non-potable and potable reuse) were proposed. Over the last 30 years, a dramatic increase has occurred in both the types of recycled water applications now available and quantities of water being reused. This increase resulted (in part) from an intense era of research and demonstration studies—beginning in the late 1960s—that provided valuable information to California regulatory agencies involved with adopting water reuse regulations. The most common concern associated with non-potable reuse is the potential transmission of infectious disease from *microbial pathogens* by (1) inadvertent ingestion of recycled water, (2) skin contact, (3) consumption of food crops irrigated with recycled water, and (4) inhalation of aerosols, although it is recognized that *chemicals* can be a concern (e.g., heavy metals taken up by food crops could present potential health risks to consumers). Consequently, California regulations for non-potable reuse focus mainly on mitigating health risks from microbial pathogens by reducing or eliminating them in recycled water and/or by imposing use area controls (e.g., fencing, signage, buffer zones, color-coded pipes and appurtenances) or other controls to prevent human contact with recycled water that contaminated fomites. A summary is provided in Table 2 of the progression of water recycling policies and regulations in California.

For more than a century, recycled water has been used intentionally as a non-potable water supply source in California. The implementation of water reclamation projects has increased significantly over the years, even in the face of regulatory, economic, and social constraints. In 1989, the reuse of municipal wastewater in California was estimated at $400 \times 10^6$ m$^3$ per year (325,000 AFY). In 2002, the State Water Board conducted a comprehensive statewide survey of municipal facilities that focused on documenting the current levels of non-potable reuse of treated municipal wastewater. The results of the 2002 survey indicated that, as of the end of 2001, $648 \times 10^6$ m$^3$ per year (525,460 AFY) of recycled water was used in California. State Water Board data indicate that during 2009 approximately $825 \times 10^6$ m$^3$ per year (669,000 AFY) of recycled water was used. The most recent State Water Board survey data, collected in 2015, indicates that approximately $879 \times 10^6$ m$^3$ per year (713,000 AFY) of recycled water was used and is illustrated in Fig. 1. At present, estimates indicate that about
8 to 10% of municipal wastewater generated in California is recycled through planned reuse projects. Estimates regarding future recycling indicate that California has the potential to recycle an additional \(3083 \times 10^6\) m\(^3\) per year (2.5 million AFY) of water by the year 2030.\(^4\)

### 2.1.1 Non-potable water reuse regulations

As the need grew for more water, additional recycled water applications (for both non-potable and potable reuse) were proposed. Over the last
30 years, a significant increase has occurred in both the types of recycled water applications now available and quantities of water being reused. As noted above, the most common concern associated with non-potable reuse is the potential transmission of infectious disease from microbial pathogens. Consequently, California regulations for non-potable reuse focus mainly on mitigating health risks from microbial pathogens by reducing or eliminating them in recycled water and/or by imposing use area controls (e.g., fencing, signage, buffer zones, color-coded pipes and appurtenances) or other controls to prevent human contact with recycled water.

California Water Recycling Criteria governing the production and use of recycled water are contained in Title 22, Division 4, of the California Code of Regulations. A summary of the criteria is presented in Table 3. As noted in Table 3, specific treatment processes have been relied on in California to significantly reduce the numbers of bacteria, viruses, and parasites (i.e., applying a process or performance standard rather than a strict pathogen standard). Specifically, the regulations include process standards for filtration and disinfection and requires a total coliform concentration of less than or equal to 2.2 MPN (most probable number) per 100mL (mL). Water quality meeting these criteria is considered “safe” for human contact. This is further supported by past experiences of health professionals and on a lack of detectable health problems associated with agricultural irrigation.

![Fig. 1 Types of wastewater reuse in California as a percentage of annual use (2015).](image)
Table 3 Summary of California Department of Public Health non-potable water reuse treatment requirements.

| Purpose of use                                                                 | Treatment requirement                             |
|-------------------------------------------------------------------------------|---------------------------------------------------|
| Orchards and vineyards (no contact with edible crops), nonfood-bearing trees, seed crops (not eaten by humans), food crops (with additional pathogen treatment for crop), and flushing sanitary sewers | Undisinfected secondary<sup>a</sup>               |
| Cemeteries, freeway landscaping, golf courses (restricted access), ornamental nursery stock, sod farms, pasture (milk animals), non-edible vegetation (controlled access), commercial/industrial cooling towers (with drift reduction), landscape impoundments (no decorative fountains), industrial boiler feed, soil compaction, mixing concrete, dust control (roads), cleaning roads, nonstructural firefighting | Disinfected secondary, 23 MPN/100 mL<sup>b</sup> |
| Food crops (edible portion of crop above ground—no contact), restricted recreational impoundments | Disinfected secondary, 2.2 MPN/100 mL<sup>c</sup> |
| Food crops (including edible root crops) where recycled water comes into contact with edible portions of the crop, parks and playgrounds, school yards, residential landscaping, golf courses (unrestricted), commercial/industrial cooling towers (mist devices), unrestricted recreational impoundments (with specific pathogen monitoring), flushing toilet and urinals, structural firefighting, decorative fountains, artificial snow making, and commercial car washes | Disinfected tertiary<sup>d</sup>, 2.2 MPN/100 mL |
| Groundwater recharge (with additional treatment—see State Water Board groundwater regulations) | Disinfected tertiary<sup>d</sup>, 2.2 MPN/100 mL with SAT or advanced treatment |

<sup>a</sup>Undisinfected secondary treatment: means oxidized wastewater (i.e., the organic matter has been stabilized, is non-putrescible, and contains dissolved oxygen).

<sup>b</sup>Disinfected secondary—23 MPN per 100 mL recycled water: oxidized and disinfected so that the median concentration of total coliform bacteria for the last 7 days for which analyses have been completed does not exceed a most probable number of 23 MPN per 100 mL, and the MPN does not exceed 240/100 mL in more than one sample in any 30-day period.

<sup>c</sup>Disinfected secondary—2.2 MPN per 100 mL recycled water: oxidized and disinfected so that the median concentration of total coliform bacteria for the last 7 days for which analyses have been completed does not exceed a most probable number of 2.2/100 mL, and the MPN does not exceed 23/100 mL in more than one sample in any 30-day period.

<sup>d</sup>Disinfected tertiary recycled water: a filtered and disinfected wastewater (see definition below) that meets a CT (product of total chlorine residual and modal contact time measured at the same point) value of not less than 450mg-min/L at all times, with a modal contact time of 90 min (min.) (based on peak dry weather design flow) or provides a 5-log removal/reduction of MS2 F-specific phage or poliovirus or similar virus. In addition, the median concentration of total coliform bacteria in the disinfected effluent cannot exceed an MPN of 2.2 per 100 mL (utilizing the bacteriological results for the last 7 days for which the analyses have been completed), and the number of total coliform bacteria does not exceed an MPN of 23 per 100 mL in more than one sample in any 30-day period. No sample can exceed an MPN of 240 total coliform bacteria per 100 mL.
2.2 Planned potable reuse

Planned potable reuse involves the use of recycled water to augment drinking water supplies. Two forms of planned potable reuse exist:

- **Indirect potable reuse (IPR):** Treated wastewater is introduced into an environmental buffer (i.e., a groundwater system or surface water system) prior to being introduced into a water supply system. The California Water Code provides regulatory definitions for the environmental buffer (e.g., groundwater basin and reservoir).

- **Direct potable reuse (DPR):** Highly treated wastewater is introduced either directly into a public water system or into the raw water supply immediately upstream of a drinking water treatment facility (DWTF).

As a result of indoor and outdoor water uses and other nonresidential municipal consumptive uses, neither DPR nor IPR can replace all current potable water demands, nor can all collected wastewater be used as part of a potable reuse project. Based on a recent estimate, roughly 30% of all wastewater collected in California—or about 50% of the water now discharged to the ocean—could be used for DPR or IPR projects. The actual amount of water available will vary by region, depending on site-specific factors, such as discharge locations for wastewater effluents.

In California, the practice of planned potable reuse has occurred in the form of IPR for over 50 years. Longstanding experience in California (and worldwide) has demonstrated that planned potable reuse using IPR can be practiced without having any apparent detrimental effects on public health. A key element of an IPR system is its reliance on an environmental buffer. While some environmental buffers might offer opportunities...
for further treatment (see Section 3.2 for further discussion), the main functions of the environmental buffer are to provide—through storage—some level of water quality equalization and time to respond to any process failures or out-of-compliance water quality monitoring results.²¹

The schematics of indirect potable reuse in California (as defined by the California Water Code) are shown in Fig. 2, which depicts advanced treated water being introduced into an environmental buffer as part of the raw water supply. Groundwater recharge can occur via surface spreading or subsurface application (Fig. 2A and B). Because spreading projects take advantage of further contaminant control through soil aquifer treatment, only disinfected tertiary treatment is required for these types of projects. Advanced treated water satisfying the requirements for “full advanced treatment” are needed for injection projects. In Fig. 2C, the environmental buffer is a surface water reservoir, so the project must meet the criteria for IPR using SWA (i.e., the reservoir has a theoretical hydraulic retention time of ≥2 to 6 months and must assure a specified hydraulic mixing).²⁷

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**Fig. 2** Schematics of indirect potable reuse in California using groundwater replenishment via surface spreading (A) or subsurface injection (B) or surface water augmentation (C).
Because a key element of an IPR system is its reliance on a regulatory defined environmental buffer, by default, all potable reuse projects that do not meet California regulations for groundwater replenishment or SWA are considered DPR. A schematic of a potable reuse project not meeting the California SWA criteria is illustrated in Fig. 3A.

Assembly Bill (AB) 574 (Chapter 528, Statutes of 2017) introduced new terminology and statutory definitions for two distinct forms of DPR, “raw water augmentation” and “treated water augmentation”:

“Direct potable reuse” means the planned introduction of recycled water either directly into a public water system, as defined in Section 116275 of the Health and Safety Code, or into a raw water supply immediately upstream of a water treatment plant. Direct potable reuse includes, but is not limited to, the following:

(1) “Raw water augmentation,” which means the planned placement of recycled water into a system of pipelines or aqueducts that deliver
raw water to a drinking water treatment plant that provides water to a public water system, as defined in Section 116275 of the Health and Safety Code.

(2) “Treated drinking water augmentation,” means the planned placement of recycled water into the water distribution system of a public water system, as defined in Section 116275 of the Health and Safety Code. With DPR, the environmental buffer is reduced or eliminated and recycled water is piped directly into the raw water supply near the inlet of a DWTF (termed raw water augmentation) or into the drinking water distribution system (termed treated water augmentation). In these scenarios, the core functions of the environmental buffer used for IPR would need to be provided and maintained in some other way to ensure public health protection. Although California’s DPR regulations are still under development, the State Water Board has indicated that it is feasible and protective of public health to evaluate an existing drinking water treatment plant (DWTP) as a train of separate treatment processes where each individual process could be validated for pathogen log reduction credits. One option is to allow existing DWTP credit to continue based on the assumption that the raw source water quality from an advanced treatment facility to the DWTP is consistent with California drinking water regulations.

The schematics of DPR are illustrated in Fig. 3A–C. In Fig. 3 (a), advanced treated water is introduced with an environmental buffer smaller than required for IPR or (b) without the use of an environmental buffer into the raw water supply immediately upstream of a DWTF. To date, permitted operational DPR projects in the United States involve this form of DPR (i.e., the Big Spring Raw Water Production Facility operated by the Colorado River Municipal Water District and the DPR Project used to produce an emergency water supply for the City of Wichita Falls. The Wichita Falls DPR project was used on an emergency basis and was replaced with an IPR project in 2018.). In Fig. 3C, finished product water is introduced directly into a drinking water distribution system.

2.2.1 Planned potable reuse criteria for groundwater replenishment (GWR)

The California criteria for groundwater recharge reflect a cautious approach towards potential short- and long-term health concerns. The criteria rely on a combination of controls intended to maintain a microbiologically and chemically public health protective groundwater recharge operation and protect current and future potable groundwater supplies. The criteria specify source control, wastewater treatment processes, water quality, dilution,
extraction well location, and monitoring frequencies and locations. A summary of the key criteria contained in the State Water Board IPR–GWR regulations is presented in Table 4.

For indirect potable water reuse practices (i.e., GWR and SWA), the State Water Board Panel updated monitoring trigger levels (MTLs) based on toxicological information gathered from several new sources, including state, federal, industry and international organizations, as well as the Panel’s own professional judgment. Regarding the selection of specific MTLs, the Panel made minor modifications to the process developed by the 2010 Panel. Greatest priority continues to be assigned to drinking water thresholds developed by the State of California followed by USEPA. The result of this update was a revised set of MTLs, some higher and some lower than MTLs used in 2010, and others included for the first time.

The Panel also updated measured environmental (or effluent, mostly composite samples) concentrations (MECs) based on more recent data collected by water reuse facilities in California. The Panel retained its conservative assumption of considering MECs for CECs measured in secondary/tertiary effluent as feed water for recycled water facilities. In addition, the Panel reviewed available monitoring data for individual treatment processes and product water for GWR applications as well as some select CEC monitoring studies outside of California. Because of wide variation in analytes reported, frequency of monitoring, and time period and duration of monitoring, the 2018 Panel compiled and reported 90th percentile concentration values to retain the conservatism established by the 2010 Panel.

The updated MECs and MTLs were employed to screen a total of 489 CECs (increased from 418 in 2010) using the same screening framework used by the 2010 Panel to identify candidate compounds for monitoring (Fig. 4). This exercise indicated that regular monitoring of three of four 2010 health-based indicator CECs (17β-estradiol, triclosan and caffeine) is no longer necessary, as the monitoring data set collected over the past several years (2008–2017) indicate that concentrations are consistently below MTLs (i.e., the MEC/MTL ratio is less than 1). In contrast, the collected monitoring data indicated that concentrations of NDMA were eight times higher than the MTL and, therefore, NDMA should be retained as a human health-based indicator. Of the remaining CECs screened, the 90th percentile MECs for two compounds, N-Nitrosomorpholine (NMOR) and 1,4-dioxane, exceed their respective MTLs by factors of 9 and 7, respectively, thus warranting their addition as human health indicators. Table 5 summarizes the updated 2018 health-based and performance-based indicators for CECs and performance surrogates.
| Criteria                        | Surface spreading application (SA)                                                                 | Subsurface application (direct injection)                                                                 |
|--------------------------------|-----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| Pre-recharge required treatment | Secondary (oxidized), filtered and disinfected recycled water<sup>a</sup> ≤ 2 NTU (during 95% of any 24-h period) ≥ 5-log virus inactivation, ≤ 2.2 total coliform per 100 mL | Secondary (oxidized), reverse osmosis, and an advanced oxidation process<sup>b</sup>                                                                     |
| Downgradient monitoring        | One location no less than 2 weeks or more than 6 months of travel through saturated zone and at least 30 days upgradient from nearest drinking water well. Additional well required between groundwater replenishment reuse project (GRRP) and nearest downgradient drinking water well | One location no less than 2 weeks nor more than 6 months of travel from the GRRP and at least 30 days upgradient from nearest drinking water well. Additional well required between GRRP and nearest downgradient drinking water well |
| Alternatives clause            | A project sponsor may use an alternative to a requirement in the Water Recycling Criteria if the project sponsor demonstrates that the proposed alternative assures at least the same level of public health protection. In addition, the TOC limit specified in the regulations may be increased if certain requirements are met | A project sponsor may use an alternative to a requirement in the Water Recycling Criteria if the project sponsor demonstrates that the proposed alternative assures at least the same level of public health protection |
| Pathogen reductions at compliance point (before extraction for potable reuse)<sup>b</sup> | 12,10,10—log reductions of viruses, *Giardia*, and *Cryptosporidium*, respectively | 12,10,10—log reductions of viruses, *Giardia*, and *Cryptosporidium*, respectively |
| Environmental buffer—allowable reduction credits | 1-log virus reduction credit for each month retained underground 10-log reduction credit for *Giardia* and *Cryptosporidium* if the municipal wastewater is retained underground for at least 6 months | 1-log virus reduction credit for each month retained underground |
| Control nitrogen compounds | Total nitrogen (TN) ≤ 10mg/L in recharge water (recycled water or combination of recycled water and credited diluent water used for recharge) | Same as for SA projects |
|----------------------------|---------------------------------------------------------------------------------------------------------------------------------|------------------------|
| Regulated contaminants     | Meet all drinking water MCLs (except nitrogen), action levels for lead and copper, notification levels, priority pollutants, and any other chemicals specified by State Water Board | Same as for SA projects |
| Retention time underground | Tracer study—retention time set at T₂ of initial tracer concentration or T₁₀ of peak tracer at the downgradient monitoring well Minimum retention time underground of 2 months | Same as for SA projects |
| Recycled water contribution (RWC) | Initial maximum RWC <20% An alternative initial RWC (up to 100%) may be approved by the State Water Board under certain conditions (see note 4) plus TOC performance over 20 weeks meets TOC max ≤ 0.5 mg/L / RWC preceding SA (with State Water Board and Regional Board approval) | No initial maximum recycled water contribution (injecting 100% recycled water may be approved). Initial maximum RWC based on State Water Board review of project engineering report, information obtained at public hearing, and sponsor’s demonstration that the treatment processes will reliably achieve a TOC concentration no greater than 0.5 mg/L/ |
| Criteria                               | Surface spreading application (SA)                                                                                                                                                                                                 | Subsurface application (direct injection)                                                                                                                                                                                                 |
|----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| TOC criteria                           | TOC performance over 20 weeks (minimum of weekly sampling) meets TOC max ≤ 0.5 mg/L/RWC based on the 20-week running average of all TOC results and the average of the last four TOC results. Increasing the TOC limit requires meeting a number of criteria, including the following: an increased limit has been approved by the State Water Board and Regional Board; the project has been in operation for the last 10 years; and a health effects study must be conducted including an exposure assessment, review of available epidemiology studies, and evaluation of individual and cumulative effects of regulated contaminants | Monitor TOC in the applied recycled water. TOC shall not exceed 0.5 mg/L based on 20-week running average of all TOC results and the average of the last four TOC results                                                                                                                                             |
| Advanced treatment criteria for CEC control | NA                                                                                                                                                                                                                                  | RO and oxidation process (AOP) require meeting specified performance requirements                                                                                                                                                              |
| Diluent water                          | Implement monitoring program, quality not to exceed primary MCLs or a secondary MCL upper limit (except turbidity, color, and odor), meet nitrogen controls and notification levels, determine volume for credit                                                                 | Same as for SA projects, though typically not required due to low TOC (< 0.5 mg/L) of RO-treated effluents                                                                                                                                                                                                 |
| Source control and outreach            | Administer an industrial pretreatment and pollutant source control program as specified in the Water Recycling Criteria                                                                                                                                                                  | Same as for SA projects                                                                                                                                                                                                                     |
| Unregulated contaminant                | Data collection for pharmaceuticals, endocrine disruptors and other State Water Board Policy CEC indicators/surrogates                                                                                                               | Same as for SA projects                                                                                                                                                                                                                     |
Response to off-spec water

Prior to operation of a groundwater replenishment project, approval of a plan describing steps that will be taken to provide an alternative source of drinking water, or an approved treatment mechanism a project sponsor will provide all owners of a producing water well, that as a result of the GRRP operation: (1) violates a California or federal drinking water standard; (2) has been degraded to a degree that it is no longer safe for drinking; or (3) receives water that fails to meet pathogen reduction levels specified in the recycling criteria. Same as for SA projects

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*See Appendix A, Section 2 “CEC Monitoring Parameters” in State Water Board Recycled Water Policy, December 11, 2018.*

Section 60320.220 provides for monitoring for priority toxic pollutants (40 CFR section 131.38), chemicals with notification levels, and other unregulated contaminants based on DDW review of the Title 22 Engineering Report.

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*See Title 22 requirements for filtered wastewater (section 60301.320) and disinfected tertiary recycled water (section 60302.230).*

*The treatment train consists of 3 separate processes, maximum credit of 6 log10 reduction per process and minimum of 1-log10 reduction per process.*

*Increasing RWC requires meeting a number of criteria. For example, a health effects study must be conducted including and exposure assessment, review of available epidemiology studies, and evaluation of individual and cumulative effects of regulated contaminants.*

*Log10 reductions vary based on tracer approach and method used to estimate retention time (refer to California Code of Regulations, Title 22 Division 4, Section 60320.124).*

*https://www.waterboards.ca.gov/water_issues/programs/water_recycling_policy/#20190221*

NA, not applicable; NTU, nephelometric turbidity unit; RWC, the percent recycled water contribution in groundwater extracted by drinking-water wells; SA, surface spreading application; TOC, total organic carbon.

Adapted from Drewes JE, Anderson P, Denslow N, Olivieri AW, Schlenk D, Snyder SA, Jakubowski W. *Monitoring Strategies for Chemicals of Emerging Concern (CECs) in Recycled Water.* Recommendations of Science Advisory Panel, Report to California State Water Resources Control Board, SCCWRP Technical Report 1032, 2018.
Fig. 4 Revised risk-based CEC selection framework.6
| Reuse practice                        | Health-based indicator | MRL (ng/L) | Bioanalytical methods | MRL (ng/L) | Performance-based indicator | Expected removal | MRL (ng/L) | Surrogate | Method | Expected removal |
|--------------------------------------|------------------------|------------|-----------------------|------------|-----------------------------|------------------|------------|-----------|--------|------------------|
| Surface spreading application (SA)    | NDMA \(^b\)            | 2          | ER-\(\alpha\)        | 0.5        | \(\Delta\)Gemfibrozil \(^c\) | >90%             | 10         | \(\Delta\)Ammonia | SM     | >90%             |
|                                      | NMOR \(^a\)            | 2          | AhR                   | 0.5        | \(\Delta\)Sulfamethoxazole \(^d\) | >30%             | 10         | \(\Delta\)Nitrate | SM     | >30%             |
|                                      | 1,4-Dioxane \(^a\)     | 100        | \(\Delta\)Iohexol \(^c\) | >90%       | 50                           | \(\Delta\)DOC   | SM         | >30%      |        |
|                                      |                        |            | \(\Delta\)Sucralose \(^e\) | <25%       | 100                          | \(\Delta\)UVA   | SM         | >30%      |        |
|                                      |                        |            | \(\Delta\)Total fluorescence |            |                              |                  |            |           |        |
| Subsurface application (direct injection) and surface water | NDMA \(^b\)            | 2          | ER-\(\alpha\)        | 0.5        | \(\Delta\)Sulfamethoxazole | >90%             | 10         | \(\Delta\)Conductivity | SM     | >90%             |
| Augmentation (SWA)                   | NMOR \(^a\)            | 2          | AhR                   | 0.5        | \(\Delta\)Sucralose         | >90%             | 100        | \(\Delta\)DOC     | SM     | >90%             |
|                                      | 1,4-Dioxane \(^a\)     | 100        | \(\Delta\)NDMA       | 25-50%     | 2                            | \(\Delta\)UVA   | SM         | >50%      |        |
| Non-potable reuse practices          | None                    |            |                       |            |                              |                  |            |           |        |

\(^a\)Industrial chemical.  
\(^b\)Disinfection byproduct.  
\(^c\)Pharmaceutical residue.  
\(^d\)Antibiotic.  
\(^e\)Food additive.  
\(^f\)Travel time in subsurface 2 weeks and no dilution, see details in reference 31; SM, standard methods; MRL, method reporting limit.  
Source: From Drewes JE, Anderson P, Denslow N, Olivieri AW, Schlenk D, Snyder SA, Jakubowski W. Monitoring Strategies for Chemicals of Emerging Concern (CECs) in Recycled Water. Recommendations of Science Advisory Panel, Report to California State Water Resources Control Board, SCCWRP Technical Report 1032, 2018.
The Panel reiterated that “… the MEC/MTL ratio employed in the risk-based, screening framework is operationally defined, and should not be compared to (or confused with) regulatory criteria (i.e., enforceable maximum contaminant levels or MCLs). Furthermore, a large margin of safety is incorporated into this framework. Therefore, a MEC/MTL ratio of greater than 1 does not represent an immediate threat to public health. With this in mind, the very small percentage of CECs that are recommended for health-based monitoring (3 of 489 or < 1%) reinforces the inherent low potential risk of CECs in recycled water to human health currently attributable to water reuse applications that include most Title 22 non-potable uses and potable reuse via groundwater and surface water augmentation under current regulatory practices.”

Bioanalytical screening tools and non-targeted analysis. While the Panel’s risk-based framework is effective in identifying CECs for which pertinent data are available, the framework cannot capture all possible new compounds that may be entering the market, nor does it adequately address their transformation products. To help identify such compounds that may occur in recycled water and their potential, if any, to affect human health, the Panel recommended that the State explore the value and applicability of bioanalytical screening methods through a series of special studies (see Fig. 4). While bioanalytical screening methods could target multiple effects, the Panel recommended that the Estrogen Receptor alpha (ER-α) and the Aryl hydrocarbon Receptor (AhR) bioassays be used initially to respectively assess estrogenic and dioxin-like biological activities in recycled water. These two in vitro bioassays were selected because each have clear adverse outcome pathways that allow specific molecular responses to be adequately standardized for screening recycled water quality at potable reuse projects. While the Panel outlined a process to interpret and respond to in vitro bioassay results, they considered that the process was not sufficiently mature to justify response actions at this time. Thus, the Panel recommended a phased implementation of bioanalytical screening, with the first phase consisting of a three to five-year data collection period, with no response actions required during this time. This applies to follow up investigations triggered by bioassay results, including voluntary targeted and non-targeted analysis, the latter of which is not sufficiently standardized at present to apply broadly for recycled water monitoring. Subsequent implementation phases will evolve from analysis of data collected during the first phase and advancements made in the development and validation of additional screening assays, as well as the interpretation of bioscreening results.
Based on the Panel recommendations the State Water Board amended the Recycled Water Policy to include requirements for facilities that produce recycled water for indirect potable reuse via groundwater recharge and reservoir water augmentation to monitor using two bioanalytical screening tools (ER\(\alpha\) and AhR) (1). Further, the SWB noted that CEC monitoring pursuant to the Recycled Water Policy is intended to be investigatory and not for regulatory compliance with a specific limit such as a maximum contaminant level or a water quality objective.

The SWB Recycled Water Policy includes requirements to ensure that data associated with CEC monitoring are of known, consistent, and documented quality and to verify that the laboratory can meet the required reporting limits for the targeted CECs and bioanalytical results. SOPs are integral to ensuring data quality. The policy also includes monitoring trigger levels (MTLs) as well as next steps based on assessment results. Finally, WateReuse California commissioned a group of experts to develop a standard operating procedure (SOP) guidance document for ER\(\alpha\) and AhR bioassays to ensure bioanalytical screening tool data collected pursuant to the Recycled Water Policy are of standard and high quality.

Relevance of antibiotic resistance to recycled water. While antibiotic resistance is still a major challenge and potentially an issue for any wastewater discharge into the environment, information to date is not complete and seems to indicate that the causes for antibiotic resistance are still not well known. Furthermore, recent literature reviews did not identify antibiotic resistance transmission as a consequence of water reuse practices. The lack of standardized methods for investigating the occurrence and removal of antibiotic resistant bacteria (ARB) and antibiotic resistance genes (ARGs) and risks associated with ARB and ARGs hinder the assessment of the severity of ARB and ARGs as an issue for potable water reuse applications in California. Focused investigations are needed to better understand the occurrence, fate and risks associated with ARB and ARGs in recycled water applications across California. Studies are currently on-going to address this knowledge gap and inform future regulatory and policy decisions.

2.2.2 Potable reuse criteria for surface water augmentation (SWA)

On February 14, 2017 the State Water Board released a Public Notice (BDDW-16-12 SWA) for the consideration of adopting surface water augmentation regulations as part of CCR Title 22. The SWA regulations establish minimum uniform water recycling criteria for the purpose of adequately
protecting public health with respect to the planned placement of recycled water into a surface water reservoir that is used as a source of domestic drinking water supply. Existing law required the State Water Board to adopt uniform water recycling criteria for SWA by December 31, 2016; subject to the condition that a statutorily mandated DPR/SWA Expert Panel found that such criteria would adequately protect public health, which occurred. On October 31, 2016, the DPR/SWA Expert Panel stated: “The Expert Panel finds, in its expert opinion, that the State Board’s proposed uniform water recycling criteria for surface water augmentation titled, ‘Surface Water Augmentation Using Recycled Water,’ as provided in Appendix C (October 12, 2016), adequately protects public health. This finding, submitted by the Expert Panel on October 31, 2016, represents the collective expert opinion of all members of the DPR/SWA Panel.” The State Water Board held a public hearing on March 6, 2018 and approved the SWA regulations, which subsequently were filed with the Secretary of State on August 7, 2018 and became effective on October 1, 2018.

The public health categories for SWA projects are similar to those for GWR projects, including requirements for pathogenic microorganism control, chemical control, advanced treatment, source control, and monitoring requirements. One notable difference is the addition of requirements related to the surface water reservoir. Because the reservoir requirements for retention time and mixing both impact the degree of treatment required, they are the focus of this discussion.

Unlike GWR, SWA requires that all water taken from the environmental buffer (i.e., the reservoir) be treated at a surface water treatment plant that is in compliance with the Surface Water Treatment Rules. The regulations define the level of treatment needed to produce a source of drinking water. In terms of pathogen control, an advanced water treatment facility is required to meet a minimum of the $8\log_{10}$ enteric virus, $7\log_{10}$ Giardia cyst, and $8\log_{10}$ Cryptosporidium oocyst reduction. Together with the surface water treatment plant—that must achieve 4-, 3-, and 2-log inactivation of the same pathogens—the minimum level of pathogen control is equal to the 12/10/10 requirements for GWR. As described in Table 5, compliance with these reductions requires multiple barriers that include secondary treatment, filtration, disinfection, reverse osmosis (RO), and advanced oxidation processes (AOP).

For SWA, the benefits of the reservoir as an environmental buffer lie primarily in the form of contaminant attenuation to mitigate the potential consequences of an AWTF treatment failure. As a result, the attenuation
is not considered part of the treatment train and may not be used as credit to meet the other regulatory requirements associated with contaminant control and removal for SWA projects. To ensure the reservoir provides a meaningful environmental buffer, two types of requirements associated with the robustness of a reservoir are in subsections. The first, the minimum theoretical retention time is an operational requirement, and the second, dilution is a performance-based criterion.

- **Minimum theoretical retention time (Tr):** for a reservoir to be used as part of a SWA project, the reservoir must initially be able to provide a Tr of at least 180 days calculated on a monthly basis. The criteria allow the operating agency the option of submitting an application for a reduced minimum Tr of no less than 60 days. Such applications are considered on a case-by-case basis. The minimum Tr requirement establishes a simple operational criterion to ensure that the reservoir is of sufficient size to be able to provide greater opportunity for responding to and potentially mitigating significant treatment failures. Thus, a Tr of less than 60 days is considered a DPR project under the current SWA criteria. Additional details can be found online at [https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/Surface_Water_Augmentation_Regulations.shtml](https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/Surface_Water_Augmentation_Regulations.shtml).

- **Dilution:** The SWA criteria require that (1) the volume of water withdrawn from an augmented reservoir contains no more than 1%, by volume, of recycled municipal wastewater that was delivered to the surface water reservoir during any 24-h period, or (2) 10%, by volume, of recycled municipal wastewater that was delivered to the surface water reservoir during any 24-h period, with the recycled municipal wastewater delivered by the project’s water recycling agency having been subjected to additional treatment producing no less than $10^{-10}$ reduction of enteric virus, *Giardia* cysts, and *Cryptosporidium* oocysts.

A SWA project must demonstrate that these dilution and mixing criteria are met under all operating conditions using hydrodynamic modeling. The modeling must simulate how different conditions (e.g., wind speed, wind direction, temperature, lake stratification, etc.) impact the dilution and mixing in the reservoir and verify its compliance with the SWA requirements. The hydrodynamic model must be validated with a tracer study prior to the project coming online, and again within 6 months of operation to validate the model. An independent advisory panel (IAP) is required to assist DDW in the review and approval of the results of the hydrodynamic modeling.

The project’s theoretical retention time also impacts the pathogen reduction required. If a project proposes a theoretical retention time less than
120 days, the regulations require no less than 1-log reduction beyond what would otherwise be required based on the dilution provided. Table 6 summarizes the treatment requirements for SWA projects depending on the dilution and theoretical retention time in the reservoir.

In addition to the key requirements mentioned previously in this section, the regulations also specify a number of requirements for additional elements. A summary of these requirements is provided in Table 7.

### 2.3 Public health considerations as a condition of potable reuse

The transition from IPR to DPR has the potential to modify conventional public health practices by removing the physical separation (i.e., environmental buffer) between wastewater disposal and water supply. Consequently, it is imperative to develop and implement basic principles for the safe design and operation of DPR systems that provide continuous protection against short-term and long-term exposures to contaminants.\(^{25,33}\)

Public health protection requires that microbiological pathogens and chemicals in wastewater be removed to the extent practical before discharge to the environment (as commonly practiced throughout the world) or for other uses (e.g., non-potable and potable reuse). Generally, low concentrations of non-pathogenic microorganisms are not harmful; therefore, a public health goal is not to eliminate all chemicals and microorganisms, but rather to limit human exposure to concentrations of chemicals and pathogens that may be harmful to human health. Such maximum allowable concentrations of potentially harmful agents are established as standards. In the United States, these

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**Table 6** Summary of treatment, dilution, and theoretical retention time criteria for SWA.

| Dilution V/Q (days) | Log removal required (V/G/C) | Number of treatment processes | Additional considerations |
|--------------------|-------------------------------|------------------------------|--------------------------|
| 100:1              | ≥180 8/7/8 12/10/10          | 2                            | -                        |
| <180–120           | 8/7/8 12/10/10               | State board approval         |
| <120–60            | ≥9/8/9 13/11/11              | State board approval         |
| 10:1               | ≥180 9/8/9 13/11/11          | 3                            | -                        |
| <180–120           | 9/8/9 13/11/11               | State board approval         |
| <120–60            | ≥10/9/10 14/12/12            | State board approval         |
Table 7: Summary of key surface water augmentation (SWA) criteria.\(^6\)

**Surface water augmentation (SWA) requirements**

| Criterion | Requirement |
|-----------|-------------|
| **Advanced treatment** | |
| Reverse osmosis | See Title 22 requirements for advanced treatment criteria (section 60320.302) |
| Advanced oxidation process | Oxidized wastewater (primary and secondary treatment)\(^a\) with RO and oxidation treatment process (i.e., AOP) (RO and oxidation process require meeting specified performance requirements) |
| **Alternatives clause** | |
| | Methods of treatment other than those included in the Water Recycling Criteria and their reliability features may be accepted if it can be demonstrated to the satisfaction of the State Water Board that the methods of treatment and their reliability features will assure an equal degree of treatment and reliability |
| **Pathogen reductions at compliance points\(^b\)** | |
| Finished potable water | |
| Advanced water treatment facility (AWTF) | Minimum—8,7,8—log\(_{10}\) reductions of V, G, C. based on 100:1 dilution additional 1 log\(_{10}\) reduction for all three organisms with 10:1 dilution at AWTF |
| Surface water treatment plant (SWTP) | Minimum 4, 3, 2—log\(_{10}\) reductions of V, G, and C at SWTP |
| **Environmental Buffer—Allowable Reduction Credits** | |
| **Reservoir theoretical retention time (Tr, months)** | Tr requires hydrodynamic modeling and tracer study |
| **Documentation** | 6 months (checked monthly) |
| **Initial (Tr months)** | Minimum 2 months (additional pathogen treatment will need to be evaluated and may be required) |
| **Alternative Tr** | |
| **Regulated contaminants** | Meet all drinking water MCLs |
| **TOC process requirement** | No TOC limit requirement; TOC is required for membrane startup performance and is required as a high-frequency monitoring surrogate for process performance |

\(^a\) RO and oxidation process require meeting specified performance requirements

\(^b\) For finished potable water, log\(_{10}\) reductions refer to the number of pathogens that are reduced by \(10^n\) at the compliance point.
standards for drinking water are known as “maximum contaminant levels” (MCLs) for chemicals and as “log_{10} reduction values” (LRVs) for pathogenic microorganisms.

Microbial contaminants—including bacteria, viruses, and protozoan parasites—are the most critical constituents to control in recycled waters due to the potential human health impacts resulting from short-term exposure. Most effects arise shortly after exposure, although chronic sequelae of acute infections are known to occur. Among the large number of chemical constituents that can be present in recycled water, some are of concern due

### Table 7 Summary of key surface water augmentation (SWA) criteria.

| Criterion                          | Requirement |
|------------------------------------|-------------|
| Alternative supply (or additional treatment) | Ensure capability to provide reliably, safe and wholesome supply of drinking water |
| Source control and outreach        | Industrial pretreatment and pollutant source control program, in addition to an enhanced source control program (section 60320.306) |
| Unregulated contaminants           | Data collection for pharmaceuticals, endocrine disruptors and other State Water Board Policy CEC indicators/surrogates (see Appendix A Section 6 “CECs Monitoring Parameters” in State Water Board Recycled Water Policy, December 11, 2018) |
| Monitoring and response to off-spec water | High-Frequency AWTF process monitoring and response in 24 h to off-spec production and potential release to reservoir Additional surrogate monitoring for pathogen log_{10} reductions and threshold criteria to address operational issues |
| Distribution system monitoring     | Assess and address potential impacts resulting from the introduction of advanced treated water into distribution system |

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aSee Title 22 requirements for disinfected filtered wastewater (section 60301.320) and disinfected tertiary recycled water (section 60302.230).

bThe treatment train consists of at least 2 separate processes for each pathogen (virus, *Giardia*, and *Cryptosporidium*). A separate treatment process may be credited with a maximum credit of 6—log_{10} reduction per process, with at least two processes each being credited with no less than 1-log_{10} reduction per process. A single treatment process may receive log_{10} reduction credits for one or more pathogens.
to their potential adverse health effects associated with both short-term and long-term exposures. Microbial and chemical contaminants in water produced for potable reuse can have adverse effects on human health. In addition, wastewater used as a direct source of drinking water raises aesthetic issues related to taste and odor, which can impact public acceptance of potable reuse projects. While conventional wastewater treatment in California provides a wastewater effluent quality that is suitable for discharge to surface water for subsequent use, treated wastewater effluents still contain a wide range of naturally occurring and anthropogenic trace organic and inorganic contaminants, residual nutrients, total dissolved solids (TDS), residual heavy metals, and pathogens mixed in with those that occur in receiving waters. What is important is regulating important constituents that may result in adverse human health impacts. Determining which constituents to regulate can be challenging, but has been done for both unplanned potable reuse and planned IPR.

2.3.1 Overview of health risk assessments
To understand the development of existing drinking water regulations and the application of these regulations to potable reuse, it is useful to:

- Consider how health effects are assessed.
- Review health effects considered in potable reuse studies conducted by the National Research Council and others.
- Review epidemiological, risk assessment, and toxicological health effects studies conducted for potable reuse.

2.3.1.1 Studies used to assess human health effects
Human health effects assessments can be based on studies using (1) test animals, (2) biochemical or cellular systems, and (3) humans. Examples include epidemiological, microbiological, and toxicological studies. Brief descriptions of these studies are provided in Table 8.

2.3.1.2 Limitations of epidemiological, microbiological, and toxicological studies
Neither epidemiological nor toxicological studies are sensitive to the low levels of exposure usually found in drinking water. Microbiological risks have been determined based on disease outbreaks attributable to a specific organism in public water supplies. In contrast, the contribution of a chemical to a specific adverse health outcome (e.g., bladder cancer) must be differentiated from other causes of that outcome (e.g., smoking), which is difficult to do.
| Type of study          | Description                                                                                                                                                                                                 |
|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Epidemiological       | **Purpose**: Identify and quantify changes in the incidence or processes of disease in human populations observed in an exposed population as compared to control groups (i.e., unexposed populations or those experiencing less exposure) |
|                       | **Examples**: Ecological epidemiology studies (which compare aggregated data from different populations) and analytical epidemiology studies (which require more detailed controls or information from individuals within the exposed and control populations) |
|                       | **Note**: In general, it is difficult to detect low incremental risks or differentiate these risks from the occurrence of background disease                                                                     |
|                       | **Consideration**: Because exposure to chemicals from food, water, and the environment is difficult to quantify, care must be taken to identify and quantify the exposure as accurately as possible and to control for variables (e.g., ethnic distribution, genetics, and social factors) that may confound the outcome or result in exposure misclassifications |
| Microbiological       | **Purpose**: Used to estimate the risks of infection by pathogens that cause human disease at various exposure levels encountered from water                                                                         |
|                       | **How It works**: Controlled dose-response infectivity studies are conducted with a known exposure to measure indications of harmful health effects through time following exposure |
|                       | **More information**: see references 33, 35–38                                                                iali |  |
| Toxicological studies | **Purpose**: Conducted in humans and on experimental animals for varying lengths of time and with multiple dose levels to identify no-effect levels and to obtain a dose-response relationship |
|                       | **How it works**: The process of using animal data for human safety assessments goes through two stages: first, adverse health outcomes are identified, and dose-response relationships are established that can be extrapolated to humans |
|                       | **Note**: Descriptive toxicological studies in animals tend to routinely employ doses much greater than human exposures from drinking water (usually to maximally tolerated dose). This practice is done to increase the sensitivity of the animal studies, which (for practical reasons) can employ only small numbers of animals relative to the human populations exposed to drinking water. Consequently, the dose-response relationship must be extrapolated to low doses (see the U.S. Environmental Protection Agency and California risk assessment websites noted in footnote 11) |
|                       | **Consideration**: “Safe” does not indicate zero risk, but rather that acceptable risks are likely to occur at doses represented by maximum contaminant levels                                                               |

Source: Adapted from Olivieri AW, Crook J, Anderson MA, Bull RJ, Drewes JE, Haas CN, Jakubowski W, McCarty PL, Nelson KL, Rose JB, Sedlak DL, Wade TJ. Expert Panel Final Report: Evaluation of the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse. Prepared by the National Water Research Institute for the State Water Resources Control Board, Sacramento, CA, 2016; Tchobanoglous G, Cotruvo J, Crook J, McDonald E, Olivieri A, Salveson A, Trussell R. S. Framework for Direct Potable Reuse, WaterReuse Association, Alexandria, VA, 2015, http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/1248321508_Vol2.pdf (accessed 9/3/2015).
With a single epidemiological study, care should be exercised in accepting either positive or negative results. The results must be confirmed independently with replication on other study populations. Multiple studies frequently are required before an association or lack thereof can be accepted as fact. When evaluating individual chemicals, these studies are conducted at high doses with the assumption that the effects observed can be extrapolated to environmental exposures at doses that are orders of magnitude lower.

Some animal studies have been conducted using concentrated samples of organic chemicals in water to accomplish the same goal; however, these studies have the additional goal of detecting the effects of unidentified chemicals that might be in water. As with epidemiological studies, these animal studies addressed a narrow range of potential adverse health effects (largely cancer, limited neurotoxicity screening, and reproductive outcomes), but have not focused on other chronic diseases and subtle effects on development. Some recycled water studies have been conducted with this goal in mind and are summarized in the 2010 Anderson et al. report.29

2.3.2 National research council studies on potable reuse

Within the past 20 years, two assessments have been conducted by the National Research Council23,25 in which potential challenges were identified and appropriate solutions were suggested to ensure potable reuse is a safe practice from the perspective of public health. Notably, the 1998 study focused solely on IPR, while the 2012 study addressed both IPR and DPR. In the intervening years between the two studies, significant advances were made in treatment technologies and monitoring capabilities, along with increased research, interest, and need to consider potable reuse as a source of drinking water supply. The findings from NRC (2012)25 with respect to chemical and microbial constituents are summarized below:

- Chemical risk—Water quality is ensured through source control programs, treatment technologies that meet drinking water maximum contaminant levels and other limits, and monitoring for constituents that present a public health risk. For advanced water treatment trains, most chemicals are not detected; those that are detected are found at levels lower than those found in conventionally treated drinking water supplies.

- Microbial risk—The risk from pathogens in potable reuse “does not appear to be any higher, and may be orders of magnitude lower, than currently experienced in at least some current (and approved) drinking water treatment systems (i.e., de facto reuse).
2.3.3 Epidemiological, risk assessment, and toxicological health effects studies on potable reuse

Several epidemiological and toxicological health effects studies have been conducted in the last 30 years to evaluate the public health implications of potable reuse. These studies are summarized in NRC (1998). Health effects data from some existing and demonstration potable reuse facilities, including the first DPR project in the world (located in Windhoek, Namibia), are summarized in Ref. Results have shown no health impacts, based on both epidemiological studies of groundwater replenishment (e.g., the Montebello Forebay groundwater replenishment project) and whole animal studies of recycled water intended for potable reuse in several locations (e.g., Denver, Tampa, and Singapore); however, the limited sensitivity and scope of these toxicological and epidemiological studies (as described above) prevent the use of these results to support the contention that potable reuse projects have been shown to be safe. Despite these complications, the results provide some assurance that risks to public health are low.

In addition, a Science Advisory Panel formed by the State Water Board reviewed the results of many key studies conducted over the past 40 years on chemicals of emerging concern (CECs) in recycled water and their toxicological relevance to humans. On the basis of this review, the Science Advisory Panel noted “…that appropriately treated recycled water represents a safe source of water to supplement potable drinking water supplies. The predominantly negative findings (regarding lack of observed adverse health effects) described above do not preclude the need to monitor recycled water to assure its continued safety.”

Finally, several narrowly focused risk-based studies have been conducted to evaluate the risks to human health associated with the use of recycled water for groundwater replenishment and other types of potable reuse.

2.3.4 Defining a tolerable level of public health risk

To quantify the potential for human health effects resulting from exposure to microbial and chemical constituents, regulatory agencies have adopted the concept of a “tolerable level of risk” to assist in setting water quality guidelines or standards.

In the regulatory realm, a “de minimis risk” is a risk that is too small to be concerned with (i.e., a “virtually safe” level) or is “below regulatory concern.” Traditionally, for drinking water supplies, de minimis risk levels are related to public health criteria (i.e., the toxicity of the constituent, characteristics of the population, and exposure). For microbial constituents of concern, the original
Surface Water Treatment Rule (40 CFR 141.70–141.75) required, in part, that DWTFs using surface water and groundwater under the direct influence of surface water (GWUDI) must filter and disinfect the water and must achieve $4 \log_{10}$ reduction of virus and $3 \log_{10}$ reduction of Giardia spp.

Subsequently, the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) (71 FR 654, Vol. 71, no. 3, Jan. 5, 2006) dealt primarily with ensuring the control of Cryptosporidium, as well as other microbial constituents. While the LT2ESWTR did not change the long-standing informal public health risk goal of no more than one in 10,000 infections per person per year, it was the first drinking water standard to establish a minimum required treatment level at individual DWTFs. It should be noted that the one in 10,000 annual risk of infection goal is similar to the drinking water guideline recommended by the World Health Organization (WHO) of one in 1,000,000 disability adjusted life years (DALYs) for microbial disease risk. Specifically, for surface waters and GWUDI, public health protection is to be achieved through installing sufficient treatment technologies to achieve $\log_{10}$ reductions of Cryptosporidium ranging from $2 \log_{10}$ (multiple disinfection types with source water concentrations of $<0.01$ oocyst per liter) to $5.5 \log_{10}$, depending upon the concentrations of Cryptosporidium measured in 24-monthly source water samplings.

Note that different risk levels are commonly used, depending on the specific situation and type of contaminant. The Office of Drinking Water of the USEPA uses a “regulatory window” for chemical carcinogens of $10^{-6}$ to $10^{-4}$ risk per person per lifetime. For pathogens, the treatment requirements as defined in Surface Water Treatment Rule and its amendments were derived using a value of $10^{-4}$ infections per person per year as the tolerable risk goal.

Pathogen performance goals for potable reuse projects in California have been proposed that are based on a tolerable risk level of $10^{-4}$ infections per person per year. Daily risk is also being discussed for RWA and TWA projects. The tolerable risk level refers to final drinking water quality.

### 3. Recycled water as a potable water

The framework for the Safe Drinking Water Act was established between the 1970s and 1990s, when the focus of regulatory efforts was limited to sources of water from streams, rivers, lakes, and groundwater aquifers. Due to competing demands for these natural water sources (e.g., in-stream flow, agricultural use, and concentrated population growth in arid portions...
of the United States), consideration is now being given to recycled water as a source of drinking water supply. In addition, advances have been made in research and practical experience has been gained regarding the removal of pollutants and naturally occurring constituents. The efficacy and cost-efficiency of wastewater and drinking water treatment technologies considered routine today have changed substantially from those used when the Safe Drinking Water Act was first drafted. Also, advanced water treatment technologies such as advanced oxidation processes were, at best, research concepts when the Safe Drinking Water Act was reauthorized for the second and third times.

At present, a sound technical basis exists for developing water recycling programs incorporating IPR and/or DPR that are protective of public health. By building on key elements of the existing framework of the Safe Drinking Water Act, the water industry can move forward to incorporate properly treated recycled water as a source of raw drinking water supply.

### 3.1 California proposed framework for regulating direct potable reuse

The State Water Board published a Report to the Legislature on the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse in December 2016. The report asserted that “Given the various possible types of DPR projects, a common framework will be needed to avoid discontinuities in the risk assessment/risk management approach as progressively more difficult conditions are addressed.” The State Water Board subsequently published “A Proposed Framework for Regulating Direct Potable Reuse in California” in April 2018. A second edition of the framework document was published in August 2019 and included an update on DDW’s thinking on the development of uniform water recycling criteria for DPR. The document addresses areas such as the types of potable reuse, the risk management approach, critical elements of potable reuse projects (e.g., permitting authority, operator certification, pathogen and chemical control and monitoring, operations plan, and source assessment and source control), and technical, managerial, and financial capacity. The revisions to the framework were the result of an extensive evaluation of diverse DPR projects and the various concepts that control the risks.

The framework document evaluates how each of several factors of varying importance (e.g., natural sources of supply, treatment through natural attenuation environmental buffers, reliability of engineered treatment, and monitoring and control systems) is expected to change over the range of
potable reuse forms, and shows how public health will be protected as the form of potable reuse changes. The document also establishes a framework for the regulation of potable reuse projects that takes into account the State Water Board’s report to the Legislature, a schedule for completing the recommended research for six research projects described in the report, and a process and timeline for updating the uniform water recycling criteria for surface water augmentation.

As previously noted, “Direct potable reuse” means the planned introduction of recycled water either directly into a public water system, as defined in Section 116275 of the Health and Safety Code, or into a raw water supply immediately upstream of a water treatment plant. Direct potable reuse includes, but is not limited to, the following:

1. “Raw water augmentation (RWA),” which means the planned placement of recycled water into a system of pipelines or aqueducts that deliver raw water to a drinking water treatment plant that provides water to a public water system, as defined in Section 116275 of the Health and Safety Code.

2. “Treated drinking water augmentation (TWA),” means the planned placement of recycled water into the water distribution system of a public water system, as defined in Section 116275 of the Health and Safety Code.

The definition of raw water augmentation allows for a wide variation of project scenarios that include the type and quality of the raw water augmented and the nature of the drinking water treatment plant. The framework document states that there are many potential configurations of the treatment facilities (i.e., advanced treatment facility and drinking water treatment plant) and the manner in which the water from a DPR treatment facility will enter the distribution. DDW believes that it is possible to develop criteria that can be used to regulate the range of potential proposals and that it is not necessary to develop formal definitions of the various potential variations. DDW believes it is feasible and protective of public health to evaluate an existing drinking water treatment plant as a train of separate treatment processes. While each individual process could be validated for pathogen reduction, it is not yet clear whether the validation frameworks from the Surface Water Treatment Rules will apply or whether DDW will require new validation studies for AWT effluents. One option, as noted previously, is to allow existing DWTP credit to continue based on the assumption that the raw source water quality to the DWTP is consistent with California drinking water regulations.
3.2 Reducing the environmental buffer & establishing “equivalent level of public health protection”

Indirect potable reuse (IPR) in the State of California includes the use of a regulatory-defined environmental buffer; however, there are likely to be potential potable reuse projects where an environmental buffer is available, but does not meet the operational and performance criteria for an IPR project using surface water augmentation (SWA). This scenario addresses such a situation.

The criteria for IPR using SWA include (1) an operational criterion of a monthly-average theoretical hydraulic residence time of at least 60 to 180 days and (2) a performance criterion requiring the dilution of a 24-h pulse of “off-spec” water of at least 1:100 or of 1:10 when an additional 1-log10 reduction of each pathogen is provided by the AWTF. These criteria ensure that a substantial environmental buffer is in place to provide the following three benefits:

- Storage of advanced treated water for subsequent potable reuse.
- Attenuation (e.g., by dilution and die-off) of any contaminants that may evade sufficient treatment.
- Time to respond to treatment plant upsets during production of advanced treated recycled water.

There is a regulatory “Gap” between IPR projects with smaller environmental buffers and DPR projects with no environmental buffers. Based on the previous analysis of an environmental buffer conducted by the Expert Panel as part of its review of proposed criteria for IPR using SWA, the Expert Panel considered IPR projects with a theoretical hydraulic retention time of \(<2\) months to be a DPR project (i.e., the Gap between IPR using SWA and DPR covers projects with theoretical hydraulic retention times of \(\geq2\) months and \(<4\) months).

As part of developing proposed IPR criteria for SWA, the State Water Board recognized that the requirement for a minimum criterion of 1:100 dilution of a 1-day pulse of off-spec water could place restraints on some projects; therefore, the proposed criteria also allowed for a minimum dilution of 1:10 if 1-log10 additional reduction for each pathogen class is provided. As a result, the proposed criteria award equivalent credit between 1-log10 less dilution and 1-log10 more treatment. This equivalence is important because it allows dilution and treatment to each pathogen class to receive log10 reduction credit. It is recognized that, in general, attaining a minimum of 1:10 dilution within the reservoir and providing 1-log10 of additional treatment may often be easily achieved. Further, a potential
Gap project might incorporate an allowance for a 1:10 dilution, but with a parallel requirement for additional $\log_{10}$ reductions through treatment (i.e., 2 or more $\log_{10}$ reductions for each reference pathogen).

It was earlier demonstrated that if a reservoir was represented as a continuous-flow stirred tank reactor (CFSTR), it could achieve a 1:10 dilution with a theoretical hydraulic residence of as little as 10 days$^{42}$; however, a reservoir with such a short theoretical hydraulic residence time would fail to serve as a significant environmental buffer as it would provide only minimal time to respond to a treatment plant upset, as well as provide limited dilution (Table 9).

Under an idealized CFSTR representation, a reservoir with a 10-day hydraulic residence time (or 0.33 month assuming a 30-day month) could provide no more than a 1:10 dilution and would export to a downstream drinking water treatment facility (DWTF) 2% of a universally distributed conservative contaminant mass within about 0.2 days (or 5h) or approximately 10% after 24h. With short-circuiting in the reservoir, even less time could be available. A reservoir achieving only 1:10 dilution, thus, would provide very little time to implement corrective action (e.g., increasing disinfection at the DWTF or switching to an alternative source supply).

| $t_r$ (months)$^b$ | Dilution factor$^b$ | $t_2$ (days)$^c$ | % In situ removal$^d$ |
|---------------------|---------------------|----------------|-----------------|
| 0.33                | 10                  | 0.2            | 43              |
| 1                   | 30                  | 0.6            | 69              |
| 2                   | 60                  | 1.3            | 81              |
| 3                   | 90                  | 2.0            | 87              |
| 4                   | 120                 | 2.7            | 90              |
| 5                   | 150                 | 3.3            | 92              |
| 6                   | 180                 | 4.0            | 93              |

$^a$Actual dilutions, travel times, and in situ removals in a reservoir will depend upon complex hydrodynamics and other factors, which can deviate substantially from these values.

$^b$Assumes the flow of advanced treated water constitutes total flow through the system.

$^c$Time for 2% of a conservative tracer or unreactive contaminant to exit the reservoir.

$^d$Assuming a first-order decay rate of $k=0.077$ per day.

Adapted from Anderson MA. Appendix 9A - Indirect potable reuse: defining the robustness of the environmental buffer, in Olivieri AW et al., Expert Panel Final Report: Evaluation of the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse. Prepared August 2016 by the National Water Research Institute for the State Water Resources Control Board, Sacramento, CA, 2016.
Moreover, such a short residence would also provide little opportunity for in situ removal. By contrast, increased hydraulic residence times provide greater dilution, increased time to respond, and (although not credited in the criteria for IPR using SWA) increased removal of pathogens and some chemical contaminants prior to the delivery of water to the downstream DWTF (see Appendix 9A).

The IPR regulations reflect the fact that public health protection relies both on engineered and environmental elements. While tertiary treatment is required for groundwater recharge via surface spreading, the regulations also require the use of soil aquifer treatment (SAT) and retention time to further attenuate both chemical and pathogenic contaminants. Acknowledging the limitations of these forms of treatment alone, dilution is also required. Because subsurface injection bypasses many benefits of SAT, additional engineered treatment (i.e., full advanced treatment of FAT) is required above ground. This trade-off between environmental and engineered benefits is also reflected in the SWA regulations. Projects that provide greater retention and dilution in the environment have engineered treatment requirements (12/10/10) that are increased 1- to 2-logs or more as the reservoir becomes smaller in size (< 6 months) and provides lower dilution (from 100-fold to 10-fold). In short, the existing IPR regulations reflect a balance of elements that tends to favor higher degrees of engineered treatment and monitoring as the benefits of the environment—in terms of treatment, retention and response time, dilution, and peak attenuation—are reduced (Fig. 5).

It is important to note that the use of environmental buffers is not precluded from DPR scenarios. While any reservoir that cannot meet the minimum 60-day theoretical retention time and 10-fold dilution requirements will be considered DPR, even a small reservoir (e.g., with a 1-month retention time) can provide significant dilution and mixing. Furthermore, the placement of a reservoir between the AWTF and drinking water treatment plant provides an opportunity to uncouple the two facilities. The reservoir provides a hydraulic buffer that allows the AWTF to continue discharging into the reservoir even if the drinking water treatment plant switches to another source water. The ability to switch off of the reservoir is another benefit of RWA scenarios that incorporate reservoirs that will not be present in hard-piped RWA scenarios (i.e., those with no reservoirs) and TWA.

This discussion illustrates the need for DPR regulations that account for and balance the multiple elements of public health that may be included in
potable reuse projects. Different combinations of treatment, retention time, dilution, monitoring, source control, etc., may all be able to meet the minimum requirements for public health protection. The following sections highlight some of the unique challenges facing DPR projects and provide further insight into how the regulations may rebalance these elements.

3.3 Filling DPR information gaps

While the SWB independent panel determined that is was feasible to develop uniform criteria for DPR that adequately protect public health, the panel identified six areas of additional investigation that would enhance the SWB efforts to develop DPR criteria and regulations. The six priority research topics pertain to the control of contaminants, both microbial pathogens and toxic chemicals (Fig. 6). The pathogen topics include developing additional information on the concentrations of pathogens present in raw wastewater (under both typical and outbreak conditions), as well as the use of quantitative microbial risk assessment (QMRA) to understand microbial risks and how treatment can be used to control those risks. For chemical risks, the SWB identified three topics of concern for DPR: (1) the need for...
enhanced source control, (2) an evaluation of strategies to define and control peaks of chemical contaminants, and (3) the need to evaluate the feasibility and use of non-targeted analysis to identify unknown contaminants or those more likely to pass through advanced treatment (low molecular weight compounds). All of the projects, with the exception of the source control project, are being managed through the Water Research Foundation and are planned to be complete by March 2021.

Develop an Enhanced Source Control Program for Potable Reuse Projects: The SWB should develop an approach to proactively monitor the literature on the potential health risks that could present serious harm to health over short durations of exposure to compounds likely to be present in recycled water. Of specific concern are chemicals that adversely affect the development of fetuses and children. A formal process should be established by the SWB that includes: (1) an internal process to monitor the literature and (2) an external peer review process to address the results of the internal efforts to maintain a high level of awareness of these issues.

Adopt the use of probabilistic methods to evaluate treatment performance and quantitative microbial risk assessment (QMRA). As California moves to DPR, there will be an increasing and unprecedented reliance on engineered solutions for public health protection. The ability of these systems to provide equivalent degrees of protection warrants further evaluation. Probabilistic assessments of both treatment train performance and QMRA offer unique opportunities to understand the reliability of DPR systems. This project—led by a Technical Working Group and a Research Team—will
develop a freely available, user-friendly tool that can be used to quantify and characterize pathogen risk in DPR applications based on an evaluation of treatment performance. The main benefit of these tools is that they can be used by the State to identify what log reduction values (LRVs)—i.e., performance requirements—are necessary to achieve different levels of public health protection from waterborne pathogens. In particular, it provides a metric to evaluate the necessary LRVs of viruses, Cryptosporidium, and Giardia needed to maintain a risk of infection equal to one or more acceptable thresholds: both $10^{-4}$ per person per year and $2.7 \times 10^{-7}$ per person per day. This approach provides a tractable metric for evaluating overall treatment plant reliability including treatment process redundancy and robustness (multiple barriers).

*Conduct pathogen monitoring in raw wastewater*—The risk-based framework used to develop the existing potable reuse regulations develops treatment requirements by understanding what level of pathogen log reduction is required to reduce the concentrations of pathogens in raw wastewater down to acceptable levels in the final potable water. Consequently, one of the key data inputs for this process is accurate information on the concentration of relevant pathogens in the source water, i.e., in raw wastewater. To better inform decisions associated with developing LRV requirements and conducting probabilistic-based QMRA and plant performance modeling, the SWB is funding a research project to assess the concentration of relevant pathogens in raw wastewater over a yearlong campaign. The two principal objectives of the research are to: 1) collect empirical data on the concentration and variability of pathogens in raw wastewater for the purpose of verifying log removal values necessary to adequately protect public health in DPR projects, and 2) develop recommendations for the collection and analysis of data on pathogens in raw wastewater for use both in this campaign and in future monitoring efforts. The monitoring campaign is assessing the raw (untreated) wastewater at five, large California wastewater agencies to provide more complete information on concentrations and variability of various waterborne pathogens and indicators.

The campaign is following a Standard Operating Procedure that uses current methods to evaluate a suite of pathogens and indicators including: enterovirus and adenovirus (using culture and molecular methods), norovirus (molecular), bacteriophage (culture and molecular), Giardia and Cryptosporidium (microscopy). The monitoring plan is designed to collect 24 samples at each of five facilities and will be completed in the spring of 2021.

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Investigate feasibility of collecting pathogen data during an outbreak—Investigate the feasibility of collecting pathogen concentration data for raw wastewater associated with community outbreaks of disease. Questions include:

- Can we use wastewater monitoring to catch an outbreak? Can we use epidemic quantities to predict the wastewater quantities?
- Can we catch an outbreak? Combine all of this to see where the gaps are. How many people in a community have it and how does that tie into WW, using excretion rates to calculate?

In addition to key waterborne pathogens SARS-CoV-2 has been added to the list of organisms of concern.

Treatment for Averaging Potential chemical peaks—The goal of this project is to investigate and identify suitable options (e.g., treatment, monitoring, operations, and source control) that can provide some “averaging” with respect to potential chemical peaks, particularly for chemicals that have the potential to persist through advanced water treatment. Averaging can take the form of a treatment process that causes the removal or transformation of a contaminant, or averaging can be a blending or dilution scheme to reduce chemical peaks to background levels. In addition, defining a chemical peak is a key component of the project.

The project will be conducted in three phases. Phase 1 was a detailed literature review of the rejection of chemical constituents or surrogates by several individual processes or a combination of advanced treatment processes. This phase included an assessment of the types of chemicals that may be addressed with industrial source control enhancement, identification of and definition of the term “peak” statistically considering influent concentration, treatment process performance, analytical variability and duration, and identification of frequency of sampling/monitoring need to effectively enable the identification of “peaks”. Phase 2 included a case study report that surveyed three utilities (City of San Diego, California; Orange County Water District, Fountain Valley, California; and the Singapore Public Utilities Board) to gather information on their experiences of detected chemical peaks as well as response protocols during such events. The case study report evaluates the impact of illicit discharges for different sewersheds and chemical volumes and identified available options for chemical peak “averaging”. Phase 3 includes experimentation to address knowledge gaps, including identifying chemicals and chemical groups of concern. Experiments will be conducted in Phase 3 to evaluate the ability of total organic carbon (TOC) analyzers to measure specific chemicals that should be targeted for reduction/removal in different water matrices. Subtasks in Phase 3 include pre-testing of laboratory sampling and analysis.
procedures, a round robin study, evaluation of online and laboratory TOC meters, and data analysis and reporting in a final report.

**Investigate Options for Non-Targeted analysis and analysis of low molecular weight compounds (LMW)—**This project focuses on evaluating potential analytical methods, including but not limited to non-targeted analysis (NTA), to identify contaminants not presently detected by current monitoring approaches, particularly LMW compounds that may occur in wastewater and recycled water and that may not be removed by advanced water treatment processes. The effort will build upon the recent results and recommendations from the SWB 2018 CEC report. This project will develop a white paper on recommendations for the use and interpretation of analytical results to identify unknown contaminants.

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