EXECUTIVE SUMMARY

California currently recycles treated wastewater at a volume of approximately 650,000 acre-feet of water per year, but has identified the potential to recycle an additional 1.5 million acre-feet in the future. To encourage the expanded use of recycled water in a state that is experiencing water shortages, the California State Water Resources Control Board (SWRCB) adopted a Recycled Water Policy in February 2009 intended to provide permitting clarity and direction for water reuse projects (California State Water Resources Control Board, 2009). A key challenge in promoting the expansion of water recycling for agricultural purposes, especially for the use of recycled water for food crop production, was addressing the perceived concern about whether recycled water produced in conformance with California's Water Recycling Criteria is protective of public health.

Recognizing that consideration of the exposure to microbial pathogens present in wastewater and their potential effects on human health is a significant concern, and that the regulatory requirements for recycling treated wastewater need to be based on best available science, the California Department of Public Health (CDPH) and SWRCB included a provision in the Recycled Water Policy to establish an expert Panel. The Panel's primary charge is to ***consider whether recycled water produced in conformance with California's Water Recycling Criteria are sufficiently protective of public health for agricultural food crop irrigation.***

Administered by the National Water Research Institute (NWRI), the NWRI Independent Advisory Panel for the Review of California's Water Recycling Criteria for Agricultural Irrigation includes nine nationally recognized experts in the fields of public health microbiology and virology, quantitative microbial risk assessment, public health infectious diseases and epidemiology, water reuse, food safety and hazard analysis, agricultural practices, irrigation management, emerging contaminants of concern (i.e., waterborne infectious agents), and water and wastewater treatment effectiveness. The Panel has over 150 years of combined experience investigating water reuse and potential public health issues. While the Panel was formed in 2008, it did not begin work until the spring of 2010. Over the past 2 years, the Panel held four meetings, a number of subcommittee meetings, and numerous conference calls. The Panel meetings included the opportunity for stakeholder input in clarifying the Panel's charge, exchange of information, dialog with the Panel, and consideration of comments from SWRCB and CDPH staff on this draft report, which was prepared by the Panel and provides the results from the deliberations.

The Panel was provided with a summary of CDPH concerns (Appendix 1-2). The Panel reviewed and discussed the CDPH summary and developed the following list of priority questions that it felt were within the Panel's charge. A brief response to each question is shown below. More detailed information is contained in Sections 3 and 4 of this report.

Question 1: How to characterize acceptable (safe) recycled water for irrigation?

Using a peer-reviewed quantitative microbial risk assessment (QMRA) model, the Panel considered and developed estimated median annualized risks of infection for the three agriculture water reuse scenarios and treatment processes shown in Table E-1 (See Section 3.0 for a detailed discussion). As shown, the QMRA results are based on conservative assumptions, including daily exposure and a 7-day environmental decay of pathogens prior to harvesting. The results of the QMRA indicate that annualized median risks of infection for full tertiary treatment (i.e., treatment that meets the requirements in the California Title 22 Water Recycling Criteria for Disinfected Tertiary Recycled Water) range from 10^{-8} to 10^{-4} (for human enteric viruses as estimated by enterovirus, *Cryptosporidium parvum* and *Giardia lamblia*, and *Escherichia coli* O157:H7, based on the assumptions noted in Table E.1, which includes daily exposure). Assuming that crops will be irrigated with recycled water only 8 percent of the time (approximately 30 days per year) by the year 2030[1] results in risks that are an order of magnitude lower (i.e., 10^{-9} to 10^{-5}). It is important to note that the estimated risks are for infection rather than disease, and that not all infections result in clinical disease (Pipes [1978] estimated that one of every 100 infections may result in disease).[2]

Table E.1 Scenarios for Agricultural Reuse, Treatment, and Conservative Exposure Assumptions

Scenario	Agricultural Use	Treatment	Conservative Exposure Assumptions
One (I)	Food crops (edible portion in contact with water)	Disinfected Tertiary	Average **daily** consumption of lettuce per body weight: 0.205 g/kg-day; Body weight: lognormal distribution with mean 61.4 and SD 13.4 kg; Volume of water on lettuce: zero-truncated normal distribution with mean 0.108 and SD 0.02 mL/g; 7-day environmental decay[a]
Two (II)	Orchards and Vineyards (no contact with edible portion of crops)	Undisinfected Secondary	0.1 mL/day, **assumes daily exposure and consumption;** 7-day environmental decay[a]
Three (III)	Food crops (edible portion above ground – no contact)	Disinfected Secondary, 2.2 MPN/100 mL	0.1 mL/day, **assumes daily exposure and consumption;** 7-day environmental decay[a]

a) Over a 7-day decay period, a mean 3.3-log reduction for enterovirus, 3-log reduction for *E. coli,* and 2-log reduction for *Giardia* and *Cryptosporidium* were assumed.

g/kg-day = grams per kilogram per day mL/g = milliliters per gram mL = milliliter kg = kilogram
MPN = most probable number SD = standard deviation mL/day = milliliters per day

Several sensitivity analyses were explored. Except where noted, all sensitivity analyses were performed for enterovirus with tertiary treatment and direct application to edible crops (see Scenario I).

---

[1] See Section 2.1.1 for a discussion on the 8-percent assumption (adjusts the daily exposure to approximately 30 days per year).
[2] In addition, Pipes et al. (1978) notes that not all infections result in disease, and that the transition to clinical disease depends on a number of factors, including the virulence of the pathogen.

- The first sensitivity analysis considered that not all exposures over the year are likely to be to crops irrigated with recycled water. As described in Section 2.1, projections suggest that recycled water may be applied to approximately 8 percent of crops by 2030. Adjusting the daily exposure rate by the 8-percent assumption (approximately 30 days of exposure) results in the adjusted annualized median risks for Scenario 1 that are approximately one order of magnitude lower (i.e., ranging from 10^{-5} to 10^{-9}) than the risks, assuming exposure to recycled water-irrigated crops every day.

- Second, a sensitivity analysis was performed on the numbers of days of environmental decay of pathogens (i.e., 7 versus 14 days) and an alternative decay rate (i.e., normal distributed k with a mean of 1.07 and an SD of 0.07 [zero truncated] as described by Petterson et al. [2001, 2002]) from Asano et al. (1992) of k=0.69 was considered. The risk results are highly sensitive to environmental decay assumptions, varying by 4 to 6 orders of magnitude, depending on the assumption used. The Panel assumed that 7 days of environmental decay was reasonable and appropriate based on practical experience and best professional judgment as opposed to a 14-day period. Thus, over a 7-day decay period, a mean 3.3-log reduction for enterovirus, 3-log reduction for *E. coli,* and 2-log reduction for *Giardia* and *Cryptosporidium* were assumed.

- Third, a sensitivity analysis was performed on the treatment efficacy. In this analysis, a single point estimate of log removal was specified to generate annualized risk. Risks vary across a wide range because a wide range of treatment efficacies were considered. Generally, each additional log removal results in approximately one order of magnitude lower annual risk.

- Finally, for Scenarios II and III, which consider applications of reclaimed water to non-edible portion of crops, an alternative exposure assumption that was one order of magnitude lower was considered (an ingestion volume of 0.01 milliliter per day [mL/day]). The annualized risk estimates, therefore, are approximately one order of magnitude lower risks than their higher exposure counterparts.

In summary, the sensitivity analyses suggest linear sensitivities to treatment efficacy (one order of magnitude risk per one log removal) and especially large sensitivities with respect to environmental decay assumptions (4 to 6 orders of magnitude in risk). The risk results are relatively insensitive to days of exposure (1.5 orders of magnitude). The Scenario II and III results are somewhat insensitive to exposure volumes assumed (one order of magnitude of risk for one order of magnitude lower volume).

The bottom line is that the median annualized risk estimates for infection are consistent with previous estimates relied on by CDPH to develop the Water Recycling Criteria[3] and, as discussed below, provided the Panel with additional evidence to confirm the conclusion that current agricultural practices that are consistent with the criteria do not measurably increase

---

[3] CDPH considers a 1 in 10,000 (i.e., $1x10^{-4}$) mean risk of infection to be an acceptable risk from exposure to treated wastewater effluent (CDPH, 2010).

public health risk, and that modifying the standards to make them more restrictive will not measurably improve public health.

Question 2: What is the basis/support for the current assumption that "essentially pathogen free" is comparable to a 1 in 10,000 annual risk of infection? Is this level of public health risk and the associated assumptions appropriate for agricultural irrigation associated exposures? If not, what are appropriate assumptions regarding an acceptable/tolerable public health risk?

Evaluating the adequacy of a particular treatment train requires a benchmark level (or set of criteria) that can be used for comparison. The selection of a benchmark level of acceptable or tolerable risk (or *de minimis* level) is a complicated process that involves evaluating technical, political, and social factors, which is outside of the Panel's charge. However, to provide input and guidance to CDPH on this subject, the Panel utilized a weight-of-evidence approach that considered available information on four key factors (See Section 3.6 for further discussion):

- Current regulatory examples of acceptable and/or tolerable risk.[4]
- CDPH historical background information and assumptions regarding public health risk associated with developing recycled water standards.
- Past and current QMRAs for recycled water.
- Comparison of estimated public health risk to U.S. diarrheal disease incidence rates.

Based on the weight-of-evidence, the Panel provides the following statements regarding two key questions:

1. Should CDPH develop an "acceptable" or "tolerable" risk metric for applications included in the Water Recycling Criteria? Based on this Panel's review and analysis, the Panel does not believe at this time that developing an acceptable or tolerable risk metric is warranted.

2. Is there any evidence that the current treatment-based requirements in the Water Recycling Criteria increase the risk to public health through the irrigation of food crops with recycled water? The Panel's review of the available weight-of-evidence, including past (Tanaka et al., 1998; Olivieri et al., 2007) and current (Section 3.0) QMRA results, confirms that the current agricultural practices consistent with the Water Recycling Criteria do not measurably increase public health risk, and that modifying the standards to make them more restrictive will not measurably improve public health.

Question 3: What is the basis for the current 5-log virus reduction criteria? Is the criterion still relevant? If not, how should it be modified (including potential indicator organism)?

---

[4] CDPH implementation of the Water Recycling Criteria is based on a goal that the treatment-based standards provide sufficient overall plant reliability to achieve the U.S. Environmental Protection Agency's (EPA's) Surface Water Treatment Rule (SWTR) (i.e., potable drinking water) acceptable risk goal of one infection per 10,000 people per year based on enteric viruses (or *de minimis* level).

and

Question 4: What is the basis for the 450 milligram-minutes per liter (mg-min/L) concentration × time (CT) chlorine disinfection criteria? Is this CT level appropriate and if not, how should it be modified?

1. Based on seeded polio virus studies on tertiary treatment using direct filtration (Pomona Virus Study [Sanitation Districts of Los Angeles County, 1977] and Monterey Wastewater Reclamation Study for Agriculture [Engineering-Science, 1987]) and other data from operational water reclamation facilities in California, the Panel concurs with the CDPH 1999 finding that – for irrigation of food crops eaten raw – requiring a CT of 450 mg-min/L for disinfected tertiary recycled water (or a 5-log inactivation/removal of poliovirus or MS2 coliphage[5] through filtration and disinfection) is appropriate. This is not meant to imply that alternative treatment technologies and/or different CTs would not ensure adequate health protection; however, studies would be needed to document that an equivalent level of health protection would be provided by the alternative treatment technologies or CTs (e.g., see Finding 2 below).

2. The CT requirement specified in the Water Recycling Criteria principally is based on the Pomona Virus Study, which used combined chlorine, a modal contact time of about 90 minutes, and seeding with Poliovirus I. It would be worthwhile for the water industry to commission a follow-up study to determine whether the use of free chlorine at different modal contact times would be able to achieve 5 logs of seeded virus removal at lower chlorine contact times, thus resulting in lower CT requirements.[6]

3. The Panel recognizes that drinking water regulations allow a lower CT to demonstrate 5 log of virus removal, but is of the opinion that it is <u>inappropriate</u> to use drinking water CT criteria for recycled water because recycled water is a more complex medium in terms of its microbial makeup (owing to its proximal wastewater origin) than drinking water, and a safety factor is needed for prudent added public health protection.

Question 5: How should multi-barrier treatment and effectiveness be defined? How should it be evaluated?

A simple approach to a multiple barrier is to provide a process train of multiple units that provides a high level of performance such that the treatment train can meet the overall removal goal even if the most effective single unit process fails. However, generally, this approach is not useful for most nonpotable uses of recycled water, since disinfection is the key step in the treatment of recycled water for such uses, and total failure of the disinfection process will almost always result in product water that does not meet microbial requirements. A better approach is to focus on the reliability and control of the disinfection process.

---

[5] Please note that achieving a 5-log reduction by relying on MS2 is not feasible based on available data (see Question 4 in Section 4.1). MS2 is more resistant to combined chlorine than poliovirus.

[6] It would be useful for CDPH to review the elements of such a study as described in the WateReuse Research Foundation (WRRF) report (WRF-03-01) by Darby et al., 2006.

Question 6: Is the current <2 nephelometric turbidity units (NTU) (average daily) turbidity criteria still a valid filtration performance standard? If not, how should it be modified?

1. The Panel agreed that the turbidity requirements specified in the Water Recycling Criteria for wastewater that has received media filtration are adequate.

2. While the Panel understands the rationale for the more restrictive turbidity requirements where membranes are used in place of media filters, the Panel noted that more information is required to document the need for the low turbidity requirements when membranes are used in place of media filters. For example, it would be important to find out whether membrane treatment that produces wastewater meeting a turbidity limit of 2 NTU indicates that more pathogens are present in the wastewater before disinfection than that for media filtration meeting the same turbidity limit.

Question 7: Should performance standards be used to define/characterize secondary treatment? If yes, how should they be described?

1. For the next revision of the Water Recycling Criteria, the Panel recommends that the term "oxidized wastewater" be replaced with "stabilized wastewater" and that numerical limits are connected to the term "stabilized wastewater." The U.S. Environmental Protection Agency (EPA) secondary treatment numerical limits would be logical values. "Stabilized" is a more inclusive and accurate term when considering emerging technologies and the goals of wastewater treatment. Newer technologies (e.g., low-pressure membrane treatment) will allow physical-chemical treatment of primary effluent and will also allow for anaerobic biological treatment. Both of these treatment approaches can have significant advantages over traditional aerobic biological treatment with respect to energy use and energy recovery from the residual solids. These emerging process approaches may eventually meet numerical limits for secondary treatment, but may not meet the current definition of oxidized wastewater. A change in terminology would allow for developing and future process trains to be more easily accepted into use if the effluents from these process trains meet specified water quality limits.

2. Until the recycling criteria are revised, the above-finding can be implemented by CDPH via use of Section 60320.5 (other methods of treatment) in the Water Recycling Criteria. This section states: "Methods of treatment other than those included in this chapter and their reliability features may be accepted if the applicant demonstrates to the satisfaction of the State Department of Health that the methods of treatment and reliability features will assure an equal degree of treatment and reliability."

Question 8: Are total coliforms still an appropriate indicator of overall disinfection performance? If not, how should it be modified?

The answer is a qualified yes. The use of coliforms as indicators of the sanitary quality of water has had a successful history for more than a century, with particular application to monitoring drinking water. The public health experience in the evaluation of the safety of wastewater effluents, especially in protecting water recreationists in direct contact with recycled water, has been positive. The use of recycled water for unrestricted food crop irrigation has less of a history, but experience to date has also been positive. A low level of total coliforms in treated effluents has proven to be an adequate indicator of the performance (reduction of microbial agents) by an entire treatment process. The ability of a wastewater treatment plant to consistently produce water that meets the total coliform standards has been the key to the protection of public health.

At this point in time, we have no practical and time-proven alternative to the coliform standard. Subsets of the total coliform group have been suggested as being more indicative of sanitary quality (i.e., fecal coliform and *E. coli,* for which recognized assay methods are available). The total coliforms are the most conservative indicator of plant performance, followed closely by fecal coliform and *E. coli,* in that order.

New indicator assay and identification methods are being developed but, thus far, they are not practical for routine monitoring, nor have they been shown to be superior to the coliform culture standard. The regulatory agencies should keep abreast of and carefully evaluate developments in this area.

Question 9: Do crops take up pathogenic viruses? If yes, is this route of exposure a public health concern for agriculture irrigation with recycled water?

The potential presence of human pathogens in recycled water and their uptake (internalization) into plant tissue via the root system, leaf stoma, etc. were raised as potential concerns. There is evidence that internalization may occur under laboratory conditions with exposure to a high concentration of pathogens. The most realistic scenario is the attachment of microbial pathogens to plant surfaces in such a way that processing sanitization or other intervention is less effective. This latter scenario is the probable mechanism of contamination associated with recent outbreaks (e.g., see a more detailed discussion under Question 9 in Section 4.1 and in Baert et al., 2011), none of which were associated with the use of recycled water for irrigation.

There are no definitive links to any outbreaks or sporadic illness associated with the irrigation of California produce with recycled wastewater, nor with recycled water used extensively in Florida for irrigation. Monterey County recycled wastewater used for irrigation of leafy greens and other produce is a local example of the use of recycled wastewater for an extended period without any known links to human illness.

Future Investigations

As part of the review of the Water Recycling Criteria, the Panel recommends that CDPH investigate addressing the following topics to refine and augment current criteria:

1. Because turbidity readings do not necessarily correlate with disinfection performance, it is recommended that CDPH should undertake a comprehensive study to assess the benefits of incorporating particle size and distribution as a performance measure for filters used for recycled water applications. Ultimately, it is envisioned that the turbidity requirement would be augmented with a requirement based on particle size distribution.

2. Because the use of free chlorine can offer significant advantages over the use of combined chlorine, it is recommended that CDPH undertake a comprehensive study of the required CT values based on free chlorine for wastewater treatment processes that nitrify completely. Ultimately, it is envisioned that the required CT values would be based on the wastewater treatment technology, process control, and process monitoring instrumentation. As part of developing the scope for this recommended investigation, CDPH should review the 2006 WateReuse Research Foundation document entitled, “Pathogen Removal and Inactivation in Reclamation Plants – Study Design” (Darby et al., 2006).

References

Asano, T., L.Y.C. Leong, M.G. Rigby, and R.H. Sakaji (1992). “Evaluation of the California Wastewater Reclamation Criteria Using Enteric Virus Monitoring Data.” *Water Sci. Technol*., 26:1513.

Baert, L., K. Mattison, F. Loisy-Hamon, J. Harlow, A. Martyres, B. Lebeau, A. Stals, E. Van Coillie, L. Herman, and M. Uyttendaele (2011). “Review: Norovirus Prevalence in Belgian, Canadian, and French Produce: A Threat to Human Health?” *Int. J. Food Microbiol.*, 151: 261-269.

California State Water Resources Control Board (2009). *Recycled Water Policy*. *Resolution No. 2009-0011*, Sacramento, California.

Darby, J., A. Olivieri, C. Tang, and A. Salveson (2006). *Pathogen Removal and Inactivation in Reclamation Plants – Study Design (WRF-03-001)*, WateReuse Research Foundation, Alexandria, Virginia.

Engineering-Science (1987). *Monterey Wastewater Reclamation Study for Agriculture: Final Report*. Prepared for the Monterey Regional Water Pollution Agency by Engineering-Science, Berkeley, California.

Olivieri, A.W., E. Seto, and J. Soller (2007). *Application of Microbial Risk Assessment Techniques to Estimate Risk Due to Exposure to Reclaimed Waters (WRF-04-001)*. WateReuse Research Foundation, Alexandria, Virginia.

Petterson, S. R., N. J. Ashbolt, et al. (2001). "Microbial risks from wastewater irrigation of salad crops: A screening-level risk assessment." *Water Environment Research*: 667-672.

Petterson, S. R., N. J. Ashbolt, et al. (2002). "Of: Microbial risks from wastewater irrigation of salad crops: A screening-level risk assessment." *Water Environment Research*: 411.

Pipes, W.O. (1978). *Water Quality and Health Significance of Bacterial Indicators of Pollution*, Drexel University, Philadelphia, Pennsylvania.

Sanitation Districts of Los Angeles County (1977). *Pomona Virus Study: Final Report*. Prepared by the Sanitation Districts of Los Angeles County for the California State Water Resources Control Board, Sacramento, California.

Tanaka, H.., T. Asano, E.D. Schroeder, and G. Tchobanoglous (1998). “Estimating the Safety of Wastewater Reclamation and Reuse Using Enteric Virus Monitoring Data.” *Water Environ. Res.*, 70(1): 39-51.