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Memorandum of Findings

Date: March 14, 2022

To: Jing Chao, PE, State Water Board Division of Drinking Water

From: Expert Advisory Panel on Direct Potable Reuse Criteria

Submitted By: Adam Olivieri, DrPH, PE, Expert Panel Co-Chair
James Crook, PhD, PE, Expert Panel Co-Chair

Subject: Expert Panel Preliminary Findings, Recommendations, and Comments on Draft DPR Criteria (dated August 17, 2021).

In March 2021, the California State Water Resources Control Board (State Water Board or SWB), Division of Drinking Water (DDW), entered into Agreement Number 20-044-400 with the National Water Research Institute (NWRI). More information about NWRI is in Appendix 1.

This three-year Agreement provides for NWRI to coordinate with SWB staff on the following tasks:

- Establish and convene an expert panel (Panel) to review proposed criteria (regulations) for direct potable reuse (DPR) and adopt a finding as to whether, in its expert opinion, the proposed criteria would adequately protect public health as mandated by Section 13561.2 of the Water Code.
- Assemble technical workgroup(s) from among selected Panel members and invited experts to provide consultation on technical and scientific questions related to the update of uniform statewide criteria for potable and non-potable recycled water.
- Provide administrative and logistical support to the SWB in administering the Panel and in supporting the technical workgroups, hold and facilitate Panel meetings, provide draft and final meeting proceeding reports, and the other necessary support functions to enable Panel members to accomplish their tasks.

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In its provisions most relevant to this Panel, Section 13561.2 of the California Water Code states:

- On or before December 31, 2023, the state board shall adopt uniform water recycling criteria for direct potable reuse through raw water augmentation.[1]
- The state board shall develop the uniform water recycling criteria for direct potable reuse using information from the recommended research.[2]
- Before adopting the initial uniform water recycling criteria for direct potable reuse, the state board shall establish and administer an expert review panel for purposes of subdivision (a).[3]

After detailed planning by and between the SWB, NWRI, and the Panel's Co-Chairs, Adam Olivieri, DrPH, PE, and James Crook PhD, PE, NWRI facilitated the Panel's first public meeting on August 24 and 25, 2021. The Panel convened additional NWRI-facilitated public meetings on December 1, 2021; January 28, 2022; and February 28, 2022. NWRI held each of the Panel's four meetings via web-enabled video conference due to SARS-COV-2 related public health mandates. In addition to the technical, scientific, and policy matters considered, each meeting agenda included time for public comment, which the Panel received at each meeting. Professional profiles of the Panel members are in Appendix 2. Recordings of the public meetings are on the SWB website; links to the recordings are in Appendix 3.

This Memorandum of Findings presents the Panel's preliminary findings to date along with related recommendations and comments. Comments are grouped by the major criteria categories and are as specific as possible. In conformance with Task 2 of the Agreement, technical workgroups of selected Panel members were consulted on technical and scientific questions. Appendices to this Memorandum contain technical documentation supporting the Panel's findings and recommendations, and links to recordings of the public meetings and other related resources. However, the findings, recommendations, and comments presented reflect only the consensus expert opinion of the Panel.

The Panel looks forward to discussing its recommendations and comments with DDW staff and coming to mutual understanding and agreement with DDW on how best to address each of these important items in the draft criteria.

[1] §13561.2(a)
[2] §13561.2(a)(1)
[3] §13561.2(c)(1)

Background

The Panel is impressed by the high quality of the SWB/DDW staff work on developing draft DPR criteria. The Panel also appreciates the quality of the material prepared by the DDW Project Team, which includes six research projects and presentations by the Water Research Foundation (WRF) Principal Investigators, and DDW staff for the Panel's review (Appendix 4). This body of work is essential for California's development of a reliable and resilient water supply.

The Panel's review is based on both an individual and holistic review of the draft criteria dated August 17, 2021. While the focus of the review is to determine if the proposed regulations provide adequate public health protection relative to the risk posed by the water being produced, the Panel has significant concerns about unintended consequences, particularly related to excessive energy consumption and carbon footprint. A responsive, sustainable, and cost-effective approach to developing these regulations includes recognition by the State Water Board of potentially over-engineered treatment barriers (treatment steps) and requires an intentional effort by DDW to develop a reasonable number and combination of such barriers.

The Panel recommends that the State Water Board address the concerns about energy use, carbon footprint, and over-engineering through a holistic risk analysis. The Panel looks forward to reviewing the analysis as part of its review of the final draft DPR criteria.

Preliminary Task 1 Panel Finding

The Panel's Preliminary Task 1 Finding is that the Early Draft of Anticipated Criteria for Direct Potable Reuse dated August 17, 2021, adequately protects public health. The Panel's preliminary finding is based on the assumption that the SWB/DDW will fully consider and address the Panel's recommendations and comments in developing a revised draft of the DPR criteria, including the holistic risk evaluation of all data and assumptions, along with an environmental review per the California Environmental Quality Act (CEQA).

The Panel review of the draft DPR criteria indicate that:

- The draft chemical control criteria for the ozone and biological activated carbon (BAC) processes do not adequately address public health concerns related to low molecular weight compounds.
- The draft pathogen control criteria are based on numerous conservative assumptions that result in an over-engineered treatment facility. Thus, the draft pathogen control criteria require additional treatment that does not contribute additional public health protection. The Panel

expects that the revised draft will be shared with the Panel for final review and the Panel's Final Finding will be considered, prior to adoption by SWB.

Preliminary Task 2 Panel Findings and Recommendations

Recommendation 1. Include raw water augmentation in criteria and/or Statement of Reasons

The Panel understands that DDW's intent is to keep the criteria broad enough to cover all forms of DPR, including raw water augmentation (RWA) and treated water augmentation (TWA). The Panel notes that there are clear features that distinguish RWA and TWA that warrant both separate and consistent specifications for treatment and monitoring within the DPR criteria. For example, inserting clear acknowledgement on how the draft criteria would apply to potential RWA projects relying on a small reservoir with an existing surface water treatment plant (SWTP), projects with a large transmission line between an advanced water treatment facility (AWTF) and SWTP, or projects with a satellite AWTF that precedes an SWTP is necessary.

Further clarification is needed because TWA would require additional treatment processes including water stabilization, addition of chemicals to maintain a chlorine residual and, in some cases, temperature control. Also, further clarification in the criteria and/or the Statement of Reasons on how DDW will determine what DPR project facilities will be covered by a Safe Drinking Water Act (SDWA) permit versus a National Pollutant Discharge Elimination System (NPDES) permit is absolutely necessary.

Recommendation 2. Use scientific justification to support assumptions to develop log reduction values (LRVs) for pathogen criteria

The Panel's analysis of the draft pathogen criteria is contained in Appendix 5 and Appendix 6. The following recommendations and comments are based on the results of the Panel's pathogen analysis. The Panel understands that the current draft criteria include a number of assumptions that were used to develop the overall pathogen LRVs. These assumptions are based on variables, which include:

a. Selected a daily risk goal of 2.7×10^{-7} infections per person per day (PPPD) versus the Safe Drinking Water Act annual risk goal of 10^{-4} infections per person per year (PPPY).

b. Selected a single virus, norovirus (NoV), to represent human virus.

c. Selected concentration of single maximum point from literature versus use of distribution.

d. Assumed a fixed ratio between gene copies (GC) and infectious units (IU) of 1:1.

e. Selected conservative dose-response functions (several for selected pathogens are available).

f. Selected volume of drinking water consumed as single daily value versus a distribution.

g. Selected representative LRVs based on maximum point estimate versus statistical characterization from LRV distribution.

When the Panel reviewed the variables above, it appeared that DDW chose the most conservative assumptions to protect public health. However, layering the most conservative assumptions upon each other results in unrealistic and impracticable processes that offer no additional significant positive effects on public health.

The Panel recommends using the Water Research Foundation (WRF) DPR-2 report (B. Pecson, E. Darby, et al. 2021) dataset rather than the literature-based static maximum point estimate approach used in 2c, above, to develop LRVs. The results of relying on NoV and the draft criteria of attaining a 16 log reduction 100 percent of the time are presented on Figure 1.

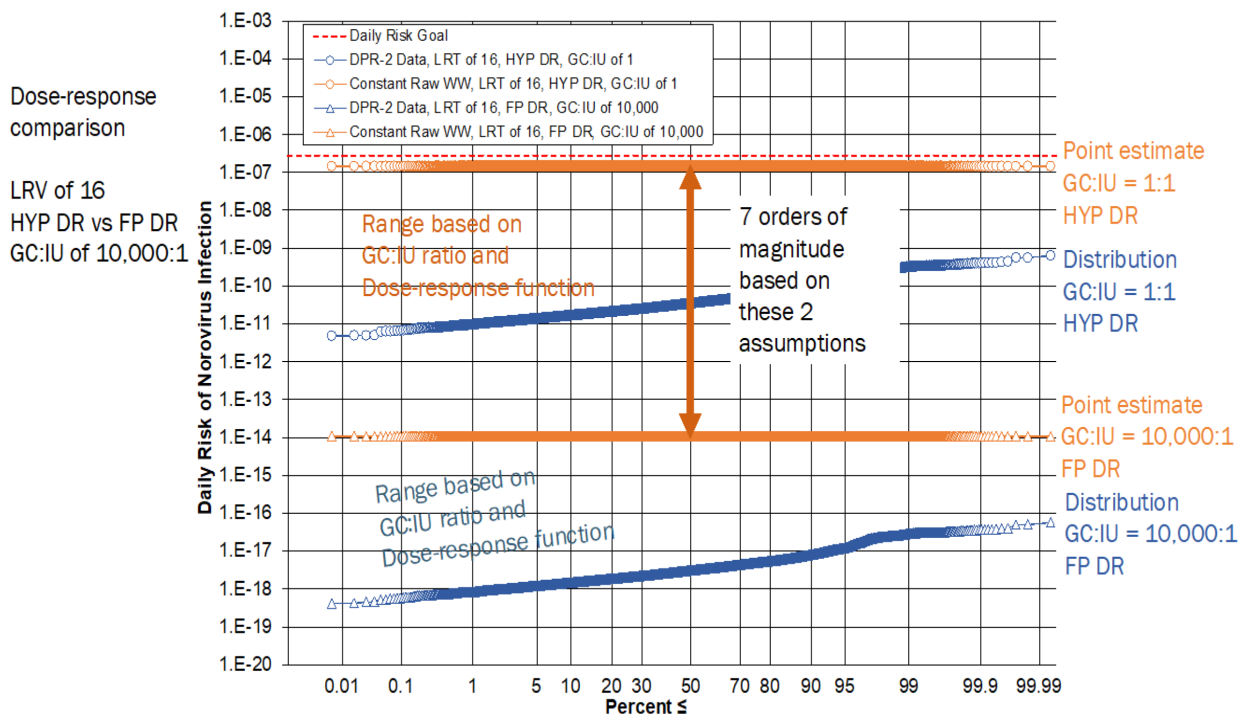


Figure 1. Illustration of conservative assumptions for GC:IU, dose-response, and point estimate of NoV and the resulting impact on daily risk based on target LRVs.

Using these conservative variables to attain the daily risk goal of 2.7×10^{-7} PPPD and operating at the 16 LRV based on a NoV point estimate concentration results in a risk goal of 10^{-14} PPPD. This value is

7 logs more conservative than the DPR daily risk goal. Specifically, this result occurs when using a GC:IU ratio of 1:1, a conservative hypergeometric dose-response function, and a literature-based maximum value of 10^9 GC/L to represent the untreated wastewater concentration instead of using the DPR-2 (B. Pecson, E. Darby, et al. 2021) distribution dataset. Table 1 compares the DDW assumptions and alternative assumptions estimated impact on log reduction.

Table 1. Comparison of several DDW assumptions with alternative assumptions and estimated impact on LRVs.

	DDW assumptions (Upper End)	**Alternative (Lower End)**	**Impact of differences on LRV requirements**
GC:IU ratio	1:1	10,000:1	4 LRVs
Dose-response function	Hypergeometric	Fractional Poisson	~3 LRVs
Wastewater concentration	10^9 GC/L point estimate	DPR-2 NoV distribution	~2-4 LRVs
Total			~9-11 LRVs

Modifying the concentration of NoV from a distribution based on DPR-2 (B. Pecson, E. Darby, et al. 2021) data to a point estimate makes the risk distribution even more conservative, adding approximately another 3 LRVs. Adding an additional 4-log reduction to compensate for a treatment failure assumption, on top of the 16-log reduction raises concerns about the compounding effects of numerous conservative assumptions.

The Panel notes that the science supporting GC:IU ratios in partially treated or fully treated recycled water is not settled. Also, the Panel notes that:

a. More data are needed on this subject.

b. It is appropriate and reasonable to consider GC:IU as a risk assessment reference given that the doses have almost all, with the exception of NoV, been determined by cell culture.

c. A GC:IU range of 1 as lower bound and 10,000 as an upper bound, based in part on the DPR-2 dataset (B. Pecson, E. Darby, et al. 2021) and the National Research Council Report on water reuse (National Research Council 2012), is appropriate to illustrate the impact of compounding conservative assumptions on the risk assessment results.

The Panel evaluated alternate LRVs for protozoa and human viruses to better understand the relationship between various risk assessment assumptions and compliance with both the daily and annual risk goals. The detailed analysis and recommendations for both protozoa and virus LRVs are in Appendix 6.

To illustrate how assumptions affect LRVs, several steps are required.

First, the distributions for log reduction are developed for NoV and enterovirus. The conservative log reduction range, without failure, for NoV is shown on Figure 2 and ranges from a 10- to 13-log reduction. The log reduction distribution for enterovirus is shown on Figure 3 and indicates that a conservative LRV estimate for enterovirus is 13, thus converging on the conservative end of the NoV range.

For the purpose of the analysis illustrated on Figures 2 through 5, several key assumptions are necessary, which are summarized in Table 2. These assumptions include:

- A GC:IU ratio for NoV ranging from a lower bound of 1 and an upper bound of 200 (Donia, et al. 2010), with the range analyzed as a uniform distribution.
- The DPR-2 enterovirus culture dataset was assumed to only represent 10 percent of cultured viruses; therefore, the distribution of viruses was increased by an order of magnitude (Gerba and Betancourt 2019).

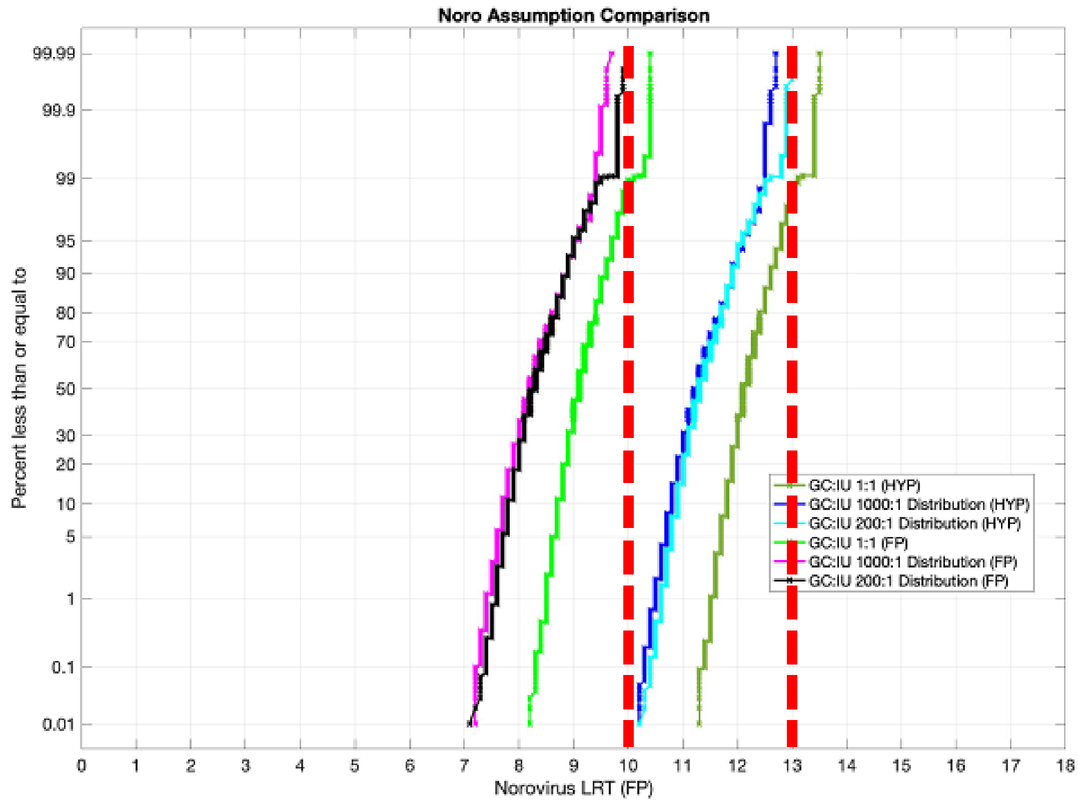
Table 2. Summary of NoV and enterovirus assumptions for estimating LRV distribution.

	Norovirus assumptions	**Enterovirus assumptions**
Wastewater concentration	DPR-2 NoV GII distribution (molecular)	DPR-2 enterovirus distribution (culture)
GC:IU ratio[1]	Range from 1:1 to 200:1[2]	--
Assumed % of viruses cultured (increased by 1 log for analysis)[3]	--	10
Dose-response functions	Hypergeometric (upper) and Fractional Poisson (lower)	Rotavirus

Notes:

1. Minimum ratio of 200:1 (Donia, et al. 2010).
1. Ratio of GC:IU will not be constant (Gerba and Betancourt 2019).
2. Safety factor of 10 is reasonable estimate (Gerba and Betancourt 2019).

Norovirus Required LRVs (impact of HYP D-R and FP D-R)



Range of potential virus LRVs based on Norovirus: 10 to 13

Figure 2. Estimated range of potential norovirus LRVs for several GC:IU assumptions and dose-response assumptions (impact of HYP D-R versus FP D-R on estimated LRVs).

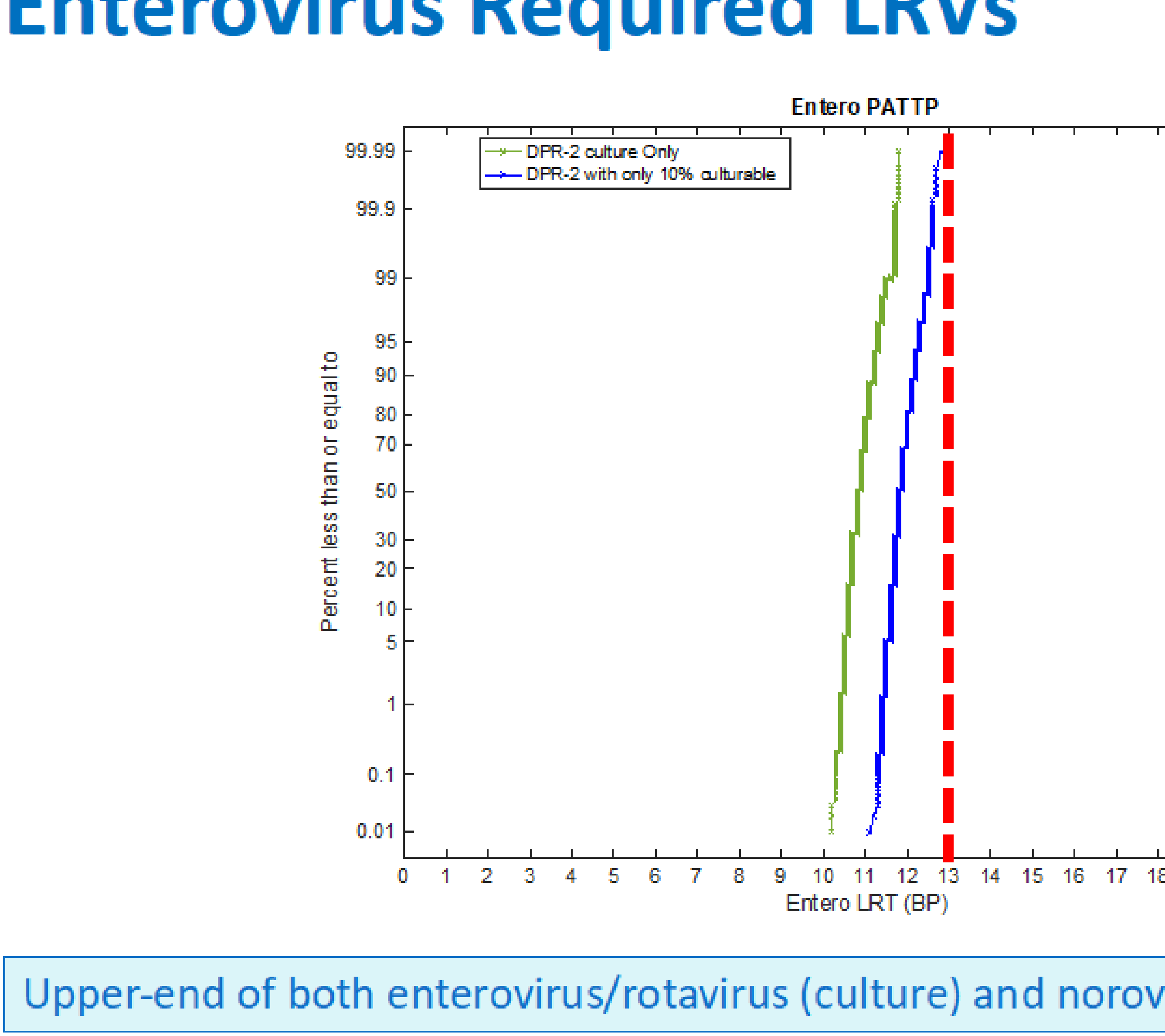


Figure 3. Estimated range of potential enterovirus (adjusted culture values) LRVs. (Note: Upper end of both enterovirus (rotavirus D-R) culture data and NoV (molecular) data shown on Figure 2 converge at an LRV of 13).

Second, treatment failure assumptions are required. Several assumptions were analyzed including the reported UV/AOP 6 LRV failure for 14 hours (Knoell 2021). To address the most severe failure that causes a 6-log increase in daily risk, a treatment redundancy of an additional 5 logs is required. Note that the DDW draft criteria assumed a 15-minute, 6-log reduction failure occurring once per year. The Panel adjusted this assumption to a 24-hour, 6-log reduction failure once per year.

Given the baseline LRV of 13 (no failures) and assuming a 5-log reduction redundancy results in the following potential treatment goals:

- Virus treatment goals: 13 LRV + 5 LRV redundancy = 18 LRV.
- Modeling includes undetected complete and intermediate failure scenarios:

- 18 LRV – 90% performance typically at design conditions (13 + 5).

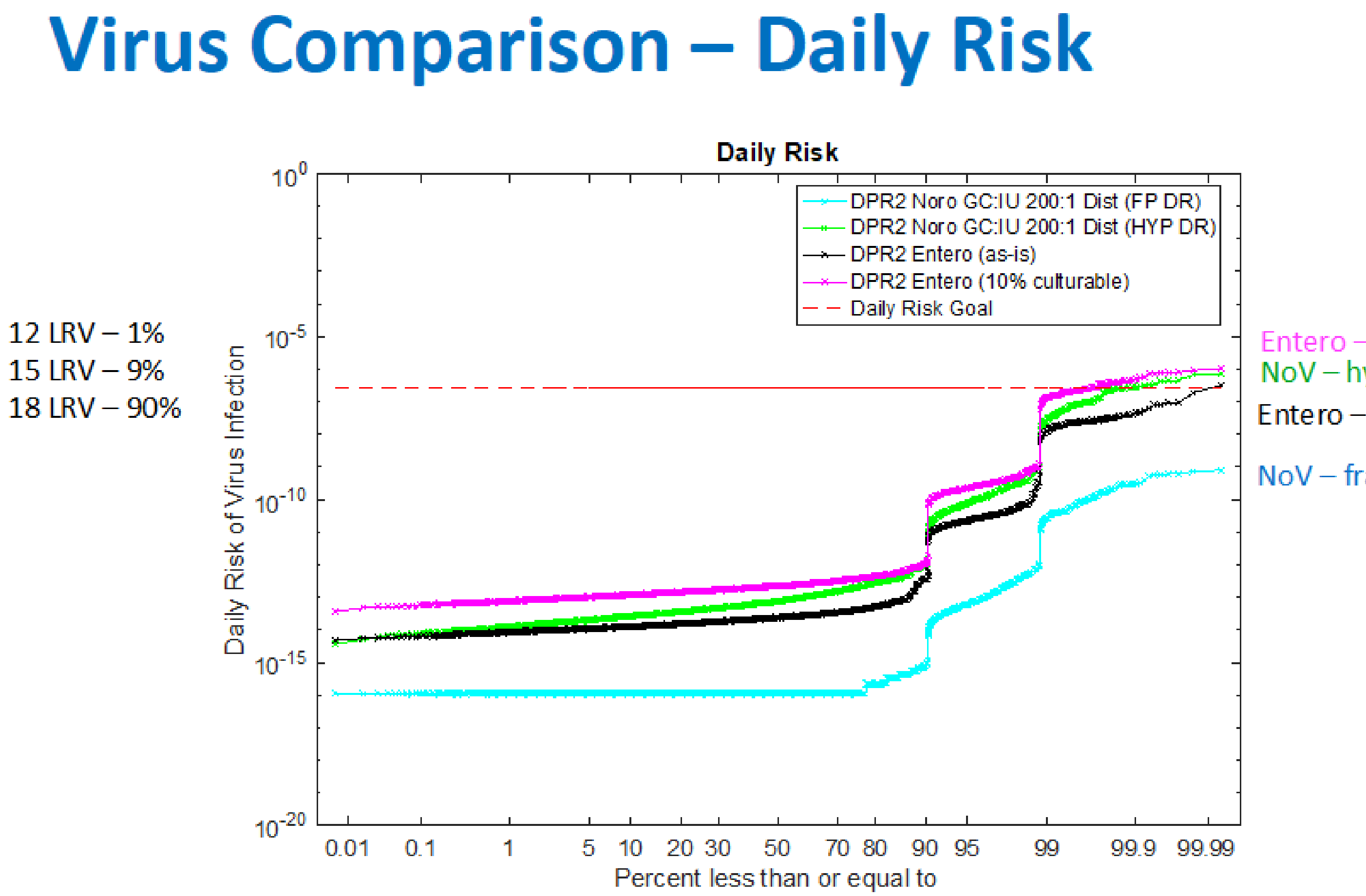


Figure 4. Comparison of risk distribution and performance assumptions (90 percent at 18 LRV, 9 percent at 15 LRV, and 1 percent at 12 LRV) for alternative viruses (NoV and Enterovirus) against daily risk goal (2.7x10^{-7} PPPD).

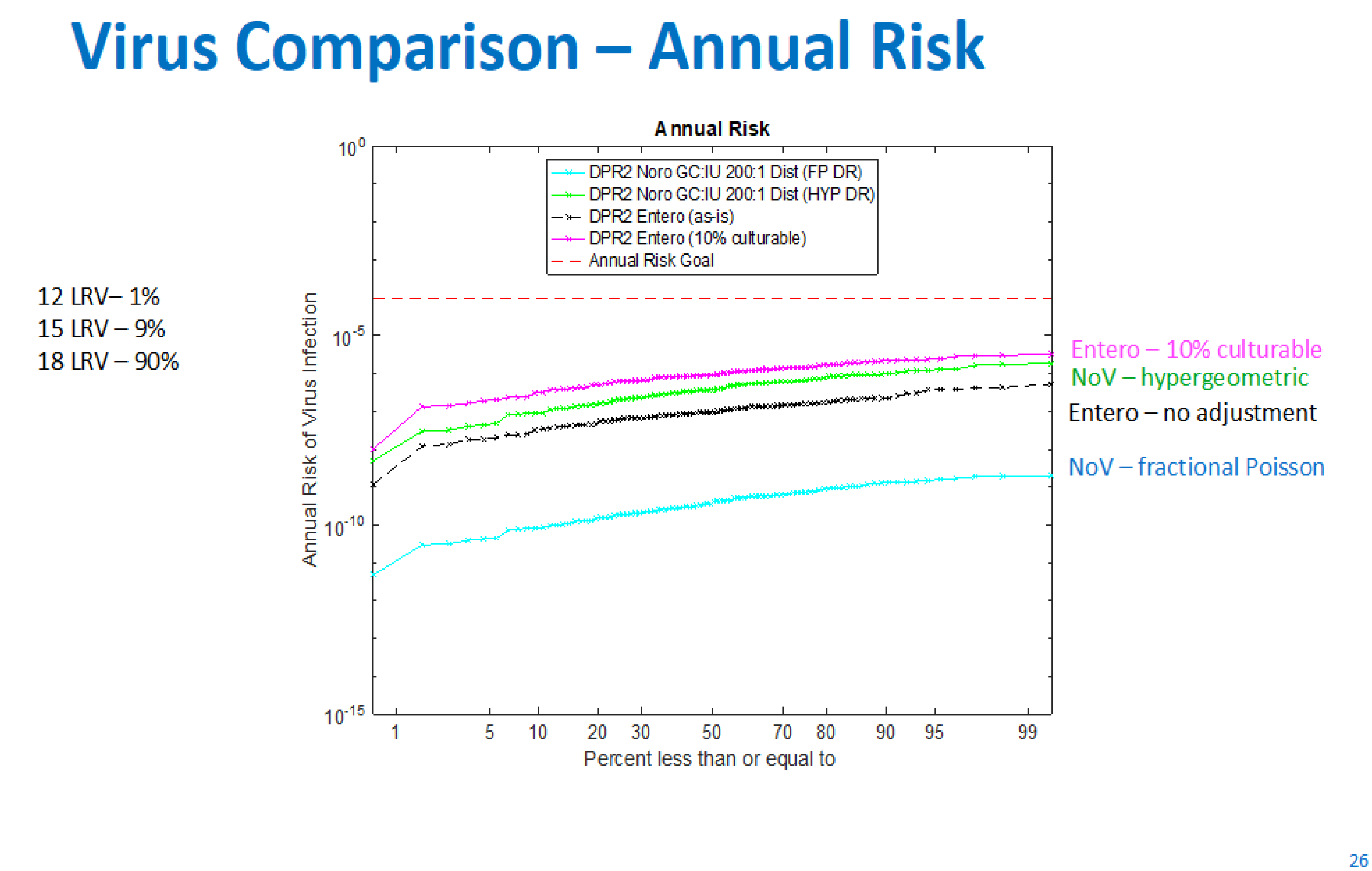


Figure 5. Comparison of risk distribution and performance assumptions (90 percent at 18 LRV, 9 percent at 15 LRV, and 1 percent at 12 LRV) for alternative viruses (NoV and enterovirus) against annual risk goal (10^{-4} PPPY).

Recommendation 3. Evaluate Pathogen LRV Criteria via Probabilistic Analysis

The current DDW proposed LRV criteria are more conservative than needed to be protective of public health and the additional LRVs do not improve public health protection. Additional analysis is recommended to address potential over-engineering of treatment barriers and to conduct an intentional effort by SWB/DDW to require a reasonable number and combination of such barriers.

The Panel recommends a probabilistic analysis as previously recommended in the feasibility report (Olivieri, et al. 2016) using the DPR-2 (B. Pecson, E. Darby, et al. 2021) report dataset rather than the literature based static maximum point estimate approach to develop the LRVs.

The Panel's probabilistic analysis identified alternative LRVs for viruses, summarized below, that adequately protect public health and are based on the following assumptions.

- Minimum treatment for public health protection is 13 LRVs.
- Minimum redundancy needed to address undetected failures is an additional 5 LRVs.
- Buffer to protect against a conservative 6 LRV failure rate (1 percent occurrence) is 5 LRVs.

- Compliance with daily risk goal is 99 percent.
- Compliance with annual risk goal (less than once in 100 years) is greater than 99 percent.

Proposed compliance requirements for LRVs are shown below, but other alternatives described in Appendix 6 also meet the daily and annual risk goals. The Panel recommends that DDW evaluate other alternatives because variability in plant performance is inevitable.

- 18 LRV – 90 percent

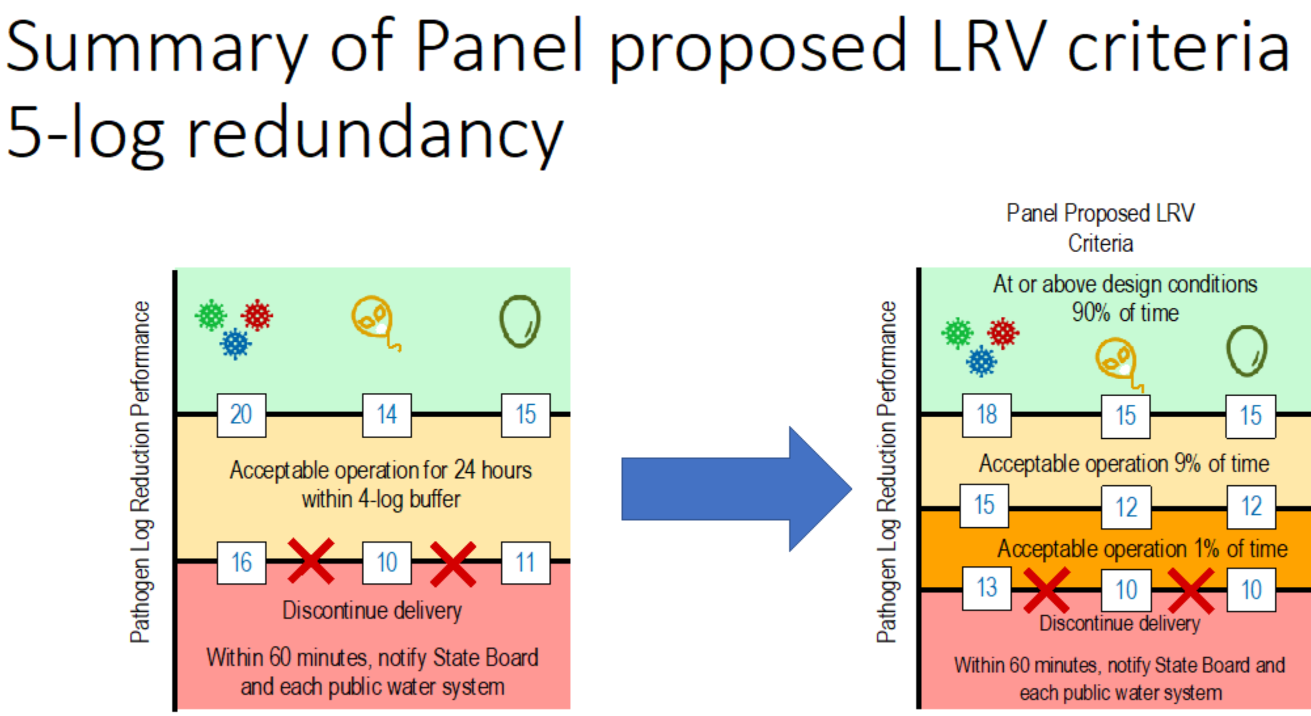


Figure 6. Summary comparison of DDW draft LRVs and panel suggested LRVs with 5 LRV redundancy and alternative compliance approach.

Finally, the Panel recommends clarifying the criteria on how alternative LRVs and compliance alternatives are addressed within the criteria so that there is no need to expand the draft criteria alternatives clause, as previously recommended by the Panel.

For example, to address LRV redundancy for an RWA project, options include clarifying the language in the criteria, expanding the alternatives clause, and/or including detailed clarification in the Statement of Reasons.

Recommendation 4. Expand engineering and operational topics

The Panel recommends expanding the engineering report section to require consideration and response to the following topics within the project engineering report. The operational topics cover a wide array of subjects within the draft criteria. Key recommendations are presented below.

Optimization of the secondary treatment process. Overall, the regulations are very prescriptive, but do not address how to optimize secondary treatment or alternatives to conventional secondary treatment for an advanced water treatment facility. Optimizing treatment is more valuable than requiring extra monitoring and over-engineering an AWTF. Municipal agencies have been optimizing to meet NPDES requirements and are now often optimizing for the AWTF. The wastewater agency and the direct potable reuse responsible agency (DiPRRA) will need to embrace the idea of spending more than what was necessary to meet NPDES requirements. This situation is true for both enhanced source control and optimized secondary treatment.

In the current draft of the proposed DPR regulations, the focus is clearly on advanced water treatment to collectively achieve stringent pathogen LRVs as well as chemical constituent limits. If maximum treatment objectives or goals are to be met with respect to the quality of the advanced treated water, it is important to determine if everything that could be done to improve the quality of the secondary effluent, which serves as the influent to the AWTF, has been implemented. Factors known to impact the performance of wastewater treatment facilities are presented in Table 3.

Table 3. Operational factors and areas of concern for optimizing secondary effluent that flows to an advanced treatment facility for potable reuse.

Area of concern	Principal impact(s)
Changing wastewater characteristics	Reduced flow rates, increased constituent concentrations (especially fats, oils, and grease and nutrients), decreased effluent quality
Climate change	Peak-flow events, surge flows, decreased effluent quality without flow equalization, washout of biological treatment process, flows exceeding disinfection facility capacity
Influent flow and load equalization	Improved treatment performance and effluent quality, improved process reliability, reduced biological reactor size
Enhanced primary treatment	Improved treatment performance and effluent quality, reduced energy usage in biological treatment
Equalization and treatment of return flows	Improved effluent quality and process reliability
Modification of biological treatment process operational mode	Improved treatment performance and effluent quality, process reliability
Implementation of new biological treatment process(es)	Improved treatment performance and effluent quality, process reliability
Improved process monitoring	Improved process performance, process reliability
Effluent filtration	Improved effluent water quality, minimizes impacts on advanced treatment from wastewater treatment upsets
Effluent disinfection method	Minimization of disinfection byproducts, microbial pathogen control consistent with advanced treatment needs

Source: (Tchobanoglous and Leverenz 2019)

The Panel recognizes that the regulations cannot be written to cover each area of concern in Table 3, but each of these factors should be identified and discussed in the engineering report (and required in the engineering report criteria provision) to assure the public that everything that potentially can be done to enhance the quality of the treated secondary effluent has been done or has otherwise been addressed. The Panel notes that many of the areas of concern in Table 3 are addressed by several currently operating facilities such as flow equalization, effluent filtration, and effluent disinfection.

The specific Panel recommendations to include in the engineering report criteria section include:

- The requirement to define a chemical peak as part of monitoring and plant operation plans, including defining corrective actions. Include the DPR-4 (Debroux, Plumlee and Trussell 2021) report as a guidance document in the Statement of Reasons.
- A requirement to address optimizing the secondary treatment process. Criteria need to result in producing a stable and high-quality nitrified water (0 to 2 mg/L NH_4 residual), prior to introduction into the AWTF. The biological treatment process should have a sufficient mean cell residence time to nitrify in cold weather.
- A reference to technical, managerial, and financial capacity (TMF) documents that DDW will use to review and approve TMF plans. It could also be included in the Statement of Reasons.

Include a requirement to address other plant operation and performance issues such as:

- Changing wastewater characteristics (both initial design and long-term).
- Climate change.
- Influent flow and load equalization.
- WWTP optimization to reduce energy and chemical use at the AWTF.
- Equalization and treatment of return flows (e.g., separation/diversion of flows).
- Temperature effects on treatment and distribution system chemistry.
- A requirement to develop a project-specific ozone/TOC dosage as part of the engineering report clause.
- A requirement to assess the project's cybersecurity plans or to develop a plan.

Recommendation 5. Redefine wastewater source control criteria

The Panel recommends redefining wastewater source control as enhanced source control and provide additional clarification criteria regarding expectations and reporting.

The term enhanced source control is used in the draft criteria but is not explicitly defined. The Panel understands that this term may be deleted. The Panel recommends that the wastewater source control criteria be redefined as "enhanced wastewater source control." In addition, the authority to request the enhanced program on behalf of the SWB needs to be clarified.

Authority within the new DiPRRA to define and implement the new criteria (e.g., expansion/enhancement of the Clean Water Act pretreatment programs) needs to be explicit, and the expected enforcement program expectations, including penalties, needs to be defined within the criteria. The authority for the DiPRRA to collect data including criteria for managing (formatting and storage) and submission to the SWB needs to be defined.

Recommendation 6. Address online wastewater collection system monitoring

While the concept is interesting and the Panel applauds the forward thinking on the topic, the technology to develop and implement such programs effectively is not currently feasible and/or practicable. The Panel recommends online wastewater collection monitoring as a permit modification when the technology is feasible and practicable. The Panel recommends including language to encourage pilot programs in the DPR criteria.

The Panel recommends that DDW include criteria that encourage DiPRRAs to continue to investigate future development and application of this concept through pilot programs. The Panel notes that DDW and/or the SWB can update regulatory permits to include online collection system monitoring as such programs become feasible and practicable.

Recommendation 7. Coordinate disease surveillance monitoring programs or community raw wastewater surveillance monitoring programs

The Panel recommends close communication with local and state public health agencies and recommends not requiring implementation of raw wastewater surveillance monitoring. The Panel assumes that the draft criteria to monitor disease surveillance programs is aimed at having the DiPRRA develop a program of close communication and coordination with local and state public health agencies as well as hospitals within the DiPRRA service area. The Panel agrees with a communication and coordination type of program. If that is the case, further clarification of the criteria is needed to define the goals and reporting for the DiPRRA to design a program for DDW review.

The concept of community raw wastewater surveillance monitoring to locate disease outbreaks within the served community may be practical as an early indicator of outbreaks but is not a practicable and/or feasible approach for assessing the adequacy of water treatment. Therefore, the Panel believes that raw wastewater surveillance monitoring should not be a requirement within the DPR criteria.

Further, the DPR-3 research report titled "Feasibility of Collecting Pathogens in Wastewater During Outbreaks," (Wiggington, et al. 2021) investigated the feasibility of linking the concentration of pathogens in wastewater with infections in a community through building a model for three human pathogens. Given infection prevalence in a community and shedding rates, the model predicts wastewater concentrations. However, it is clear that available community prevalence and fecal shedding data are the weak links in the model and significant community data are required to improve the predictions and, thus, reduce uncertainty. DDW staff should continue to stay informed on raw waster surveillance advances and, if appropriate, can modify surveillance monitoring program language in the future.

Recommendation 8. Modify chemical criteria

A number of comments and recommendations for chemicals are presented below:

- Recommend that ozone and biological activated carbon (BAC) processes be located appropriately before the reverse osmosis (RO) process to manage low molecular weight compounds as well as other chemicals of emerging concern (CECs). As currently drafted, the criteria imply that ozonation and BAC are one process. Biological treatment is a powerful barrier, and it should count as a separate barrier. The criteria should recognize these treatment processes as two separate barriers and the criteria should include a clear definition of expected functions of each process.
- The Expert Panel feasibility report (Olivieri, et al. 2016) pointed to the need to address low molecular weight compounds passing through RO. The current draft criteria imply that the use of ozone/BAC on RO permeate is acceptable. The approach will not be effective on RO permeate because there's not enough carbon left in the system to support the biological function of the BAC filter. Also, ozonation works better at elevated pH, while the RO permeate due to control of scaling has a pH of less than 7 (in the range of 6.2 to 6.5). The criteria document should clearly recognize ozonation and BAC as processes that precede RO. Also note that the ozonation and BAC barriers are synergistic—the sum of the effectiveness of ozonation alone or BAC alone is not as effective as the two combined. The potential use of ozonation and/or BAC after RO can be considered, if appropriate, as part of the alternative language.
- Recommend carbamazepine and sulfamethoxazole as ozone performance indicators.
- Recommend using acetone and formaldehyde as BAC performance indicators.
- Delete the applied ozone/total organic carbon (ozone/TOC) dosage language and include a requirement to develop a project-specific dosage as part of the engineering report. stated during a public hearing, the value of 1 mg ozone/mg TOC is not justified. The Panel understands that the DDW Project Team relied on a study titled "Persistent contaminants of emerging concern in ozone biofiltration systems: Analysis from multiple studies," to support the draft criteria (Sari, et al. 2020). Sari, et al. 2020 is a literature review of studies that target CEC and pathogen removal. To achieve LRVs for pathogens, higher specific dosages were applied.

- The focus of the draft DPR criteria should solely be CEC removal, specifically low molecular weight compounds. As stated in the paper, much lower specific dosages are sufficient. Because the treatment process is specified (ozone/BAC) and log removal values for several indicator chemicals are defined, there is no need to specify a specific ozone dose. Therefore, the ozone/TOC requirement can and should be deleted. Further, treatment should be optimized for the feedwater to maximize biotransformation and minimize ozone byproducts, such as bromate.
- Recommend online nitrite monitoring for ozone feedwater.
- Address alternatives to ozone/BAC as part of the alternatives clause. As alternatives are approved by DDW, it is important to recognize the need to consider extension of the approvals, as appropriate, to other projects. Any extension of such approvals to other projects should be based on the alternative(s) having addressed a wide variety of wastewater characteristics and operating conditions, including key chemical and microbial process performance indicators and surrogates. In particular, the startup and adaptation time of the BAC filter should be addressed.
- Define chemical peak to differentiate normal facility variation in water quality from true chemical peaks. In this study, chemical peaks are defined as resulting from intentional or unintentional illicit discharges of chemicals to the wastewater collection system (Debroux, Plumlee and Trussell 2021).
- Online TOC monitoring [see Chapters 4 and 6 in (Debroux, Plumlee and Trussell 2021)] is recommended as a feasible option for capturing chemical peaks. TOC is already used as a compliance critical control point monitoring device for RO systems.
- Experimental results suggest that commercially available TOC analyzers have the ability to detect chemical peaks originating from volatile organic compounds. Among the TOC meters that were tested, at least two models demonstrated acceptable performance and are recommended for DPR projects.
- Recommend no more frequent than 15-minute minimum sampling intervals for online TOC analyzers, given that chemical peaks last on the order of hours to days.

Recommendation 9. Require Third-party review of the Technical, Managerial, and Financial Plan

The criteria appropriately require development of a technical, managerial, and financial (TMF) plan. The Panel recommends the criteria include an independent third-party review of the TMF plan. The Panel also recommends that DDW include the following in the criteria or Statement of Reasons:

- Information (example if available) on what is expected to be included in the TMF documentation.

- Information identifying the key factors DDW staff will use to review the plan and determine acceptability.

Recommendation 10. Require third-party engineering review

The Panel recommends that the DPR criteria include a requirement for third-party peer review to:

- Review designs, including instrumentation, controls, and the SCADA system prior to preparation of project bid documents.
- Review project plans at commissioning.
- Review operational projects to identify engineering best practices that can be incorporated into future engineering designs.

These reviews, because they lead to improved practices, will also inherently benefit the public health, safety, and welfare (National Society of Professional Engineers 2022).

Recommendation 11. Clarify communication and notification requirements

All notifications to the public and public agencies need to be consistent with those currently required as part of the California potable water regulations and the SDWA. References to existing potable water notification regulations should be included in the DPR criteria.

Recommendation 12. Other recommendations

1. Include a criterion that requires 24/7 operation for at least 12 months before considering a request for reducing the number of operators and/or unstaffed operations.
2. Include a clear linkage in the DPR criteria for monitoring and/or source control and/or in the Statement of Reasons to the SWB Recycled Water Policy for chemicals of emerging concern. Criteria should include constituents to be monitored, the monitoring trigger levels, and the response action plan.
3. Include TOC monitoring criteria in several locations. The use of the 0.5 mg/L TOC, as written, could imply that TOC is a health-based criterion. The Panel recommends that the criteria and the Statement of Reasons should clarify that TOC is not a health-based criterion.
4. The criteria should include specific time frames and digital formats for submitting monitoring data to the SWB/DDW.
5. Include a 20-year life cycle planning horizon for the DiPRRA Joint Plan and a limited life-cycle cost analysis (LCCA) update every five years.

6. The Panel agrees with the DDW draft criteria that existing drinking water treatment plant treatment processes that have been validated for LRVs and approved by DDW do not need to be revalidated.
7. The source control section criteria requires quantitative risk assessment (QRA) which is confusing, probably not productive for each utility to conduct, and duplicative of SWB-CEC risk-based efforts and should be deleted. The Panel suggests adding a specific reference to the Statement of Reasons regarding enhanced source control qualitative risk-assessment background information and to the SWB-CEC risk-based documents to eliminate confusion with other risk assessment approaches.

Works Cited

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Appendix 1 • About NWRI

Disclaimer

This report was prepared by an Independent Expert Advisory Panel (Panel), which is administered by National Water Research Institute. Any opinions, findings, conclusions, orrecommendations expressed in this report were prepared by the Panel. This report was published for informational purposes.

About NWRI

A 501c3 nonprofit organization, National Water Research Institute (NWRI) was founded in 1991 by a group of California water agencies in partnership with the Joan Irvine Smith andAthalie R. Clarke Foundation to promote the protection, maintenance, and restoration of water supplies and to protect public health and improve the environment. NWRI's memberagencies include Inland Empire Utilities Agency, Irvine Ranch Water District, Los Angeles Department of Water and Power, Orange County Sanitation District, Orange County Water District, and West Basin Municipal Water District.

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Appendix 2 • Expert Panel Profiles

James Crook, PhD, PE, Environmental Engineering Consultant

Panel Co-Chair Dr. James Crook has more than 45 years of experience in state government and consulting engineering, serving public and private sectors in the United States and abroad. He has authored more than 100 publications and is an internationally recognized expert in water reclamation and reuse. Crook spent 15 years directing the California Department of Health Services water reuse program, during which time he developed California's first comprehensive water reuse criteria. He spent 15 years consulting for engineering firms overseeing water reuse projects and is now an independent consultant specializing in water reuse. He was elected as a Water Environment Federation Fellow in 2014 and selected as the AAEE 2002 Kappe Lecturer and the WateReuse Association's 2005 Person of the Year. Crook has a BS in Civil Engineering from the University of Massachusetts and MS and PhD degrees in Environmental Engineering from the University of Cincinnati. He is a registered professional engineer in California and Florida.

Co-Chair: Adam Olivieri, DrPH, PE, EOA, Inc.,

Panel Co-Chair Dr. Adam Olivieri has over 35 years of experience leading technical and regulatory projects that involve wastewater, water recycling and reuse, groundwater, stormwater, and chemical and microbial public health risk assessments. Olivieri has worked in public, private, and university settings, giving him a unique perspective on water quality policy in California. He is Vice President at EOA and works as a project manager, principal engineer, and technical advisor on a wide variety of environmental projects. He has extensive experience in microbial risk assessment and modeling to make engineering and public health policy/regulatory decisions. Olivieri received his BS in Civil Engineering and his MS in Civil/Environmental engineering from the University of Connecticut. He received his MPH and Doctor of Public Health (DrPH) in Environmental Health Sciences from the University of California at Berkeley. Adam is a Registered Civil Engineer in the State of California.

Richard Bull, PhD, Washington State University (Emeritus)

Dr. Richard Bull was a senior staff scientist at the Department of Energy's Pacific Northwest National Laboratory, was a Professor of Pharmacology and Toxicology at Washington State University and was Director of the Toxicology and Microbiology Division in the EPA's Cincinnati Laboratories. He is a Consulting Toxicologist and researcher who consults on chemical problems in water for water utilities and government agencies. His research focused on central nervous system effects of heavy metals and studies of carcinogenic and toxicological effects of disinfectants and disinfection byproducts, halogenated solvents, acrylamide, and other drinking water contaminants. Bull was a member of the EPA's Science Advisory Board and Chair of the Drinking Water Committee and has served on committees for the National Academy of Sciences. Bull has a PhD in Pharmacology from University of California, San Francisco, and a BS in Pharmacy from University of Washington.

Jörg E. Drewes, PhD, Technical University of Munich

Dr. Jörg E. Drewes is Chair Professor of Urban Water Systems Engineering at Technical University of Munich (TUM) Germany. Previously, he served as Full Professor of Civil and Environmental Engineering at the Colorado School of Mines and as Director of the National Science Foundation Engineering Research Center on Reinventing the Nation's Urban Water Infrastructure (ReNUWIt). His research includes development of sustainable urban water systems that include energy recovery from waste streams, membrane hybrid processes, engineered natural treatment systems for groundwater recharge, water recycling, and the fate and transport of emerging trace organic chemicals in the environment. Drewes has published more than 300 journal papers, book contributions, and conference proceedings. HIs awards include the AWWA Rocky Mountain Section Outstanding Research Award and the Quentin Mees Research Award. Drewes holds an MS and PhD in Environmental Engineering from Technical University of Berlin, Germany.

Charles Gerba, PhD, University of Arizona

Dr. Charles P. Gerba is Professor of Virology in the Department of Environmental Science at University of Arizona, where he researches pathogen transmission in the environment. His recent research encompasses pathogen transmission by water, food, and fomites; fate of pathogens in land-applied wastes; development of new disinfectants; domestic microbiology, and microbial risk assessment. He has authored more than 500 articles, including several books in environmental microbiology, risk assessment, and pollution science. He is a fellow of the American Academy of Microbiology, American Association for the Advancement of Science, and the International Water Association. He is on the editorial board of the Journal of Water and Health sponsored by the World Health Organization and has served on the Science Advisory Board of the EPA and the Food Advisory Board of the FDA. Gerba received the A. P. Black Award from the American Water Works Association for outstanding contributions to water science and the McKee medal from the Water Environment Federation for outstanding contributions to groundwater protection. He holds a PhD in Microbiology from the University of Miami.

Charles Haas, PhD, Drexel University

Dr. Charles Haas is the L. D. Betz Professor of Environmental Engineering in the Department of Civil, Architectural, and Environmental Engineering at Drexel University. He has more than 45 years of experience researching water treatment, risk assessment, environmental modeling and statistics, microbiology, and environmental health. Haas has been at Drexel University since 1991, serving as

Department Head from 2005-2020. He previously served on the faculties of Rensselaer Polytechnic Institute and Illinois Institute of Technology. Haas holds a BS in Biology and an MS in Environmental Engineering from Illinois Institute of Technology, and a PhD in Environmental and Civil Engineering from University of Illinois. He is a 2021 Member of the National Academy of Engineering and recipient of the 2021 College of Engineering Outstanding Career Research Award.

Amy Pruden, PhD, Virginia Tech

Dr. Amy Pruden is a University Distinguished Professor in the Department of Civil and Environmental Engineering at Virginia Tech. Her research focuses on microbial ecology in the design and management of water, wastewater, and recycled water systems. Her research focuses on advancing practical means of antibiotic resistance monitoring, mitigation, and risk assessment. Recently, she served on the NASEM committee on management of *Legionella* in Water Systems and co-authored a consensus report. She has authored over 175 peer-reviewed scientific journal articles and is an Associate Editor of *Environmental Science & Technology*. Pruden is the recipient of the Presidential Early Career Award in Science and Engineering, the Paul L. Busch Award for innovation in water research, the ReciPharm International Environmental Award, and is a fellow of the International Water Association. Pruden received her BS in Biological Sciences her PhD in Environmental Science at the University of Cincinnati.

Joan Rose, PhD, Michigan State University

Dr. Joan Rose is the Homer Nowlin Endowed Chair for Water Research at Michigan State University. She has made groundbreaking advances in understanding water quality and protecting public health for more than 20 years and has published over 300 articles. Rose is widely regarded as the world's foremost authority on *Cryptosporidium* and was the first person to present a method for detecting this pathogen in water supplies. She is a member of the National Academy of Engineering. Rose served as the Chair of the Science Advisory Board for the EPA's Drinking Water Committee for four years and serves on the Science Advisory Board for the Great Lakes and on the NWRI Expert Panel for the state of California on developing water recycling criteria for indirect potable reuse through surface water augmentation and determining the feasibility of developing criteria for direct potable reuse. Rose received a BS in Microbiology from the University of Arizona, an MS in Microbiology from the University of Wyoming, and a PhD in Microbiology from the University of Arizona.

Shane Snyder, PhD, Nanyang Technological University

Dr. Shane Snyder is a Professor and Executive Director at Nanyang Technological University in Singapore. His research has focused on the identification, fate, and health relevance of emerging water pollutants. Snyder and his teams have published over 100 peer-reviewed manuscripts and chapters on emerging contaminant analysis, treatment, and toxicology. He has been invited to testify before the US Senate about pharmaceuticals in water four times. Snyder has served two terms on the advisory committee to EPA's Endocrine Disruptor Screening Program and was an expert panel member for EPA's CCL3. He was a member of the National Academy of Science's committee on Water Reuse and served twice on the California Chemicals of Emerging Concern Expert Panel. At NTU Singapore, Dr. Snyder leads a team of over 300 faculty, staff, research fellows, and students to advance water and environmental research, including wastewater and solid waste management, recycling, and upcycling. Snyder received a BA in Chemistry from Thiel College and a PhD in Zoology and Environmental Toxicology from Michigan State University.

Jacqueline E. Taylor, REHS, MPA, LA County Department of Public Health (Retired)

Jacqueline Taylor, MPA, is a Registered Environmental Health Specialist with over 30 years of experience. She has managed and directed environmental health programs in one of the largest, most diverse, and progressive environmental health departments in the nation. Her work experience has involved policy development and regulatory oversight in food and housing protection, water and wastewater resource management, recreational water and beach monitoring, cross connections and water pollution control, land use planning, solid waste management, radiation management, lead poisoning prevention, staff development, and program planning. In addition to her professional career, Ms. Taylor has had hands-on volunteer experience in the field working to better the lives of those affected by environmental and natural disasters.

George Tchobanoglous, PhD, PE, University of California, Davis (Emeritus)

For more than 35 years, Dr. George Tchobanoglous taught courses on water and wastewater treatment and solid waste management at the University of California, Davis in the Department of Civil and Environmental Engineering. He has authored or coauthored more than 550 publications, including 23 textbooks and 8 engineering reference books. With coauthors, he has written extensively on water reuse, including the textbook Water Reuse: Issues, Technologies, and Applications; the report Direct Potable Reuse: A Path Forward; and the NWRI white paper Direct Potable Reuse: Benefits for Public Water Supplies, Agriculture, the Environment, and Energy Conservation. He is a member of the National Academy of Engineers and has an Honorary Doctor of Engineering from the Colorado School of Mines. In 2012, he received the first Excellence in Engineering Education Award from the American Academy of Environmental Engineers (AAEE) and AEESP. Tchobanoglous has a BS in Civil Engineering from the University of the Pacific, an MS in Sanitary Engineering from the University of California, Berkeley, and a PhD in Environmental Engineering from Stanford University.

Michael P. Wehner, MPA, Assistant General Manager, OCWD (Retired)

Mike Wehner, MPA, has almost 40 years of experience in water quality control and water resources management. He spent 20 years with the Orange County Health Care Agency and moved to the Orange County Water District (OCWD) in 1991. He managed the Water Quality and Technology Group, including Laboratory, Water Quality, Research and Development, and Health and Regulatory Affairs. He was involved in many aspects of OCWD's Groundwater Replenishment System, the nation's largest IPR project, including providing technical guidance on treatment and quality, as well as managing monitoring programs for the purification facility and receiving groundwater. He also managed OCWD's eight-year Santa Ana River Water Quality and Health Study, which evaluated the impact of using effluent-dominated river water for groundwater recharge. He received a Masters of Public Administration from California State University Long Beach and a BS in Biological Sciences from the University of California, Irvine.

Appendix 3 • Links to SWB/DDW DPR Expert Panel Meeting Recordings

The California State Water Resources Control Board Division of Drinking Water has held four public meetings with the Expert Panel. Links to all of the meeting agendas, PowerPoint presentations, and video recordings of the meetings are located at:

https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/direct_potable_reuse.html

Appendix 4 • Pathogen Technical Work Group Briefing, October 27, 2021

Appendix 5 • Pathogen Technical Work Group Briefing, January 26, 2022

Appendix 6 • Pathogen Technical Work Group Presentation, January 31, 2022