



Independent Science Advisory Panel Report No. 2

Review of Metropolitan Water District's Regional Recycled Water Program Advanced Purification Center Demonstration Project

**Based on the Independent Science Advisory Panel
Workshop No. 2 held December 4 and 5, 2019**

Prepared by

National Water Research Institute
Independent Science Advisory Panel

Prepared for

Metropolitan Water District of Southern California
700 N. Alameda St.
Los Angeles, CA 90012

Submitted

January 21, 2020



Disclaimer

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

About NWRI

A 501c3 nonprofit organization and California Joint Powers Authority (JPA), National Water Research Institute (NWRI) was founded in 1991 by a group of California water agencies in partnership with the Joan Irvine Smith and Athalie R. Clarke Foundation to promote the protection, maintenance, and restoration of water supplies and to protect public health and improve the environment. NWRI's member agencies 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.

For more information, please contact:

National Water Research Institute
18700 Ward Street
Fountain Valley, California 92708 USA
Phone: (714) 378-3278
www.nwri-usa.org
Kevin Hardy, Executive Director
Mary Collins, Communications Manager

Publication Number: NWRI-2020-01



Contents

Independent Science Advisory Panel Workshop No. 2.....	4
About the Regional Recycled Water Program.....	5
Advanced Purification Center Demonstration Project	6
Panel Process Administered by NWRI	6
Panel Findings and Recommendations	7
Pre-Workshop Review.....	8
Key Questions for the Panel.....	8
Appendix A Panel Member Biographies.....	16
Appendix B Agenda.....	20
Appendix C Meeting Attendees	24
Appendix D: Temperature and time dependence of log survival of <i>Cryptosporidium</i>	27
Appendix E: References	30
Appendix F: About NWRI Panels.....	32



RRWP Independent Science Advisory Panel Workshop No. 2

The National Water Research Institute (NWRI) is pleased to present this report on the findings and recommendations from Workshop No. 2 of the Independent Science Advisory Panel (Panel) for the Regional Recycled Water Program (RRWP), Advanced Purification Center Demonstration Project (Project). The Panel met on December 4 and 5, 2019, at the Joint Water Pollution Control Plant in Carson, California.

Objectives

The goals for Workshop No. 2 were to update the Panel on the Project and to solicit answers to key questions. Specifically, the meeting objectives were to:

- Update the Panel on general project activities.
- Describe the tertiary membrane bioreactor (MBR) test approach and obtain Panel feedback on microbiological method development and preliminary microbiological and pre-testing performance results.
- Present the secondary MBR test approach and obtain Panel feedback on analyses needed to validate the overall log reduction values for the treatment process.
- Solicit preliminary Panel feedback on the raw water augmentation concept.

The key questions that Metropolitan asked to Panel to respond to are:

- Question 1: What are the Panel's suggestions on the MBR testing progress, including microbiological method development and preliminary microbiological and pretesting performance results?
- Question 2: What analyses do the Panel suggest to validate overall log reduction values for the treatment process, with a focus on MBR treatment of primary effluent?
- Question 3: What preliminary guidance does the panel have regarding provision and achievement of log removal value (LRV) credits for downstream drinking and/or satellite water treatment plants (WTPs)?



About the Regional Recycled Water Program

The RRWP is a partnership of Metropolitan Water District of Southern California (Metropolitan) and the Sanitation Districts of Los Angeles County (LACSD). The partners are exploring the potential of a program to create a new water resource with regional benefit for Southern California. The RRWP would consist of an advanced water treatment (AWT) facility at the LACSD Joint Water Pollution Control Plant (JWPCP) in Carson, California, and a new regional conveyance system to beneficially reuse water that is currently discharged to the Pacific Ocean.

Metropolitan and LACSD envision this AWT facility would treat secondary effluent from the JWPCP and with AWT processes to purify the water for recharge in Los Angeles and Orange counties. In the future, the potential exists for the Project to provide a source of water for other indirect and direct potable uses. The RRWP would diversify the region's water resources and significantly contribute to long-term water supply targets outlined in Metropolitan's Integrated Resources Plan.

California remains a leader in water recycling for beneficial reuse. The RRWP would be designed to meet the water quality parameters of other successful indirect potable reuse (IPR) projects in California, including the Groundwater Replenishment System developed collaboratively by Orange County Water District and Orange County Sanitation District, and the Montebello Forebay Groundwater Recharge project operated in partnership with the Water Replenishment District, LA county Department of Public Works, and LACSD. The RRWP design would direct purified water through a new regional distribution system for delivery to Metropolitan's member agencies to meet regional groundwater replenishment needs. Groundwater basins currently being considered as users of the RRWP product water include West Coast Basin, Central Basin, Main San Gabriel Basin, and Orange County Basin.

In addition to giving Metropolitan a significant drought-resistant water supply, the RRWP would contribute to the LACSD's goal to maximize reuse of treated wastewater. If Metropolitan and LACSD move forward with the RRWP, the full-scale facilities would likely be implemented over multiple phases to a maximum build-out of up to 150 million gallons per day (mgd).



Advanced Purification Center Demonstration Project

The Project will provide critical input for the design of full-scale RRWP facilities, clarify capital and operational and maintenance costs for advanced treatment and, ultimately, acquire the necessary regulatory permits for a full-scale facility should the RRWP proceed. The Project builds upon a successful pilot study conducted by Metropolitan and LACSD between 2010 and 2012, evaluating two AWT process trains. Construction of the 0.5 mgd AWT demonstration plant, now known as the Regional Recycled Water Advanced Purification Center (RRWAPC) Demonstration Facility, was completed in 2019.

The Project enables the partners to test AWT processes to support regulatory acceptance of an advanced treatment train that includes an MBR, reverse osmosis, and advanced oxidation processes (AOP). It is noteworthy that this is the first potable reuse project in California that proposes an MBR as the core treatment process.

The partners have planned an initial 15-month testing period for the Demonstration Facility, and the RRWAPC will provide opportunities for public outreach aimed at obtaining public acceptance for the Project. The partners engaged NWRI in early 2018 to administer and facilitate the Independent Scientific Advisory Panel for this Project as required by Title 22. The Panel's charge is to review the scientific, technical, and regulatory aspects of the Project.

Panel Process Administered by NWRI

To ensure the success of Workshop No. 2, NWRI coordinated with the Project Planning Team, the Panel Chair, and Panel members. NWRI wanted to: (a) plan an effective process that met the expectations of Metropolitan-LACSD; (b) ensure good communication among Metropolitan-LACSD, the NWRI team, and the Panel; (c) focus the Panel's scope of review; and, (d) draft, review, and finalize the Key Questions to guide the Panel's consensus-based process for writing their Findings and Recommendations.

Panel Workshop No. 2 was held December 4 and 5, 2019, at the Joint Water Pollution Control Plant, 24501 S. Figueroa St. in Carson, California. The meeting was facilitated by Ed Means of Means Consulting, LLC, under contract to NWRI.



The following Panel members attended Workshop No. 2:

- Chair: Charles Haas, PhD, Expert in Microbiology, Drexel University
- Richard “Dick” Bull, PhD, Expert in Toxicology, MoBull Consulting
- Joseph Cotruvo, PhD, Expert in Chemistry, Joseph Cotruvo and Associates, LLC
- Thomas Harder, PG, PHG, Expert in Hydrogeology, Thomas Harder & Co.
- Nancy G. Love, PhD, PE, Expert in Wastewater Treatment Technology and Process, University of Michigan
- Adam Olivieri, DrPH, PE, Expert in Potable Reuse Permitting and Public Health, EOA, Inc.
- Vernon Snoeyink, PhD, Expert in Corrosion; University of Illinois
- Paul Westerhoff, PhD, PE, Expert in Water Treatment Technology and Process, Arizona State University

Dr. Nancy Love of University of Michigan is new to this Panel, and this is the first meeting she attended for the project. Short biographies for each Panel member are provided in **Appendix A**. The Agenda for Workshop No. 2 is included as **Appendix B** and a list of Workshop No. 2 attendees is presented in **Appendix C**. Information and references to support consideration of time/temperature inactivation of *Cryptosporidium* are in **Appendix D**, and other references identified by the Panel are listed in **Appendix E**. Background information about the NWRI Independent Science Advisory Panel process is included in **Appendix F**.

Panel Findings and Recommendations

These Findings and Recommendations address the Metropolitan–LACSD Key Questions and respond to the presentations provided by Metropolitan, LACSD, and their consultants.

In addition, the Panel was encouraged to provide input in any other areas that could strengthen the Project. The Panel’s feedback is organized as answers to the Key Questions along with their observations related to the scope of review.



Pre-Workshop Review

Before Workshop No. 2, the Panel received the following documents to review:

1. Demonstration Facility Testing and Monitoring Approach for Advanced Water Treatment of Primary Wastewater Effluent (Metropolitan/LACSD). Nov 2019.
2. RRWAPC Program Implementation and Delivery Board Workshop No. 1 Slides (Met/LACSD). Jul 2019.
3. RRWP Program Implementation and Delivery White Paper (Metropolitan). Jul 2019.
4. Framework for Regulating DPR in California (State Water Board). Aug 2019.
5. Regulatory Update Slides (Brian Bernados, DDW). Nov 2019.
6. Panel Workshop No. 1 Report (NWRI Panel). Sep 2018.
7. MBR National Validation Guidelines (Australian Water Recycling Centre of Excellence). Nov 2015.
8. MBR Validation Protocol (Waterval). Jun 2016.

Dr. Nancy Love received copies of past meeting review documents and Panel reports to acquaint her with past work on the project.

Key Questions for the Panel

Question 1: What are the Panel's suggestions on the MBR testing progress, including microbiological method development and preliminary microbiological and pretesting performance results?

1. The Panel supports the plan for influent on-line surrogate monitoring at the JWPCP to understand contaminant spikes as part of a multi-barrier approach. These on-line parameters can include oxidation reduction potential (ORP), pH, electrical conductivity (EC), temperature, turbidity, ammonium, and others. This information should be linked to monitoring the reverse osmosis (RO) product water quality as well (total organic carbon (TOC), nitrate, EC, etc.).
 - a. The goal of using RO product water monitoring with surrogates in support of establishing LRVs for microbial agents appears well embedded in the program.



- b. On-line physical/chemical monitoring of RO and final product water will also be used, but should be expanded to identify water quality characteristics that will guide further treatment or polishing of water that enters satellite plants.
- c. Monitoring TOC of RO product water could be an important tool for real-time detection of chemical spills that penetrate the RO membrane. “Spills” refers to industrial discharges within the sewershed, which pass through, at some level, primary and secondary treatment at the wastewater treatment plant. There are a number of reasons why detection spikes could occur, beyond spills in the sewershed. Therefore, spills are a subset of spikes and should be separate. Other reasons for spikes can be related to operational issues within the primary or secondary treatment processes.

The RO will limit these chemicals to low molecular weight, non-polar, and volatile chemicals. The on-line monitoring approach can also be used to help rapidly identify the source(s) of spills. If an anomaly is detected, this can trigger immediate, strategic sampling to capture the spill as it passes through the advanced purification center (APC) plant. Targeted chemical analysis of samples can help identify which permitted discharger is responsible. Once likely dischargers (those using the chemical(s) in bulk) are identified, appropriate monitors for such spills could be distributed within the sewershed to allow for detection and action closer to the source.

On-line TOC probes, such as those used by Orange County, can be used at this site. These sensors are sensitive in the 10s to 100s ppb range. After setting up the TOC and other sensors, the sensors detect anomalies by a deviation from normal operating baseline conditions. As part of critical control points, sensors must be integrated into the supervisory control and data acquisition (SCADA) system and anomaly detection software. New demonstration testing will provide opportunities to develop and train such software.

Using multi-component monitoring that detects anomalies in the upstream wastewater system is becoming more common. This process can be compared to TOC anomaly detection in permeate.

- 2. The Panel had several observations about nitrogen. It is important to understand the sources and dynamics of nitrogen loading into and through the JWPCP, and how problematic nitrogen species are produced in the MBR. Since ammonia drives design and operation of the MBR, continuously measuring MBR influent ammonia would help understand influent variability. Also, identification, characterization, and the fate of



industrial sources of organic nitrogen, which can inhibit nitrification, and other nitrification or denitrification inhibitors would be helpful. (Resources on typical levels of organic nitrogen found in the domestic fraction of wastewater include Pagilla et al. (2008), Urgun–Demirtas et al. (2008), Bronk et al. (2010), and Mesfioui et al. (2012). References on nitrification inhibitors include Hockenbury and Grady (1977), Kelly et al. (2004), and Nowak (1993).)

The Panel has several other observations:

- a. The cause of nitrite building up in the MBR should be clarified, and a plan should be developed to prevent nitrite buildup.
 - b. The Panel is interested in seeing the post–RO nitrogen information.
 - c. The Project can consider other sources of organic carbon to support denitrification, such as exogenous or internally generated acetic acid. Alcohols are often used, but acetate gives good kinetic performance; please consider the WRF report: <https://www.waterrf.org/research/projects/protocol-evaluate-alternative-external-carbon-sources-denitrification-full-scale> as well as this paper: <https://iwaponline.com/wst/article-abstract/60/10/2485/17721>
 - d. To speed up adaptation in the AWT bioreactors and keep the project on schedule, it is worth considering alternate seeding sources, for example, from a facility that nitrifies and denitrifies.
 - e. The mainstream anammox process has matured and may be a promising option.
 - f. Note that MBRs create smaller flocs than gravity clarifiers in suspended growth systems, making them more vulnerable to soluble inhibitors (Henriques, et al., 2005). The demonstration team should be aware of this.
3. Methods development.
- a. The Panel was impressed with the work staff has done on methods development and supports the development of a proposed pathogen/indicator suite to allow LRV determination.
 - b. The Project should develop criteria for rejecting analytical data, especially related to recovery data. The Panel would be interested in seeing the QA/QC program.
 - c. The Project should consider that seasonal variation in water quality (for example, due to wet weather and temperature variation) could affect valid LRV challenge testing. Appendix D contains reference information related to pathogen survival.



4. Pretesting results.

- a. The Panel commends the project team's coordination/cooperation on microbiological analyses. It will be important to understand the variability of source contributions in the sewershed, for example, wastewater from hospitals. The Panel would like to understand what the current thinking is about operational responsibility for stable water quality from JWPCP to the AWT.
- b. Secondary and tertiary MBR effluents are not the same. For example, fragrances and other volatile organic compounds (VOCs) are more likely to be present in primary effluent than in secondary effluent, which is exposed to extended air sparging during aeration. While not a public health concern, fragrances and other nonregulated VOCs can cause aesthetic issues (such as odor) that consumers can detect. Many VOCs are neutral organic molecules and can pass through RO membranes. Public perception is an important aspect of this project. On-line monitoring, as discussed in item 1, can help identify when problematic levels of these chemicals are present in the MBR effluent/RO influent.
- c. The Panel is interested in how Tier 3 of the Australian Three-Tier Concept for MBR removal of pathogens correlations will be developed.

Question 2: What analyses do the Panel suggest in order to validate overall log reduction values for the treatment process, with a focus on MBR treatment of primary effluent?

1. The Panel believes the current 2020 testing plan (four month/eight month split) appears reasonable. The plan for 2021 and secondary MBR appears to appropriately mimic the tertiary MBR sampling plan. All the documents assume denitrification is required. Denitrification is beneficial and adds important, multiple barriers that provide chemical and microbial control benefits. Denitrification also adds a very high cost to the capital and O&M of this project. However, RO can remove more than 75 percent of the nitrate and nitrite. The document should include a brief justification for why biological denitrification is a critical element in the design.
2. Analytical methods for *Giardia* and *Cryptosporidium* should mimic the State Water Board/WRF Grant-Direct Potable Reuse (DPR) Project 2 raw wastewater methods.
3. The Project should conduct LRV challenge testing on membranes from both vendors, under the same conditions, during the second phase of MBR testing. The question of whether LRV testing would need to be expanded to other potential full-scale, AWT-



qualified MBR vendors that were not installed or tested at the demonstration facility should be posed to the regulator.

4. Membranes are backwashed and cleaned to address possible biofouling (implying biofilm features). The Panel believes the Project should consider variation in degree of biofouling with distance from the vacuum header when identifying fibers to cut. A standard operating procedure should be developed for fiber severing.
5. LRV should be based on recovery-adjusted concentration. Consider using more frequent controls to estimate recovery. Recovery standards can run in parallel on every analytical run, so recovery efficiency would be measured for every run and every day. Some projects report recoveries and don't correct answers if recoveries are 90 percent or better. Recovery adjustment would provide a more accurate estimate of actual numbers in the environmental samples. Otherwise, there is the potential to underestimate risk from pathogens by creating false negatives. With time, recovery variability will help provide bounds of confidence around the repeatability of recovery.
6. The Project can consider the value of DNA sequencing to understand pathogens. This analysis may complement some of the pathogen culture work and help identify the most dominant microorganisms and genes that are present before and after key unit processes. This approach may also identify selected microbial taxa that provide beneficial information and can be analyzed more frequently by specific and more quantitative methods. Consideration can be given to sequencing only intracellular DNA, and to confirming the viability of potential microbial pathogens identified by DNA-based methods using culture-based methods. Relevant references include Stamps et al. (2018) and Papp et al. (2020).
7. The Panel supports following the Hazard Analysis and Critical Control Points (HACCP) framework. **Reliability** assurance is a critical issue. Simply adding LRVs is not an optimal way to address deviations. Failure Mode and Effects Analysis (FMEA), is another approach to reliability that involves looking at each component of a treatment train—such as how each process depends on the performance of other processes in the full system, including influent quality, the effect of the effluent quality of each process on downstream process performance, pumps, piping, analytical procedures, and monitoring requirements. It then considers what the effects of a deviation would be and how the adverse effects can be avoided and what to do in the event of a deviation. The detailed analysis is carried out by a group of experts knowledgeable in all aspects of a given system. The FMEA process facilitates decisions on the need for duplicate processes, influent and effluent monitoring



requirements, the need to keep critical spare parts on hand, the need for critical items to be researched, etc.

These analyses are a final design issue since they mainly pertain to the O&M manual and monitoring for maintaining operational control, recognizing that Metropolitan is essentially applying HACCP/FMEA in the preliminary design when pilot MBR/RO/AOP results are evaluated for the purpose of deciding whether or not to use granular activated carbon (GAC) after AOP.

8. The high-purity-oxygen activated sludge basin wastewater supply is inadequate to provide the desired flow for both the JWPCP and the AWT under some conditions. The Panel is interested in seeing proposed solutions to address this; for example, equalization, improved distribution of flow across multiple basins, etc.
9. The project team could more clearly articulate and justify the need for biological nitrification/denitrification. The Panel recommends that the project team state more clearly why ammonium ion rejection by reverse osmosis would not meet the nitrogen goal. Similarly, the use/need for second-pass RO should be discussed.
10. Secondary MBR options will impact sludge handling and should be understood (dewatering, sludge volumes, energy impacts, land application, etc.)

Question 3: What preliminary guidance does the panel have regarding provision and achievement of LRV credits for downstream drinking and/or satellite WTPs?

The Panel's initial reaction/guidance regarding raw water augmentation is based on limited information that was presented, including the current assumptions about a 10 percent blend of AWPf water with other source waters; however, the Panel does not anticipate that the logic applied here would be significantly different with a higher blend. The Panel assumes that the water leaving the AWT meets surface water augmentation (SWA) requirements. The Panel assumes the 40-mile pipeline provides an engineered buffer (for example, contact time and reaction time) and establishes a minimum hydraulic retention time in the pipeline that is necessary to provide reaction time to address significant treatment excursions. (Appendix D contains reference information regarding *Cryptosporidium* mortality as a function of time and temperature). Specific post-treatment goals will vary depending on whether the water is spread/injected or introduced ahead of a WTP. The Panel assumes the Project includes enhanced source control, additional treatment to address chemical peaks, and enhanced operations and monitoring. Given these assumptions:



1. Metropolitan should evaluate additional monitoring of the product water leaving the AWT and at the Junction Structure that would affect performance at the Weymouth WTP (for example, turbidity, TOC, conductivity, alkalinity, etc.) and establish critical control triggers. The monitoring should occur at the point where mixing has been complete, at the exit from the Junction Structure at the Weymouth WTP. Water that significantly exceeds those critical control triggers could be rerouted to spreading basins or injection facilities as an additional contingency (assuming the water meets IPR requirements for groundwater spreading/injection). If IPR requirements are not met, the water could be routed to flood control and wasted.
2. The effluent from the Junction Structure should be the sampling point for determining whether the blended water quality falls within the historical range for feedwaters that have been successfully treated under the Surface Water Treatment Rule (SWTR). The Panel believes that as long as the water quality of the blended sources (CRW/SPW/AWT product water measured at the Junction Structure) is within historical source water quality ranges (for example, turbidity, DOC, pH, alkalinity, temperature, EC, and LT2 requirements all statistically characterized) that has been successfully treated, the WTP should continue to receive LRV credits using typical SWTR requirements, such as finished water turbidity and CT.
3. The Panel has the following thoughts on a satellite process configuration:
 - a. The Panel would like to have access to the technical memo on satellite treatment.
 - b. Given the current design, and the limited information the Panel has, satellite treatment does not appear to be necessary for LRV credit for IPR projects, but additional treatment may be needed as noted below in item four.
 - c. Dechlorination will be needed before blending to manage disinfection byproduct (DBP) formation. Dechlorination is recommend at the point immediately before the AWT water blends with any untreated surface water that contains TOC. Otherwise, there is a risk of producing DBPs.
 - d. Potential introduction of the Los Angeles Department of Water and Power AWT water into the regional transmission system may have satellite treatment implications but there is insufficient information to confirm this at this time.
 - e. Satellite treatment for boron management may be required to meet the water quality objective of 0.5 milligram per liter for the Main San Gabriel Groundwater Basin. The current California requirement (0.5 mg/L). is quite stringent; both USEPA (6 mg/L) and World Health Organization (2.4 mg/L) are higher. There might be an opportunity to



discuss the issue with DDW to obviate the need and expense for supplemental treatment for boron.

- f. Post-RO GAC could be considered if source water risk assessment demonstrates the presence of certain chemicals in the feedwater.
4. Additional processes (ozone, biological activated carbon (BAC), microfiltration (MF)) added to the AWT should only be considered if currently planned processes are deemed insufficient to manage microbial or chemical risks. Full advanced treatment (FAT), is defined in CA Title 22, §60320.201, Advanced Treatment Criteria, (contained in the Groundwater Replenishment Regulations and 60320.302 of the Surface Water Augmentation regulations). FAT, although not mandatory for all potable reuse projects in California (for example, groundwater replenishment via surface spreading), is commonly employed and will, for the near term, be the main treatment train for DPR projects in California. FAT consists of high-pressure membrane filtration (such as reverse osmosis/RO) followed by advanced oxidation processes (AOP). In addition, RO is generally preceded by low-pressure membrane filtration, such as microfiltration or ultrafiltration.

Although FAT does an excellent job of removing organic contaminants of concern, typically low levels (< 0.5 mg/L) of total organic carbon persist in FAT product waters. It has been observed that larger compounds (MW > 200) and/or charged compounds are typically very well removed (>90 percent) by RO membranes (Drewes et al., 2006; Howe et al., 2019), and UV/AOP is an effective process to oxidize key contaminants, such as NDMA and 1,4-dioxane, and likely others that are not fully rejected by RO (Plumlee et al., 2008, Mestankova et al., 2016).

Short-duration chemical peaks have been observed in RO feed and RO permeate at the OCWD full-scale groundwater recharge facility (Olivieri et al., 2016) due to certain low-molecular-weight compounds that are not fully removed by FAT. These compounds were detected by an on-line TOC analyzer that continuously monitors the RO permeate quality.

When applied to some wastewater, some processes (such as ozonation) can produce disinfection byproducts (for example, NDMA, aldehydes) that must be managed, because they could pass through MF/RO. Some DBPs are biodegradable and an additional unit process following ozone may be considered if warranted by concentrations, regulations, and calculated risks. Ozone was successfully implemented at the Scottsdale Water campus, which is primarily domestic wastewater, and reduces both NDMA levels post-RO and reduces MF and RO fouling by wastewater organics.



Appendix A · Panel Member Biographies

Chair: Charles N. Haas, PhD, BCEEM, Professor of Environmental Engineering and Head, Department of Civil, Architectural and Environmental Engineering, Drexel University

Dr. Charles Haas has more than 45 years of experience conducting research in water treatment, risk assessment, environmental modeling and statistics, microbiology, and environmental health. He has led the Department of Civil, Architectural, and Environmental Engineering at Drexel University since 1991, and 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.

Richard J. Bull, PhD, MoBull Consulting, and Professor Emeritus, Pharmacology/Toxicology, Washington State University

Dr. Richard Bull has been involved in toxicological research for 48 years and has focused on human health effects of drinking water contaminants, including mechanisms of carcinogenesis of halogenated solvents and disinfectant byproducts including trihalomethanes, haloacetic acids and bromate. He has been recognized with two EPA Scientific Achievement Awards and the Distinguished Service Medal from the US Public Health Service. He is a Member of Consultations on the World Health Organization (WHO) Guidelines for Drinking Water Quality, serves on International Agency for Research on Cancer (IARC) Working Groups on the Evaluation of Carcinogenic Risks to Humans, and chaired the EPA Science Advisory Board's Drinking Water Committee. Bull is author or coauthor of more than 135 peer-reviewed publications, and has written reviews, books, and chapters relating to toxicology of drinking water contaminants. His most recent research has focused on mechanisms involved in the carcinogenic effects of disinfection byproducts. Bull holds a BS in Pharmacy from University of Washington and a PhD in Pharmacology from the School of Medicine at University of California, San Francisco.



Joseph A. Cotruvo, PhD, BCES, President, Joseph Cotruvo and Associates, LLC

Dr. Joe Cotruvo is president of Joseph Cotruvo & Associates, an environmental and public health consulting firm in Washington, DC, and a Research Professor in the Departments of Chemistry and Biochemistry, and Environmental Sciences, at the University of Toledo. Previously, he served as director of the Drinking Water Standards Division of the EPA Office of Drinking Water, where his organization developed the Drinking Water Health Advisory System and numerous National Drinking Water Quality Standards and Guidelines. He was also director of the EPA's Risk Assessment Division, and a former vice president for Environmental Health Sciences at NSF International. He is a member of WHO's Drinking Water Guidelines development committees, and he has developed monographs on Desalination Technology, Health and Environmental Impacts, Chlorination Chemistry in Foods Processing, Heterotrophic Plate Counts in Drinking Water Safety, Waterborne Zoonoses, and Drinking Water Quality and Contaminants Guidebook. He also led studies on bromate metabolism through the Water Research Foundation and on recycled water contaminants for the WaterReuse Foundation. He was chair of the Water Quality and Water Services Committee of the Board of Directors of the District of Columbia Water and Sewer Authority. He was chair of the WaterReuse Association National Regulatory Committee. He received a BS in Chemistry from the University of Toledo and a PhD in Physical Organic Chemistry from the Ohio State University. He is board certified by the American Academy of Environmental Engineers and Scientists and recipient of the AAEEES Science Award for 2019.

Thomas E. Harder, PG, CHG, Principal Hydrogeologist, Thomas Harder & Co.

Mr. Thomas Harder has more than 22 years of professional groundwater consulting experience. He has provided technical direction and management for large water resource projects in southern California, including the Chino Desalter Well Field Design and Construction, the West Coast Basin Barrier Project, and the Mojave Water Agency's Regional Recharge and Recovery Project. His expertise includes regional groundwater basin analysis, perennial (safe) yield, artificial recharge, groundwater management and models, contaminant hydrogeology, and wells. Harder holds a BS in Geology from California Polytechnic University, Pomona, and an MS in Geology with emphasis in Hydrogeology from California State University, Los Angeles. He is a registered geologist and hydrogeologist in California.



**Nancy G. Love, PhD, PE, BCEE, Borchardt and Glysson Collegiate Professor,
University of Michigan**

Dr. Nancy Love is the Borchardt and Glysson Collegiate Professor in the Department of Civil and Environmental Engineering at the University of Michigan. There, she directs the Love Research Group, which works at the interface of water, infrastructure, and public health in both domestic and global settings. They focus on assessing and advancing public and environmental health using chemical, biological, and analytical approaches applied to water systems using both physical experiments and computational models. The Love Research Group evaluates the fate of chemicals, pathogens, and contaminants of emerging concern in water with relevance to public health and the environment; uses technologies to sense and remove these constituents; and advances technologies that recover useful resources from water. Dr. Love received her BS and MS at the University of Illinois, Urbana, and her PhD is from Clemson University. She has also been recognized for her scholarship and leadership with the WEF, the Water Research Foundation, and the National Science Foundation.

Adam Olivieri, DrPH, PE, Principal/Founder, EOA, Inc.

Dr. Adam Olivier has more than 35 years of experience in the technical and regulatory aspects of water recycling, groundwater contamination by hazardous materials, water quality and public health risk assessments, water quality planning, wastewater facility planning, urban runoff management, and on-site waste treatment systems. He has gained this experience through a number of positions, including: Staff Engineer with the California Regional Water Quality Control Board (San Francisco Bay Region); Staff Specialist and Post-Doctoral Fellow with the School of Public Health at University of California, Berkeley; Project Manager/Researcher for the Public Health Institute; and as a Consulting Engineer, Dr. Olivieri is currently Vice President of EOA, Inc., in Oakland, California, where he manages a variety of projects, including serving as Santa Clara County Urban Runoff Program's Manager since 1998. He received a BS in Civil Engineering from University of Connecticut, an MS in Civil and Sanitary Engineering from University of Connecticut, and both an MPH and DrPH in Environmental Health Sciences from University of California, Berkeley.



Vernon Snoeyink, PhD, Professor Emeritus, Civil and Environmental Engineering, University of Illinois

Dr. Vernon Snoeyink's research has focused on drinking water quality control, including removal of organic and inorganic contaminants from water using adsorption systems, especially granular and powdered activated carbon systems coupled with membrane systems. His expertise includes mechanisms of formation and means to control water quality in distribution systems in response to reactions of iron, aluminum, and other inorganics. Snoeyink is a member of National Academy of Engineering, American Society of Civil Engineers (ASCE), American Water Works Association (AWWA), Association of Environmental Engineering and Science Professors (AEESP), and International Water Association. He served as President of AEESP and on the Editorial Advisory Board of AQUA. His awards include the AEESP Distinguished Lectureship, the Research Award from AWWA, the Warren A. Hall Medal from the University Council on Water Resources, the Samuel Arnold Greeley Award and the Simon Freese Award from ASCE, the Thomas Feng Distinguished Lectureship from University of Massachusetts, and the Tau Beta Pi Daniel C. Drucker Eminent Faculty Award from University of Illinois. He has also been recognized for excellence in teaching and advising. He holds a BS in Civil Engineering, an MS in Sanitary Engineering, and PhD in Water Resources Engineering from University of Michigan.

Paul K. Westerhoff, PhD, PE, BCEE, Professor, Sustainable Engineering/Built Environment, Arizona State University

Dr. Paul Westerhoff's research focuses on emerging contaminants, water treatment processes, and water quality, including: occurrence, characterization, and oxidation of natural organic matter; removal of oxo-anions from drinking water; algal metabolites and algal biotechnology; wastewater reuse; and nanotechnology and sensors. He was awarded the Editors' Choice Award for 2016 in Environmental Science: Water Research & Technology for the paper entitled *N-Nitrosamine Formation Kinetics in Wastewater Effluents and Surface Waters*. Westerhoff holds a BS in Civil Engineering from Lehigh University, an MS in Civil and Environmental Engineering from University of Massachusetts, Amherst, and a PhD in Civil, Architectural, and Environmental Engineering from University of Colorado at Boulder. He is a Registered Professional Engineer in Arizona.



Appendix B · Agenda



Independent Science Advisory Panel for Metropolitan Water District Regional Recycled Water Program

Workshop No. 2

December 4–5, 2019

Location

Administration Building, Multipurpose Room
Joint Water Pollution Control Plant
24501 S. Figueroa Street, Carson, CA 90745

Contacts

Kevin Hardy cell: 760.801.9111
Mary Collins cell: 206.380.1930
Ed Means cell: 949-439-9120
Natalie Roberts cell: 530-574-0287
NWRI Office: 714-378-3278

Meeting Objectives

- Update the NWRI Panel on general project activities
- Describe the tertiary MBR test approach and obtain Panel feedback on microbiological method development and preliminary microbiological and pre-testing performance results
- Present the secondary MBR test approach and obtain Panel feedback on analyses needed to validate the overall log reduction values for the treatment process
- Solicit preliminary Panel feedback on the raw water augmentation concept

Question to the Panel

1. What are the Panel's suggestions on the MBR testing progress, including microbiological method development and preliminary microbiological and pre-testing performance results?
2. What analyses do the Panel suggest in order to validate overall log reduction values for the treatment process, with a focus on MBR treatment of primary effluent?
3. What preliminary guidance does the panel have regarding provision and achievement of LRV credits for downstream drinking and/or satellite WTPs?



Day 1 • December 4

OPEN STAKEHOLDER WORKSHOP: includes Panel, project team, stakeholders, and NWRI

8:00 a.m.	Coffee and continental breakfast	
8:30 a.m.	Introductions, logistics, review meeting agenda and Panel charge for this workshop	Kevin Hardy and Ed Means, NWRI
9:00 a.m.	Regional Recycled Water Program Update	MWD
9:30 a.m.	Tertiary MBR Testing Approach: Presentations <ul style="list-style-type: none"> • Review of Testing and Monitoring Plan (25 mins) • Microbiological analytical method and results (15 mins) • Pre-testing performance results (20 mins) 	MWD and LACSD MWD and LACSD Trussell
10:30 a.m.	Break	
10:45 a.m.	Tertiary MBR Testing Approach: Q & A	MWD and LACSD
11:45 a.m.	Lunch/Panel photo	
12:30 p.m.	Secondary MBR Testing Approach: Presentations <ul style="list-style-type: none"> • Background: Industry developments on testing and validation for pathogen removal (10 min) • Proposed Secondary MBR Approach <ul style="list-style-type: none"> ○ Similarities/differences with tertiary MBR and overview of the approach/challenges (30 min) ○ Operational considerations for JWPCP (20 min) 	Carollo MWD and LACSD
1:30 p.m.	Secondary MBR Testing Approach: Q & A	
2:30 pm	Break	
2:45 p.m.	Tour of Advanced Purification Center Demo Facility	

CLOSED WORKING SESSION: Includes Panel and NWRI Staff

4:00 p.m.	Closed Panel-Only Working Session
5:00 p.m.	Adjourn



Day 2 • December 5

OPEN STAKEHOLDER WORKSHOP: includes Panel, project team, stakeholders, and NWRI

8:30 a.m. Future Raw Water Augmentation Opportunities MWD

CLOSED WORKING SESSION: Includes Panel and NWRI Staff

9:30 a.m. Panel-Only Working Session (North Conference Room)

12:00 p.m. Working Lunch

12:30 pm Continue Closed Panel Working Session

1:45 p.m. Panel Report Out Panel

2:45 p.m. Next Steps NWRI

3:00 p.m. Adjourn



Appendix C · Meeting Attendees

Panel Members

- Panel Chair: Charles Haas, PhD, BCEEM, Expert in Microbiology, Drexel University
- Richard Bull, PhD, Expert in Toxicology, MoBull Consulting
- Joseph Cotruvo, PhD, BCES, Expert in Chemistry, Joseph Cotruvo and Associates, LLC
- Thomas Harder; PG, PHG, Expert in Hydrogeology, Thomas Harder & Co.
- Nancy G. Love, PhD, PE, BCEE, Expert in Wastewater Treatment Technology and Process, University of Michigan
- Adam Olivieri, DrPH, PE, Expert in Potable Reuse Permitting and Public Health, EOA, Inc.
- Vernon Snoeyink, PhD, Expert in Corrosion; University of Illinois
- Paul Westerhoff, PhD, PE, BCEEM Expert in Water Treatment Technology and Process, Arizona State University

Panel Facilitator

Ed Means, Means Consulting

National Water Research Institute

- Kevin M. Hardy, Executive Director
- Mary Collins, Communications Manager
- Natalie Roberts, Coordinator

Metropolitan Water District

- Bruce Chalmers
- Mickey Chaudhuri
- Heather Collins
- George Di Giovanni
- Anne Johnson
- Gloria Lai-Bluml



- Joyce Lehman
- Sun Liang
- Paul Rochelle
- Alan Ronn
- Rupam Soni
- Mic Stewart
- Melinda Tan

Sanitation Districts of Los Angeles County

- Erika Bensch
- Huy Do
- Lysa Gaboudian
- Ann Heil
- Michael Liu
- Nikos Melitas
- Ken Rademacher
- Shawn Thompson
- Martha Tremblay
- Chris Wissman

State Water Resources Control Board

- Faraz Asad
- Brian Bernados
- Saeed Hafeznezami
- Sean McCarthy

Los Angeles Regional Water Quality Control Board

- Jeong-Hee Lim
- Cris Morris



- Steven Webb

Industry/Technical/Research Groups

- Jim Borchardt, Stantec
- Amos Branch, Carollo
- Zakir Hirani, Stantec
- Andy Salveson, Carollo
- Bryan Trussell, Trussell Technologies
- Shane Trussell, Trussell Technologies



Appendix D: Temperature and time dependence of log survival of *Cryptosporidium*

Effect of Temperature on Survival of Microorganisms

Some of these survival and infectivity factors include humidity/water, ambient temperature, exposure to solar radiation, water quality/composition, and presence of larger scavenger organisms. Numerous ambient water quality factors may also influence the survival or inactivation of microorganisms in water. These could include temperature, dissolved solids, chloride, pH, hardness, and turbidity. Temperature is a dominant factor with inactivation rates generally increasing as temperature increase.

Yates *et al* (1985, 1990) concluded that for all the viruses that they studied, temperature was the only factor significantly correlated with their inactivation rates. In other examples, Keswick *et al* (1982) reported inactivation rates ranging from 0.19 to 0.39 logs/day for six bacteria and viruses that they studied at temperatures between 3°C and 15°C. Studies have shown that inactivation rates of many bacteria are temperature dependent. Examples of temperature-dependent rates of inactivation in logs/day were *E. coli*, 0.033 (2°C) to 0.35 (25°C), and fecal streptococci, 0.04 (2°C) to 0.43 (20°C). *Cryptosporidium* have very long survival in water at low temperatures; as temperatures rise above 5°C, long-term survival begins to decline. (Fayer, 2004) Other studies discussed below have quantified the more rapid temperature dependent loss of infectivity at warmer ambient levels. Fujima *et al* (2002) found that *C. parvum* oocysts and a few others are more heat sensitive at pasteurization temperatures, being killed at 55°C in 15 to 30 seconds. Apart from these natural factors, disinfection treatment process Concentration x Time (CT) factors are highly temperature dependent and become smaller (more rapid inactivation at lower concentrations) as temperature increases.

EPA's analytical Method 1623 (EPA, 2005 at 11) for *Cryptosporidium* and *Giardia* states that "Samples that were not collected on the same day they were received (at the analytical laboratory), and that are received at >20°C ... must be rejected. After receipt, samples must be stored at the laboratory between 1°C and 10°C... until processed." This amply demonstrates the critical effect of temperature on survival of *Cryptosporidium* and *Giardia*.



Even so, the analytical method employed in EPA 1623 does not distinguish between viability and infectivity of the detected oocysts. (Schets, 2004; LeChevalier *et al*, 2003; Di Giovanni et al., 1999)

A variety of experimental methods have been developed to measure viability and infectivity of *Cryptosporidium* oocysts. Surrogate methods, such as vital dye exclusion assays used to determine oocyst viability versus infectivity will overestimate the number of infectious oocysts when applied to naturally contaminated water samples. (Schets et al, 2004) Cell culture infectivity declined “far more rapidly” than the surrogate methods they used. They concluded that using viability alone as a measure in risk assessment will overestimate the risk of infection with *Cryptosporidium*. Thus, detected cysts may or may not be viable, and a viable cyst may not be infectious to humans.

Survival (inactivation/die-off) of *Cryptosporidium* as a Function of Water Temperature

A study (King et al, 2005) contains a detailed quantitative investigation of the temperature-dependent inactivation (loss of infectivity) of *C. parvum* and it demonstrates that the rates of inactivation increase rapidly as the water temperature rises from 15°C to 37°C, and especially as temperatures exceed 20°C. Comparative studies were initially conducted in a raw water, autoclaved raw water, and MilliQ water, a highly purified laboratory water, and then more detailed studies were run in MilliQ water. Inactivation was followed both by cell culture–TaqMan PCR (Polymerase Chain Reaction) assay and by ATP (Adenosine Triphosphate) content, and both were well correlated. Inactivation at 15°C or lower was not significant over 10 weeks, whereas 4 logs of inactivation were achieved in 70 to 80 hours (three days) at 37°C, as shown in Table 1.

Table 1 *Cryptosporidium* Inactivation Results by Time (days) and Water Temperature

Temperature	1 log	2 log	3 log	4 log
15°C	-	-	-	-
20°C	56	70	-	-
25°C	28	35	49	56
30°C	4	7	10-15	15-20
37°C	<2	~2.5		<3

(from King et al, 2005)

These data are very consistent with earlier work conducted in both filter-sterilized and non-filter-sterilized river water samples. The numbers of infective oocysts stored at 21° to 23°C



decreased by 3.3 and 2.6 logs respectively over 12 weeks and no infective foci were detected in 14 weeks (Pokorny, 2002).

Citations on *Cryptosporidium* survival and treatment

Cornwell DA, 2003. Demonstrating *Cryptosporidium* Removal Using Spore Monitoring at Lime Softening Plants. J Am Water Works Assoc. 94:5 124-.

Fayer R, 2004. *Cryptosporidium*: A Waterborne Zoonotic Parasite. Veterinary Parasitology 126, 37-56.

Fujima T, et al, 2002. The Effect of Heating Against *Cryptosporidium* Oocysts. J. Vet. Med. Sci. , 199-200.

Keswick BH, Gerba CP, Secor SL, Cech I, 1982. Survival of Enteric Viruses and Indicator Organisms in Groundwater. J. Environ. Sci. Health, Part A: Environ. Sci. Eng, Toxic Hazard Subst. Control, 17, 903-912.

King JK, Keegan AR, Monis PT, Saint CP, 2005. Environmental Temperature Controls *Cryptosporidium* Oocyst Metabolic Rate and Associated Retention of Infectivity. Applied and Environmental Microbiology, 71:1 3848-3857.

Schets FM, Engels GB, During M, de Roda Husman AM, 2004. Detection of infectious *Cryptosporidium* oocysts by cell culture: applicability to environmental samples. RIVM report 330000005.

Yates MV, Gerba CP 1985. Factors Controlling the Survival of Viruses in Groundwater, Water Science and Technology, 17, 681-687.

Yates MV, Stetzenbach LD, Gerba CP, Sinclair, NA (1990) The effect of indigenous bacteria on virus survival in ground water. J Environ Sci Health Part A- Environ Sci Eng Toxicol 25(1):81-100.



Appendix E: References

Bronk, D.A., Q. Roberts, E. Canuel, P. Hatcher, R. Mesfioui, K.C. Filippino, M.R. Mulholland, and N.G. Love. (2010). Effluent organic nitrogen (EON): bioavailability, and photochemical and salinity release. *Environmental Science and Technology*, 44(15): 5830–5835.

Drewes, J.E., P. Xu, C. Bellona, M. Oedekoven, D. Macalady, G. Amy, T.–U. and Kim. (2006). Rejection of Wastewater–Derived Micropollutants in High–Pressure Membrane Applications Leading to Indirect Potable Reuse, Report WateReuse Foundation, Alexandria, Virginia.

Henriques, I.D.S., R.D. Holbrook, R.T. Kelly, and N.G. Love. (2005). The impact of floc size on respiration inhibition by soluble toxicants – a comparative investigation. *Water Research*, 39(12): 2559–2568.

Hockenbury, M. R. and C.P.L. Grady Jr. (1977). Inhibition of nitrification – effects of selected organic compounds. *Journal Water Pollution Control Federation*, 49(5): 768–777.

Howe, K., et al. (2019) Predicting Reverse Osmosis Removal of Unique Organics. Water Research Foundation, WRF Project Number: Reuse–14–19/4769.

Kelly, R. T., I.D.S. Henriques, N.G. Love. (2004). Chemical inhibition of nitrification in activated sludge. *Biotechnol. Bioeng.* 85(6): 683–694.

Mesfioui, R., N.G. Love, D.A. Bronk, M.R. Mulholland, and P.G. Hatcher. (2012). Reactivity and chemical characterization of effluent organic nitrogen from wastewater treatment plants determined by Fourier transform ion cyclotron resonance mass spectrometry. *Water Research*, 46(3):622–634. DOI:10.1016/j.watres.2011.11.022.

Mestankova, H., A.M. Parker, N. Bramaz, S. Canonica, K Schirmer, U von Guten, and K.G. Linden. (2016). Transformation of Contaminant Candidate List (CCL3) compounds during ozonation and advanced oxidation processes in drinking water: Assessment of biological effects. *Water Research*93: 110–120.

Nowak O., K. Svardal. (1993). Observations on the kinetics of nitrification under inhibiting conditions caused by industrial waste–water compounds. *Water Sci Technol* 28: 115–123.

Olivieri, A., J. Crook, M. Anderson, R. Bull, J. Drewes, C. Haas, W. Jukubowski, P. McCarty, K. Nelson, J. Rose, D. Sedlak, and T. Wade. (2016). EXPERT PANEL FINAL REPORT: Evaluation of



the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse, Report State Water Resources Control Board Division of Drinking Water, Sacramento, California.

Pagilla, K.R., K. Czerwionka, M. Urgan-Demirtas and J. Makinia. (2008). Nitrogen speciation in wastewater treatment plant influents and effluents—the US and Polish case studies. *Water Science & Technology*, 57(10): 1511–1517. doi: 10.2166/wst.2008.213.

Papp, K., D. Moser, and D Gerrity. (2020). Viral Surrogates in Potable Reuse Applications: Evaluation of a Membrane Bioreactor and Full Advanced Treatment, *J. Environ. Eng.*, 2020, 146(2): 04019103.

Plumlee, M., et al. (2008). N-nitrosodimethylamine (NDMA) removal by reverse osmosis and UV treatment and analysis via LC-MS/MS. *Water Research* 42: 347–355.

Stamps, B.W., M.B. Leddy, M.H. Plumlee, N.A. Hasan, R.R. Colwell, and J.R. Spear. (2018). Characterization of the Microbiome at the World’s Largest Potable Water Reuse Facility. *Frontiers in Microbiology*, V.9, Article 2435: 1–16.

Urgan-Demirtas, M., C. Sattayatewa and K. R. Pagilla. (2008). Bioavailability of dissolved organic nitrogen in effluents. *Water Env. Res.*, 80.



Appendix F: About NWRI Panels

About NWRI

For more than 20 years, NWRI—a science-based 501c3 nonprofit and joint powers authority located in Fountain Valley, California—has sponsored projects and programs to improve water quality, protect public health and the environment, and create safe, new sources of water. NWRI specializes in working with researchers across the country, such as laboratories at universities and water agencies. NWRI is guided by a Board of Directors representing water and wastewater agencies in Southern California.

Through NWRI's research program, NWRI supports multidisciplinary research projects with partners and collaborators relevant to treatment and monitoring, water quality assessment, knowledge management, and exploratory research. Altogether, NWRI's research program has produced over 300 publications and conference presentations.

NWRI also promotes better science and technology through extensive outreach and educational activities, which includes facilitating workshops and conferences and publishing White Papers, guidance manuals, and other informational material.

More information on NWRI can be found online at www.nwri-usa.org.

About NWRI Panels

NWRI specializes in facilitating Independent Expert Advisory Panels on behalf of water and wastewater utilities, as well as local, county, and state government agencies, to provide credible, objective review of scientific studies and projects in the water industry. NWRI Panels consist of academics, industry professionals, government representatives, and independent consultants who are experts in their fields.

The NWRI Panel process provides numerous benefits, including:

- Third-party review and evaluation.
- Scientific and technical advice by leading experts.
- Assistance with challenging scientific questions and regulatory requirements.



- Validation of proposed project objectives.
- Increased credibility with stakeholders and the public.
- Support of sound public-policy decisions.

NWRI has extensive experience in developing, coordinating, facilitating, and managing expert Panels. Efforts include:

- Selecting individuals with the appropriate expertise, background, credibility, and level of commitment to serve as Panel members.
- Facilitating hands-on Panel meetings held at the project's site or location.
- Providing written report(s) prepared by the Panel that focus on findings and recommendations of various technical, scientific, and public health aspects of the project or study.

NWRI has coordinated more than 40 Panels for water and wastewater utilities, city and state agencies, and consulting firms. Many of these Panels have focused on projects or policies involving groundwater replenishment and potable (indirect and direct) reuse. Specifically, these Panels have provided peer review of a wide range of scientific and technical areas related to water quality and monitoring, constituents of emerging concern, treatment technologies and operations, public health, hydrogeology, water reuse criteria and regulatory requirements, and outreach, among others.

More information about the NWRI Independent Advisory Panel Program can be found on the NWRI website at <http://nwri-usa.org/Panels.htm>.