California
Water Boards
Protecting California's Water

Recycled Water Research Needs in California: Monitoring and Treatment Performance for Constituents of Emerging Concern

October 27-28, 2015

Draft Workshop Summary

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DISCLAIMER

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Acronyms

AhR	Aryl hydrocarbon receptor
AOP	Advanced oxidation process
BAC	Biological activated carbon
BMP	Best Management Practice
CAS	Chemical Abstracts Service
CCP	Critical control point
CEC	Constituent of emerging concern
DPR	Direct potable reuse
EDSP	Endocrine Disruptor Screening Program
EEM	Excitation and emission matrix
ER	Estrogen receptor
FAT	Full advanced treatment
GC/MS	Gas chromatography mass spectrometry
HACCP	Hazard analysis and critical control point
HPLC-MS	High performance liquid chromatography mass spectrometry
IPR	Indirect potable reuse
MF	Microfiltration
MCHM	4-methylcyclohexanemethanol
NDMA	N-Nitrosodimethylamine
NTA	Non-targeted analysis
NWRI	National Water Research Institute
OECD	Organization for Economic Co-Operation and Development
QA/QC	Quality assurance/quality control
RO	Reverse osmosis
SAT	Soil aquifer treatment
SCCWRP	Southern California Coastal Water Research Project
SOP	Standard Operation Procedure
SRT	Solid residence time
TOC	Total organic carbon
ToxCast	USEPA's Toxicity Forecaster
UCMR	Unregulated Contaminant Monitoring Rule
USEPA	United States Environmental Protection Agency
UV	Ultraviolet disinfection
VOC	Volatile organic compound
WE&RF	Water Environment & Reuse Foundation

Executive Summary

The California State Water Resources Control Board (State Water Board) held a workshop on October 27-28, 2015 in Costa Mesa focused on the state of the science, monitoring techniques, and water treatment reliability for constituents of emerging concern (CECs) in recycled water. The goal of the workshop was to help the State Water Board identify knowledge gaps to identify and prioritize CEC monitoring and treatment activities that will ensure water supplies from recycled water, including potable reuse, are protective of public health and the environment.

The workshop included presentations from experts regarding monitoring and treatment performance for CECs, as well as breakout sessions intended to review and discuss the most important CEC research needs. At the conclusion of each day, a summary of recommendations based on the breakout discussions was developed by the participants. Below are general takeaway messages developed during the workshop. These messages reflect discussions at the workshop and are not intended to represent the views of all participants.

- Many participants expressed confidence that **current monitoring and treatment approaches for potable reuse, including for direct potable reuse (DPR), are protective of public health** for pathogens and chemicals, including CECs. They affirmed, however, that there are opportunities for research to improve monitoring and treatment systems to improve CEC removal, energy use, and cost of treatments.

- Research to **improve the list of indicators and surrogates** used for water quality monitoring was a high priority, particularly for treatment plant operations that rely on the use of indicators and surrogates as key measures of treatment performance. Specifically, participants were interested in the development of indicators and surrogates for CECs, unknown chemicals, and transformational products that can occur at different stages of treatment and that may have different chemical properties than known chemicals for which indicators and surrogates are presently targeted.

- **Development of bioanalytical techniques, specifically cell bioassays, or "bioscreening"** as a supplement to current targeted chemical-by-chemical monitoring and assessment was identified as a research priority because it provides a mechanism for assessing chemical mixtures, unknown chemicals including CECs, and difficult-to-analyze transformation products. However, bioscreening and a supporting interpretive framework will require considerable research investment before these techniques are ready for routine application. Participants agreed that initial application should be focused on using bioanalytical methods as screening tools for characterizing the effectiveness of treatment designs and operational controls.

- Participants placed priority on **developing non-targeted analytical methods for CECs**, suggesting that it was a promising tool for evaluating the broader range of chemicals present at various stages of the treatment process. They thought this technique was important because non-targeted approaches provide the ability to identify possible indicators and chemicals not detected by current targeted monitoring. Participants also agreed that non-targeted analysis is a necessary companion to bioscreening, which does not identify specific chemicals, but measures biological responses to the presence of chemicals.

- Research options for developing new treatment technologies were discussed, but were not rated a high priority by participants. Rather, participants felt that the greater research need is to **optimize and validate existing and emerging technologies**. Existing and emerging technologies should be standardized and evaluated for treatment effectiveness. It addition, these technologies should be optimized to be more cost and energy efficient. Participants suggested that research should be conducted to establish consistent guidelines for source control, operating procedures, maintenance, validation, and operator training.

After the workshop, two surveys – one of workshop attendees and one of non-attendees (i.e., other industry professionals) – were conducted to prioritize the research needs. The results of the two surveys differed from each other and from the input received during the workshop. These differences may be indicative of knowledge shared at the workshop, or of the variations in professional backgrounds represented by each survey. These differences between the survey results can aid in finding common research priorities across sectors, and in understanding the relative importance of specific research priorities for different constituencies. The workshop summary and the results of the surveys will be used by the State Water Board when developing priorities for funding recycled water research projects. In addition, ongoing collaborative efforts between workshop participants will continue to inform the State Water Board on emerging research, and aid in expanding the use of recycled water in California while protecting water quality and the environment.

Introduction

The State Water Board hosted a Recycled Water Research Workshop on October 27-28, 2015 to review and discuss the need for research on the monitoring and treatment of CECs in recycled water. At the workshop, scientists presented on the state of the science of monitoring techniques and water treatment reliability for CECs. The scientists engaged in discussions with members of the recycled water community to discuss data gaps, research needs, and funding priorities. A total of 55 attendees representing water districts, sanitation districts, utilities districts, joint power authorities, cities, trade associations, research groups, and state government participated in the workshop.

In hosting this workshop, the State Water Board collaborated with the National Water Research Institute (NWRI), Southern California Coastal Water Research Project (SCCWRP), and WateReuse Research Foundation [now Water Environment & Reuse Foundation (WE&RF)] to facilitate discussions on strategies for addressing CECs in recycled water.

At the workshop, each day began with technical presentations that were followed by breakout sessions to discuss data gaps and research priorities within a topical theme (e.g., chemical testing, bioanalytical screening). Meeting participants rotated through each of the topic-based facilitated breakout sessions. At the end of each day, breakout session facilitators summarized the session discussions, and meeting facilitators surveyed the meeting participants to develop recommendations on priority research needs.

The thematic topics on the first day of the workshop focused on monitoring for CECs. The technical presentations covered:

- Chemical testing
- Bioanalytical screening
- Applications of bioassays for recycled water
- Non-targeted analyses for CECs

The thematic topics on the second day of the workshop focused on treatment performance for CECs and the technical presentations covered:

- Source control, operations, maintenance, and training
- Assessment of CEC performance using current technologies
- Assessment of emerging and innovative technologies and monitoring strategies
- Reliability and resiliency of treatment systems for CECs

Summaries of the technical presentations and the associated breakout sessions discussions are provided below.

After the workshop, the State Water Board developed a survey to poll meeting attendees and recycled water professionals on the research priorities developed during the workshop. The list of 43 potential projects identified during the workshop (Table 1) was consolidated into 36 potential projects (Table 2) and used in the post-workshop surveys. The survey was administered twice: once to workshop attendees and once to non-attendees (i.e., other recycled water professionals). Full results of both surveys can be found in Appendix D, and are further discussed below.

Breakout Session Summaries

This section contains a summary of topics discussed at each of the eight afternoon breakout sessions. Each summary contains an overview of the topic area, a list of priority research projects, and additional topics discussed. The projects prioritized by each breakout session are summarized in Table 1.

Breakout Session 1-1: Chemical Testing

Group Leaders: Mike Wehner (Orange County Water District) and Melissa Meeker (WE&RF)

Overview

This research theme focuses on how chemical testing is being used currently and could be refined further to measure CECs in recycled water. CECs are defined as chemicals, compounds, constituents, and contaminants that are typically unregulated and/or in which there is increased interest due to emerging public attention. The actual health risks of many CECs are not known because toxicity data is limited or nonexistent. In fact, toxicity evaluations indicate that most CECs for which sufficient data are available are below levels of heath concern prior to advanced treatment. Notable exceptions include N-Nitrosodimethylamine (NDMA) and 1,4-dioxane. NDMA is made as a result of the treatment process, while 1,4-dioxane is used in industrial activities.

The list of CECs currently tested for is driven by a number of different factors, and not necessarily by specific risks to the public or environment. These factors include:

- California's 2013 Recycled Water Policy
- Notification levels in recycled water permits
- U.S. EPA's Unregulated Contaminant Monitoring Rule (UCMR) lists
- Compounds that are known to be resistant to degradation in the environment or through treatment
- Chemical indicators of wastewater
- Public and media interests
- Available testing methods

Analytical methods for CECs include, but are not limited to:

- Automated solid phase extraction of target CECs from water
- Gas chromatography coupled to tandem mass spectrometry (GC/MS/MS)
- High-performance liquid chromatography coupled to tandem mass spectrometry (HPLC-MS/MS)
- Liquid chromatography coupled to tandem mass spectrometry (LC-MS/MS)
- Ion chromatography coupled to tandem mass spectrometry (IC-MS/MS)
- Quantitation of target CECs by isotopic dilution

Although the monitoring and method sensitivity should be driven by health risks, monitoring is driven by the continuing sophistication of the analytical equipment and the laboratory's capability and testing protocols. This trend results in the ability to detect CECs at low levels, but the low detection limits are not necessarily based on thresholds established to protect public health.

A review of existing water quality data has shown that reverse osmosis (RO) is the main CEC barrier in full advanced treatment (FAT) processes. In addition, when placed downstream of RO, advanced oxidation processes (AOPs) are effective additional barriers for CECs. However, certain processes can lead to the reformation of NDMA during advanced treatment. As a result, the general practice is to couple ultraviolet (UV) disinfection with AOP to ensure NDMA occurrence is controlled. One critical concern is that RO membranes have specific expected lifespans, which results in less efficiency over time and the need to use higher pressures to treat the water. In addition, cleaning the membranes can cause some degradation, which may result in reduced efficacy of CEC removal.

Research Priorities

The workshop breakout groups rated the following three topics as high priorities for chemical testing:

- Toxicological Assessment of CECs.
- Identification of Indicator Compounds that Correlate with the Removal of CECs of Health Concern.
- Standardization of the Methods for Laboratory Analysis.

In addition to the three topical areas of priorities for chemical testing, the following projects were identified as research needs related to improve chemical testing for CECs:

- **Project #01: Evaluate CECs of Health Concern.** The list of CECs has grown exponentially as we learn more about their potential to exist in the environment, but less is known about the levels of CECs in drinking water that would correspond to a health concern (i.e., what are the safe or acceptable concentrations of specific CECs?). This project would use tools from WERF-05-005 on “Identifying Pharmaceuticals/Personal Care Products of the Highest Health Concern/Persistence through Water Treatments Used for Indirect Potable Reuse” to evaluate CECs of health concern in recycled water and drinking water.

- **Project #02: Recycled Water Impacts upon Aquatic Life.** Recent research has given us the tools to measure the removal of many contaminants and compounds over the course of the treatment process. This project would investigate how aquatic life could be affected by exposure to recycled water and its treatment products (e.g., RO concentrate), comparing different treatment types and end uses to determine relative risk.

- **Project #03: Health Risks Associated with Irrigating Crops with Recycled Water**. A common use for recycled water is to irrigate food crops. This project aims to determine if any risk to human health exists when recycled water is used on food crops, comparing possible exposure for crops (1) grown underground or aboveground and (2) crops processed before consumption.

- **Project #04: Indicator Monitoring.** It is important to identify a suite of indicators that correlate with the occurrence and removal of CECs that could be of human health concern in potable reuse treatment systems. Indicator monitoring will serve as a verification of the performance of the system. Although past studies and regulatory guidance have identified useful indicator compounds, new research has been conducted and the lists of indicator compounds (for different applications) should be updated. For treatment performance verification indicators, revisit Attachment A: Tables 1, 2, and 6 from the Recycled Water Policy to use new research/data to update and correlate groups of compounds to assess, based on different treatment processes to demonstrate the effectiveness of the processes.

- **Project #05: Standard Methods for CEC Analysis.** New analytical methods are continually being developed for chemicals, including CECs; however there is a need to standardize these methods. This project will evaluate candidate analytical methods for CECs that could become standard industry methods. The focus would be on the most efficient and cost-effective options to achieve the necessary detection limits. A round robin analysis will be conducted on the same set of CECs to determine the consistency and dependability of the methods in different laboratories.

- **Project #06: Transformation of CECs during Treatment.** One concern is the potential transformation of chemical constituents during the treatment process. This project would examine (1) the transformation potential for common CECs during treatment processes such as oxidation, biological activated carbon (BAC), advanced oxidation, and soil aquifer treatment (SAT) and (2) potential health risks of the transformation products.

- **Project #07: CEC Reporting Limits.** With increased monitoring capabilities and sensitivities of advanced instrumentation (i.e., resulting in lower and lower detection limits) comes increased concerns over the potential health risks of CECs at very low concentrations. Therefore, it is critical to determine how sensitive the detection limits must be to ensure the protection of public health, based on the range of safe (acceptable) concentrations of compounds in drinking water. This project would determine the required reporting limits for key CECs based on public health protection, which are independent of the limits of detection.

- **Project #08: Validation on Online Sensors for CECs.** Online sensors, which are an increasingly important part of the monitoring system for potable reuse, can be used to ensure the treatment process is operating within appropriate parameters. Research is needed to correlate CEC removal with monitoring data from online sensor systems (e.g., data for indicator and surrogate parameters). This project will validate sensors to be used for correlation with CEC detection and/or removal.

- **Project #09: Tools to Predict the Replacement of RO Membranes.** It is critical to keep a potable reuse treatment train running reliably, but it can be difficult to predict the appropriate time to replace RO membranes in advance of failure. This project will develop tools (e.g., using trend analysis or log removals of pathogens) to predict the need for the replacement of RO membranes before that need becomes acute.

- **Project #10: Optimizing Source Control for CEC Removal.** The source water for a wastewater collection system plays a large role in the contaminants present at the wastewater treatment facility, as well as the advanced treatments required to remove those contaminants. This project will look at the impact of source control on the presence of CECs and how source control programs can be optimized for CEC removal.

- **Project #11: CEC Monitoring Program Guidance.** This project will produce a guidance document for utilities and water agencies on the development of a voluntary CEC monitoring program. It will also include information (e.g., a state-of-the-science report) on the relationships between targeted chemical data and non-targeted chemicals analysis and bioscreening results, and how these data may be interpreted.

Additional Topics Discussed
In the case of the Groundwater Replenishment System at the Orange County Water District, the scope of CEC testing is guided by an independent advisory panel that includes a number of experts. It is essential to tailor monitoring requirements to treatment processes rather than the advanced treated water quality (which only increases the scope and cost of monitoring).

Breakout Session 1-2: Bioanalytical Screening

Group Leaders: Michael S. Denison (University of California, Davis) and Alvine C. Mehinto (Southern California Coastal Water Research Project)

Overview

This research theme focused on the use, optimization, and validation of cell bioassays. These techniques, which are typically used in the pharmaceutical industry and academic research, were proposed as new screening methods for monitoring and assessing CECs in recycled water. The presentation overview identified the following three areas of future research:

- Identification of relevant bioassays for recycled water.
- Improvement of the technology to increase sensitivity and speed and to reduce costs.
- Inter-laboratory validation studies.

Workshop participants saw merit in investigating the use of bioassays as a tool for assessing chemicals, including CECs, in recycled water. Bioassays present the advantage of integrating the response of known and unknown chemicals capable of activating specific receptors and receptor pathways. As such, they could be useful in assessing the presence of unknown CECs and transformation products.

There was overall agreement that bioassays should be considered as monitoring tools, but not as part of the regulations for recycled water. Among the possible applications discussed was the use of these technologies as a screening tool of chemicals with potential adverse effects in humans and aquatic life. Bioassays can represent molecular initiating events that may lead to adverse outcomes, such as impaired reproduction or immune deficiencies; therefore, the results could be used as a screening tool to assess the possible presence of CECs in recycled water that may pose risks to humans and aquatic organisms. Three of the four breakout groups also considered applying bioassays to the various treatment processes as a surrogate measure (similar to total organic carbon [TOC]) for CEC removal and treatment efficiency.

Although bioassays offer some advantages for assessing chemicals in recycled water, the technology is not sufficiently developed and standardized for routine monitoring applications at the present time. The main concern from the participants was the lack of an interpretation framework to explain positive results, which could lead to misunderstanding of the significance of the results. For example, the direct linkage between bioassay responses and adverse health effects in animals and humans has been established for only a few endpoints and certain classes of chemicals. It was also noted that only a few bioassays (i.e., estrogen receptors [ERs] and aryl hydrocarbon receptors [AhRs]) have been well defined, optimized and subjected to extensive validation studies. Therefore, participants suggested that bioassays considered for CEC monitoring should be subjected to standardization and inter-laboratory validation studies to determine their reliability and comparability of results.

Research Priorities

- **Project #12: Selection of Endpoints to Assess CECs in Recycled Water.** This research area was identified as a top research priority by all the breakout groups. Participants recognized that bioassay endpoints for specific adverse health effects may be used as screening for potential risk to humans and aquatic wildlife. They proposed to investigate the relationships between existing bioassay endpoints and adverse effects to identify and validate the most useful bioassays for assessing CECs in recycled water. The use of non-specific bioassays (e.g., acute toxicity, cell death) was also suggested as a surrogate measure of CEC removal efficiency. Participants discussed the need to conduct pilot studies that evaluate the usefulness of these bioassays in detecting known and unknown CECs in waters produced from various treatment technologies.

- **Project #13: Interpretation Framework for Bioassay Results.** This topic was also endorsed by the majority of workshop participants. The recommendation was that careful interpretation and extrapolation of bioassay results must be conducted to ensure that there is no misperception from the public regarding the quality of recycled water. Research projects applying bioassays to various treatment plants should be conducted to establish baseline responses. Linkage studies (i.e., analysis of the relationship between *in vitro* cell bioassay responses and biological/health effects) should also be performed and the results used to establish clear thresholds of concern and corresponding management actions. Bioassay monitoring results should be integrated with current (e.g., targeted chemical analysis, TOC) and new (e.g., non-targeted chemical analysis) CEC monitoring techniques.

- **Project #14: Standardization of Methods and Technology Transfer.** Workshop participants discussed the need for standardization with appropriate quality assurance/quality control (QA/QC) to ensure that bioassays are robust and results are sufficiently accurate and precise. With appropriate training, it is possible for water agencies and treatment facilities to establish and run bioassays in-house. The capital cost necessary to equip the laboratory to carry out cell bioassay analyses should not be significant for those with an existing microbiology laboratory. Therefore, workshops and training sessions should be set up for these laboratories, and part of the training should include round-robin blinded analyses to evaluate individual laboratory performance. Additionally, periodic inter-laboratory validation studies should be carried out to ensure that bioassay performance guidelines and standards are met.

- **Project #15: Multiplexing Cell Bioassay Technologies.** Projects funding the development of multiplexed bioassay endpoints (i.e., using cell lines containing receptors for several desired biological pathways) were suggested to reduce time and cost.

Other Topics Discussed

Participants also suggested that a white paper be produced that summarizes the following:

- Current availability of both academic and commercial cell bioassays.
- Current status and acceptance of bioassays for screening and/or biomonitoring purposes in Europe, Australia, and elsewhere.
- Description of protocols currently validated by national and/or international institutions (e.g., Organization for Economic Co-Operation and Development [OECD], U.S. Environmental Protection Agency [USEPA]).
- Application of bioassays in the U.S. (e.g., USEPA's Toxicity Forecaster [ToxCast] and Endocrine Disruptor Screening Program [EDSP]).

Breakout Session 1-3: Application of Bioassays for Recycled Water

Group Leaders: Shane Snyder (University of Arizona) and Jeff Mosher (National Water Research Institute)

Overview

This theme focused on how bioanalytical methods and bioassays have been and can be used for recycled water monitoring. Over the past 50 years, a wide variety of approaches has been developed and used to evaluate chemicals for potential human health effects. Early on, most efforts were directed at whole animal testing for a variety of endpoints and routes of administration, depending largely upon the expected route of exposure to the chemical; however, concerns regarding time, expense, new endpoints of concern, and animal welfare have driven the development of new approaches. One of the more commonly employed alternative screening techniques is *in vitro*, which uses cells or tissues in small containers. These methods can be used to prioritize those chemicals that require testing in animals and to define the dosing range for animal testing to reduce the number of animals sacrificed in toxicology studies.

Within the U.S. EPA, the National Computational Toxicology Program has spearheaded an investigation into the use of *in vitro* methods by developing massive databases of *in vivo* data against which various *in vitro* systems can be evaluated collectively for their predictive values based on what has been observed with chemicals that have known values. This data is generated through the U.S. EPA's ToxCast.

An interagency program also has been instituted, referred to as Tox21, to reduce reliance on *in vivo* methods by focusing on *in vitro* methods to research and test the toxicity of chemicals. In addition, there are specific programs established for validating assays, particularly in the area of endocrine disruptors. One goal is to develop approaches ranging from the application of bioassays for screening chemicals to the use of test results for hazard and risk assessment. It should be noted that, currently, the major use of these approaches is to screen chemicals for prioritization for further testing; however, *in vitro* bioassays have been approved by the U.S. EPA and in Europe for monitoring dioxin-like substances in environmental samples, including for compliance in Superfund remediation programs.

Current research shows the evolution in thinking since the establishment of these programs. Studies have suggested a more structured strategy for using these systems in a tiered framework to illustrate how *in vitro* methods can be used to:

- Eliminate chemicals that do not require *in vivo* testing.
- Confine animal testing to prioritized chemicals that require animal data for the purpose of risk assessment.

Essentially, this testing would be confined to chemicals for which there is substantial human exposure. Recent research in the water industry has described much of the bioassay work in detail and suggested a methodology for establishing effect-based target values; however, the rationales used for the development of these target values were not completely developed. In addition, the analytical methods required to extract and concentrate chemicals from water are not consistent among laboratories, and many chemicals may not be isolated at all using currently applied techniques.

The Australian Water Recycling Center of Excellence convened a workshop in Leura, New South Wales, Australia, on February 9-11, 2015, in which a number of academicians, regulatory agency representatives, scientists, and engineers participated. The workshop summary document recognized the following three primary uses for bioanalytical tools in recycled water assessment:

- Characterizing source water.
- Optimizing technology and monitoring treatment performance.
- Assessing the safety of product water for human health.

Workshop participants concluded that the first two items have been demonstrated, but much work is still needed to show that certain bioassays can be used as a basis of risk assessment. The goal of the workshop was to identify those steps that must be defined before *in vitro* bioassays can be used for estimating risk. Currently, there is discussion among participants as to whether these steps are, in fact, able to reach the workshop goal.

Research Priorities

Potential uses for bioassays in recycled water include: benchmarking different waters; assessing treatment performance; evaluating chemical isolation and concentration techniques;

and improving the monitoring and assessment framework for protecting human health. In addition, there is the potential for running recycled water samples though the full range of bioassays in the U.S. EPA's ToxCast program; however, this program currently focuses on individual chemicals as opposed to complex mixtures. Bioassays exist (e.g. ER, AhR) that are capable of benchmarking water quality.

Specific research priorities identified at the workshop include the following:

- **Project #16: Assess the Universe of Bioassays and Universe of Chemicals of Interest.** Based on the needs and applications associated with potable reuse, investigate and evaluate:
    - The range of bioassays (including health endpoints of concern). Develop a list of specific endpoints that is meaningful and part of a larger program to assess CECs in recycled water.
    - The range of chemicals or classes of chemicals of potential importance from a bioassay point-of-view. Determine a process and develop the drivers for determining a core set of bioassays for potable reuse.

- **Project #17: Develop Standard Operation Procedures (SOPs) for Sample Preparation and QA/QC for Bioassays for Use in Potable Reuse Applications.** For bioassays for use in potable reuse applications, develop standardized procedures addressing sample preparation and QA/QC. Develop, test, and revise specific standard operating procedures (SOPs). Classes of chemicals that are not likely to be isolated and concentrated (i.e., perchlorate and volatile organic compounds [VOCs]) should be identified and alternatives considered. Field validation is necessary.

- **Project #18: Benchmark Bioassay Techniques across and within Treatment Systems, and Compare to Other Water Sources.** Bioassays need to address specific endpoints and have the potential to provide meaningful information. For example, how can bioassays be part of the larger CEC monitoring program? Bioassays for potable reuse and non-potable applications would be needed. Develop an appropriate approach and test plan to (1) assess biological activity within potable reuse treatment systems, and (2) benchmark advanced treatment recycled water with other water sources. If a broad array of bioassays is used, a project of this size and scope will provide a more structured and broader base for identifying potential health hazards than a collection of individual assays. It must be a well-designed study with a sufficient number of systems to provide a meaningful benchmark for treatment.

- **Project #19: Develop a Work Flow Toolbox – What Do You Do with Bioassay Results (e.g., a "Hit" or "False Negative")?** Develop a "work flow" or set of "treatment, monitoring, or management" procedures or steps to follow when addressing the results of bioassays, including positives, false positives, and false negatives. QA/QC information would inform this exercise. These steps would address where in the treatment train bioassay results are relevant, whether bioactivity decreases or increases across unit treatment processes, and if said results would trigger other analyses, additional monitoring or other follow-on activities.

- **Project #20: Communication Plan for Bioassays.** A communication plan for internal and external outreach would address the needs associated with the interpretation of bioassay results, follow-up on results, screening versus compliance monitoring, public understanding, and regulatory requirements. Communicating the purpose and results of bioassays will be critical to the understanding, usefulness, and acceptance of these methods. Bioassays are new in the recycled water arena and will be potentially difficult and challenging to explain. Communication would take different forms based on the purpose, such as: (1) specific communication instructions for following up on results is needed for internal use; (2) communication requirements will differ where the analyses are used for screening purposes or compliance purposes; (3) communication with certain groups (i.e., regulators, the public) needs definition; and (4) a critical area is communicating the interpretation of results. A project is needed to develop procedures and best practices for this communication.

Additional Topics Discussed

In general, participants suggested that bioassays are currently suited for (1) characterizing or benchmarking source water and finished water and (2) assessing or optimizing technology and monitoring treatment performance. Participants agreed that bioassays should not be required for potable reuse projects at this time as they need to be developed further. It was suggested that research on bioassays could inform areas with knowledge gaps and possibly monitoring decisions in the future. In particular, participants were interested in research associated with the following general areas:

- Improving bioassay procedures (e.g., choice of endpoints, sample collection and preparation, QA/QC, classes of chemicals).
- Using bioassays for benchmarking (based on outcomes of the first item).
- Developing operating procedures for addressing bioassay results (from an operational point-of-view for a facility).
- Providing information on communicating bioassay results to various stakeholders.

In addition, the participants mentioned trying to collaborate with current U.S. EPA bioassay programs. For instance, a large array of bioassays could be used from one of the U.S. EPA's established programs to evaluate critical steps in advanced water treatment processes at different locations. In addition, the intent of bioassays and interpretation of results should be uniform and consistent across the industry. Lastly, participants suggested that an approach for assessing the safety of product water for human health could be improved and that the effort to develop such an approach with bioassays would be a significant task. It was suggested that the U.S. EPA could play a role in this area due to its increased interest in potable reuse.

Breakout Session 1-4: Non-Targeted Analysis

Group Leaders: Lee Ferguson (Duke University) and Keith Maruya (Southern California Coastal Water Research Project)

Overview

This research theme focused on potential applications for non-targeted chemical analysis (NTA) in identifying unknown chemicals in recycled water, including CECs. A mass-spectrometry-based fingerprinting and identification tool, NTA eschews a fixed list of known chemicals in favor of characterizing the broader universe of residual chemicals present, including transformation products formed during treatment. Reliable, robust treatment, monitoring, *and* diagnostic systems that together minimize the risk of exposure to potentially harmful CECs are essential for building confidence in recycled water. In conjunction with other monitoring tools, NTA provides the means to identify recalcitrant and/or indicator chemicals, which may vary both in space and time. Moreover, NTA can define the boundaries of chemical space occupied by CECs, resulting in the fingerprinting of source, treated, and product waters, including waste streams from recycled water facilities. NTA is at the cutting edge of diagnostic technology; however, significant challenges must be overcome to make it a robust, useful tool. The overview presentation identified the following three areas of potential research:

- Development of data management and analysis tools for NTA.
- Harmonization of approaches and products generated by independent research groups to identify the most problematic CECs.
- Useful applications of NTA in recycled water treatment research, as well as for investigative studies and routine monitoring of operational facilities.

Research Priorities

The concept of NTA for identifying unknown chemicals was well received by workshop participants as (1) a means to improve recycled water treatment design and (2) an important addition to the monitoring toolbox (particularly for addressing CEC fate during treatment and coupled with effects-directed tools, such as screening level bioassays). However, participants also agreed that NTA tools will require additional development before they are ready for routine application. Specific research projects including the following:

- **Project #21: Develop NTA Tools and Standardizing Protocols**. Whereas the instrumentation currently available for NTA is capable of discriminating among thousands of CECs in a single sample, information on CECs detectable in water matrices remains scarce (largely due to the lack of robust, standardized data management and analysis tools designed to deal with the copious amounts of multidimensional data generated by NTA). As more groups embrace and develop NTA as a diagnostic tool, it will be critical to harmonize strategies and standardize methods, including data analysis, to realize its full potential; therefore, efforts to develop and standardize end-to-end NTA protocols focused on addressing recycled water issues was recognized as the critical first step toward applying NTA as a research tool and, eventually, for more routine diagnosis in operational recycled water facilities. Participants strongly endorsed this topic as the highest research priority in this category.

- **Project #22: Identify Transformation Products and Other Unknowns.** Participants agreed that the largest, most diverse, and potentially most problematic group of unknown CECs are transformation products produced during treatment (e.g., by AOPs), which are missed by conventional targeted monitoring methods. Participants felt that NTA could be developed to identify transformation products at different stages of treatment, including the analysis of reject from RO membranes (i.e., RO concentrate). The latter option would serve as a worst-case scenario for ambient exposure and would form the basis of a comprehensive library of transformation products and other CECs to inform other facets of recycled water treatment, including the research and development of alternative treatment processes.

- **Project #23: Characterize Source Water Quality**. Many participants expressed concern over the treatability of recycled water in the face of changing source water quality, both over time and across geographies. The groups recognized the potential for NTA to assess changing source water quality, taking advantage of its fingerprinting capability. Source water fingerprints generated by NTA could be compared across treatment facilities and at different time scales to help determine if treatment design and operations are sufficiently robust for variations in source water quality. NTA could also serve as a safety net against unanticipated contaminants. Participants agreed that NTA would make a useful early warning system when used in conjunction with other monitoring tools (i.e., targeted analysis, bioanalytical screening assays).

- **Project #24: Update Indicator Lists for Targeted Monitoring.** The success and efficiency of targeted monitoring relies on indicator chemicals that best mimic the fate of larger groups of residual chemicals known to occur in recycled water. Current indicators of wastewater (e.g., carbamazepine, sucralose) may be phased out and/or replaced by newer generation products, while alternative treatment processes are being validated and incorporated into treatment train. Therefore, a need exists to periodically update the lists of surrogates used to validate treatment designs and to optimize process control measures. With its ability to provide chemical identifications and fingerprints, NTA could be applied to inform the selection of appropriate indicators, including transformation product candidates, more efficiently than currently available identification methods.

Additional Topics Discussed

The practicality of applying NTA for frequent and/or more routine monitoring purposes was raised. What is the anticipated cost per sample? What equipment and facilities are needed to outfit a laboratory for NTA? Participants discussed the appropriate scale and timing of NTA application, highlighting in particular one effort where funding was dedicated to carry out pilot monitoring of water quality along the Rhine River, which is the drinking water source for a large population in Europe. It was noted that although NTA, as a new and relatively specialized method, is not yet widely practiced for water quality monitoring due in part to prohibitive cost and time constraints, future research investment and technology development could make it more accessible. A smaller group of participants envisioned NTA being applied to a broader scope of recycled water issues (e.g., as a diagnostic tool to investigate the effect of recycled water waste streams on non-human receptors and as a means to characterize the quality of captured stormwater as a recycled water source). Source control investigation was also offered as a potential application (i.e., the capability of NTA to track and identify sources of CECs coming from discrete sources within a collection system).

Breakout Session 2-1: Source Control, Operations, Maintenance, and Training for Direct Potable Reuse

Group Leaders: Ben Stanford (Hazen and Sawyer) and Claire Waggoner (State Water Resources Control Board)

Overview

As of June 23, 2015, a compound to treat leukemia became the 100-millionth registered substance in the Chemical Abstracts Service (CAS) Registry. Seventy-five million chemicals have been added in the past 10 years alone. The number and frequency of chemicals introduced every year creates an insurmountable challenge to characterize each compound and assess toxicity, let alone understand chemical fate and transport through wastewater treatment systems and advanced water treatment systems. One strategy to address the issue is to initially focus efforts on high-production volume chemicals and CECs; however, this strategy could present a serious risk to human health since some of the CECs (e.g., 4-methylcyclohexanemethanol [MCHM] and 1,4-dioxane) are not on those lists and have limited removal through advanced treatment systems and existing drinking water systems. The presence and persistence of chemicals creates the need for a tool to assess and manage the risks associated with the chemicals while being flexible enough to incorporate the assessment and management of new risks as they are identified.

The hazard analysis and critical control point (HACCP) framework can be an integral part of planning and operating direct potable reuse (DPR) facilities without being a burden from a regulatory or certification standpoint. The focus of HACCP is on developing a risk assessment team (or HACCP team) whose job it is to collaboratively:

- Determine water quality goals.
- Assess inherent risk from source water and production inputs (i.e., chemicals added during treatment).
- Challenge assumptions around selected treatment processes to determine if a given process train is likely to produce water quality that meets goals.
- Assess (test) the ability of single and combined processes to meet water quality goals.
- Determine monitoring needs, operational plans, and response procedures required to produce water suitable for potable reuse.

When applied properly, HACCP provides a framework for ensuring that the water being produced from a DPR facility is safe and ready for further drinking water treatment or direct blending into a distribution system rather than waiting for end-of-pipe testing to provide a moment-in-time snapshot of the quality of a given sample of water.

The HACCP framework includes operations, maintenance, and training that could be used to establish a DPR certification. However, operations staff and management teams will need additional training in handling DPR treatment processes and integrating HACCP into operations.

While there are a number of parallel efforts to develop training manuals and curricula for operators, there is still a need for standardizing training and training materials to ensure that operators have sufficient knowledge and skills to be certified to operate advanced water treatment systems and respond to excursions. Operator certification programs could be tailored to accommodate facility-specific needs such as source water risks and advanced water treatment technology use. Alternatively, the training program could include all types of source water risks and advanced water treatment systems.

Single event excursions in advanced water treatment systems are not a major cause of concern for risks to human health from a CEC exposure standpoint because CECs typically pose a risk to human health after chronic exposure and are generally well removed by advanced water treatment processes; however, it is critical for the success of a DPR system that adequate systems are in place to monitor process (barrier) performance for more relevant health risks, such as pathogens and regulated contaminants. Monitor maintenance, calibration, and validation are key aspects of a HACCP program.

- When considering process monitors, redundant monitors and monitoring of multiple process parameters provides confidence that we do not “fail to notice failure.” It is important that adequate systems are in place to identify failure, respond to non-conformance, and fix the problem.

- When failures do occur, it is not likely from the entire process failing, but rather from components within the process failing. For example, an RO membrane system would have many racks of RO membrane vessels running in parallel, so the failure of one would simply cause the shutdown of that unit, not of the entire process train. The result is that production can still be maintained at the same time as public health protection.

- It is important to train operations teams on how to use the equipment. We need not only technical people to train the teams, but also educators who can assist with impacting multiple types of learners from diverse educational backgrounds.

Research Priorities

- **Project #25: Assess How the Quality of Secondary Treated Effluent Impacts the Selection of the Type and Level of Treatment Needed to Produce Recycled Water for Potable Reuse Applications.** The initial step in this project would be to characterize the quality of a wide range of secondary treated effluent samples, specifically related to pathogen and chemical occurrence. The second part of the project would be to identify the type and level of treatment, based on the quality of secondary treated effluent, required to produce recycled water that meets drinking water quality standards.

- **Project #26: Develop a Guidance Manual for Implementing the HACCP Framework for Assessing and Managing the Risk of Contaminants in Recycled Water.** Assess and manage the risk associated with CECs and other chemical and microbial contaminants during treatment that takes into account the source of the water and combination of individual processes selected for use at the advanced water treatment system. Develop a "how-to manual" for implementing a HACCP management system to assess and manage the risk of CECs in recycled water on a site-specific basis.

- **Project #27: Develop Training Manuals and Curricula for Operators within the DPR Context.** Conduct a review of critical information for training recycled water facility operators and develop training manuals and curricula. The organization that develops the training materials and curricula would continue to update and maintain these materials.

- **Project #28: Develop Reliable Sensors to Alert Operators of Treatment Excursions.** Sensors should be developed for use at the interface of the wastewater treatment plant and advanced water treatment facility to inform operators of events that could impact the quality of advanced treatment product water. The sensors could also be used to alert operators to issues with upstream treatment performance or events that may have occurred in the collection system that could impact water quality.

Additional Topics Discussed

Participants consistently raised the issue that there is a need to improve communication within the recycled water community regarding source control operations, maintenance, and training for recycled water for DPR applications. There are numerous efforts running in parallel to address issues related to source control, maintenance, and training; however, the information from these efforts is not being shared effectively or efficiently. The industry would benefit from improving communications between agencies producing source water for recycled water facilities and recycled water producers, particularly regarding source control.

There is a need to develop a communication plan that would include multi-agency topic-specific workshops (e.g., source control, training) where members of the recycled water community would share information and discuss means to move the topic forward and communicate information regarding the topic. This information-sharing process will lead to a consistent flow of information and prevent duplicative research efforts. One of the specific projects should be to investigate successful source control programs and identify why they are effective. The project would include strategies for collecting information on industrial sources and pretreatment requirements.

In addition to improving communication, participants identified a need to develop guidance for asset management (e.g., RO membranes, UV bulbs). Treatment performance is highly dependent on the quality and condition of assets; therefore, it is important to be able to identify when to replace assets to ensure treatment systems are operating as intended. Manufacturers provide some guidance for the maintenance and replacement of assets, but the degradation rate of assets is highly dependent on the quality and volume of water going through the system. There is a need to develop a guidance document for how to assess the end of asset life, when to replace the asset, and calibration and maintenance protocols for equipment, including equipment performance reliability.

Breakout Session 2-2: Assessing CEC Performance of Currently Used Technologies

Group Leaders: Jeff Mosher (National Water Research Institute), Andy Salveson (Carollo Engineers), and Melissa Meeker (WateReuse)

Overview

During the workshop presentation on assessing CEC performance, a summary was provided of current treatment technologies for potable reuse and their performance in the control of chemicals, including CECs. Based on studies at current potable water reuse facilities and research conducted by water research organizations, a growing database of information exists on the identification and characterization of CECs in wastewater effluents and recycled water and the removal or control of CECs through currently used treatment processes and treatment trains. As technologies evolve and new chemicals are used, this extensive research database on water quality and treatment performance of CECs should be updated.

Current analytical methods exist for identifying a wide range of CECs in wastewater and recycled water, such as:

- Pharmaceuticals.
- Potential endocrine disrupting compounds.
- Ingredients in personal care products.
- Hormones.
- Polyflorinated chemicals.
- Nitrosamines, including NDMA.
- Trihalomethanes and haloacetic acids.
- 1,4-dioxane.
- And many others.

Current potable water reuse facilities and numerous research studies have verified the removal of these constituents in wastewater, advanced water treatment processes, and SAT (spreading and percolation of treated water through a natural process).

Treatment requirements for existing regulations provide specific control for trace organic compounds, including CECs. Wastewater treatment (i.e., biological treatment) has been shown to reduce CECs by varying degrees. Many CECs are reduced considerably though biotransformation or by sorption; however, some recalcitrant CECs may have little to no removal. Removal during wastewater treatment is affected by solid residence time (SRT) and other factors. As an example, the SRT needed for 80-percent removal can range from less than 2 days for some CECs to more than 30 days for others. According to available studies, CEC removal through wastewater treatment plants can be reasonably predicted based on chemical characteristics and operational configurations of the secondary treatment processes.

Advanced water treatment technologies are specifically required to remove trace organic chemicals for potable water reuse applications. These advanced technologies can be membranes, advanced oxidation, carbon based systems, and natural systems such as biofiltration or SAT, among other options.

The performance of advanced water treatment technologies for potable water reuse (i.e., FAT, including RO and AOP) has been well documented for known CECs. Except for a handful of recalcitrant compounds, RO has been shown to provide several log reductions for CECs. RO works by forcing water through a semi-permeable barrier (i.e., membrane) and separating the trace organics and salts into a reject stream. AOPs, such as UV with hydrogen peroxide to form highly oxidative hydroxyl radicals, provide final treatment of CECs by oxidizing many of the remaining chemicals and providing photolysis of other chemicals. As examples, NDMA has been widely shown to be reduced by UV photolysis, and 1-4-dioxane reduced by advanced oxidation.

Verifying the treatment performance for FAT and the removal of CECs is assessed through the use of indicators and critical control points (CCPs). A CCP is a location in a treatment train where there is meaningful opportunity to demonstrate risk reduction or, in this case, the reduction or removal of CECs. Specific CCPs for CECs include RO and AOP. For each CCP, a specific monitoring technique is employed to assess treatment performance. Ideally, this technique is both accurate and precise, although conservative and precise techniques are also useful. For RO, online monitoring of TOC (before and after RO) provides a measure of treatment performance (i.e., the reduction in TOC across RO is a conservative and precise indicator of pathogen removal). In the future, more sensitive techniques for RO performance may be further developed (e.g., the use of fluorescent dye removal by RO, which is both precise and accurate). For UV photolysis, total chlorine destruction could be a CCP for NDMA removal. For AOPs that use UV and sodium hypochlorite or UV with hydrogen peroxide, total and/or free chlorine weighted dose or hydrogen peroxide weighted dose can be a CCP for 1,4-dioxane destruction.

More work is encouraged to better correlate online indicators with CEC removal through RO, which can be done through extensive monitoring and challenge studies, including failure analysis. New trends suggest good online indicators for CEC removal by AOP. Lastly, further work is needed to define the impact of water quality variables on RO performance and AOP.

Regarding unknown CECs, it is expected that the removal of known CECs through FAT indicates the removal of many, if not most, of the unknown CECs since removal is expected to be similar by chemical classes. TOC, an indicator of organic chemicals, shows a large removal across RO, yet some CECs remain in RO permeate. Continued investigation is warranted of what levels of TOC in finished water are necessary to protect public health, including better chemical characterization of the TOC after RO and after RO/AOP.

Research Priorities

The following research projects were considered high priority by workshop participants:

- **Project #29: CEC Removal Comparative Analysis.** What is the level of success of CEC removal by different wastewater treatment technologies and how can these systems be modified to optimize CEC removal? Conduct a comparative analysis of key CECs and the effectiveness of the most common wastewater treatment technologies, including determining actions to optimize these treatments.

- **Project #30: Evaluate the Removal of CECs by Ozone/ BAC Treatment.** How effective is ozone/BAC treatment for the removal of CECs and as a pretreatment method for microfiltration (MF) and RO? Are there appropriate surrogates for BAC operations? What are the cost and treatment benefits relative to other treatment trains? Identify appropriate online surrogates for ozone/BAC operations. Determine the cost and benefits relative to alternate treatment trains.

- **Project #31: Standardize Operational Practices for CEC Removal by AOPs.** The industry would benefit from standardized operational practices to optimize performance and CEC/organic matter removal (resilience) for AOP systems. Develop a guidance manual standardizing practices and optimizing performance across different utilities for AOP (like the existing UV disinfection guidelines).

- **Project #32: Concentrate Treatment.** As technology develops to allow us to remove more impurities during the treatment process, the management of the resulting concentrate (including CECs, breakdown products, and salts) becomes a more critical process. Identify and categorize constituents, including breakdown products, present in the concentrate and summarize the objectives for and potential treatment technologies for treating concentrate.

- **Project #33: Categorize and Prioritize CECs.** As detection methods have been developed and improved, the list of CECs has grown to include a wide variety of compounds with a potential range of human health impacts. In addition, the term "CECs" includes many different types of compounds. CECs need to be placed into categories and rated for priority based on the potential severity of impacts to human health and the environment, persistence in the system, wideness of distribution, and other qualities. Doing so will (1) allow for a better understanding of the types of CECs and (2) focus future research on contaminants with the highest cause for concern.

Additional Topics Discussed

Workshop participants discussed additional research questions and topics that were considered to be a lower priority at this time given the other research needs. These included:

- **Online surrogates that can be used to demonstrate CEC removal with RO.** Conduct extensive monitoring and challenge studies, including failure analysis. Conduct a detailed trend (not snapshot) analysis of the effectiveness of RO over time to remove CECs. Include correlative analyses with surrogates. Ideally, this work is done online, but could use grab sampling for monitoring.

- **New trends suggest there are online surrogates for CEC removal and production by AOP. What surrogates are indicative of CEC removal and production in AOP?** Determine the effectiveness of AOPs over time (and as they age) to remove CECs. Conduct a trend (not snapshot) analysis, including correlation with surrogates.

- **Efficacy of CEC removal through SAT for groundwater spreading projects.** Document and summarize existing information on CEC removal by SAT in groundwater spreading of recycled water and the reliability of removal over time, as well as categorize CECs by type and structure that are removed through SAT.

- **Value of a reservoir as an environmental buffer for CEC removal.** Assess and compare the presence of CECs in existing reservoirs and recycled water (before and after the environmental buffer) to assess the removal of CECs. Discuss potential mechanisms.

- **The development of new CEC treatment processes/trains (such as ozone).** New processes/treatment trains may have unintended impacts on water quality or on the environment. The environmental impacts of CECs are understudied and not well understood. How do evolving treatment processes impact the environment (e.g., via concentrate), and is there a need to alter Best Management Practices (BMPs) to address potential impacts? Should we assess environmental impacts associated with CEC treatment processes and determine if there is a need to alter BMPs to mitigate these effects?

- **Standardizing the usage of excitation and emission matrix (EEM) fluorescence.** The first step in making EEM fluorescence into a tool for the optimization of water treatment process parameters and improvement of performance of the treatment train would be to standardize its usage. Determine whether EEM fluorescence could be an effective CCP monitoring tool (e.g., for ozone/BAC, RO, and AOP). Determine whether EEM fluorescence can be a quantitative (correlated with CEC chemical analysis), semi quantitative, or qualitative analysis.

- **Sensor technologies are rapidly developing and have become an important tool for monitoring. Their usefulness can be expanded by developing sensors that could monitor CECs.** This project would build on existing studies and summarize the potential for new sensors in monitoring CECs in potable water reuse treatment trains. Develop sensor technologies that have the potential to monitor CECs.

Breakout Session 2-3: Emerging Technologies for Recycled Water Treatment

Group Leaders: Karl Linden (University of Colorado) and Julie Minton (WateReuse)

Overview

This research theme focused on the status and potential for emerging, innovative treatment technologies and monitoring strategies for the control of CECs and the assessment of treatment performance in recycled water applications.

Potable reuse must be protective of public health; therefore, applications must consider the appropriate inactivation of pathogens and removal of chemical constituents (including the management of additional chemical byproduct formation), as well as the maintenance of favorable aesthetics. Additionally, these treatment technologies should:

- Not form additional byproducts.

- Minimize the formation of residuals.
- Where possible, use sustainable materials and low or no energy.
- Be straightforward to operate.

There are promising new and innovative technologies, such as osmotic membrane bioreactors (MBRs), membrane distillation, microbial electrochemical technology, and UV-chlorine advanced oxidation, that have the potential to advance the efficiency, improve the sustainability, and lower the cost of existing FAT approaches; however, we need to understand any potential challenges associated with these new technologies.

For a new treatment technology to be accepted, it must include upfront basic research, validation procedures, safety factors, sensors, and supporting mathematical models. In addition, other positive attributes would include the minimization of residuals, byproducts, harmful side effects, toxic materials, and/or dangerous handling. Through validation, a technology must verify that it achieves a given level of performance under specified circumstances.

Likewise, new and innovative monitoring techniques and strategies provide an opportunity to enhance monitoring for treatment performance, assign pathogen credits, identify new indicators, ensure water quality compliance, and other related needs. Advances are being made in monitoring techniques for both microbials and chemicals. Improvements to existing methods and new methods will allow for more precise and accurate measurements, as well as improve detection limits. Innovative methods may also provide more real-time and online monitoring of treatment processes. An area that is seeing large advances is in the use of sensors for monitoring. Many of these techniques are being developed for non-water applications.

For treatment technologies, there is need to evaluate and monitor performance parameters like dose delivery because monitoring provides the basis for assigning removal credits for pathogens during operation. Once a technology is validated under a set of water quality parameters, it can be approved for use within those parameters. Manufacturers typically validate their technologies over a range of water quality conditions to cover various source water applications. Otherwise, site-specific conditions could require revalidation or verification. The acceptance of technology validation rests with state regulators. Prior to the implementation of a new technology, validation and/or demonstration testing may be desirable to verify manufacturer claims, achieve the approval of regulators, and document operational needs.

Research Priorities

Research discussed at the workshop was categorized into three areas: (1) validation of new technologies; (2) development of new sensors and/or monitoring tools; and (3) development of new treatment technologies. Specific research priorities identified at the workshop by category are as follows:

<u>Validation of New Technologies</u>

- **Project #34: Validation Program for New and Emerging Technologies.** The development of a validation program, including standardized testing protocols and related information, is needed to verify the performance of new, emerging, and innovative technologies. This project would include developing a process for establishing: (1) the protocols to validate emerging technologies, (2) an onsite verification plan, and (3) a sustainability assessment (e.g., energy usage).

- **Project #35: Critical Control Points (CCPs) to Verify Control of Pathogens and Chemicals.** CCPs (e.g., locations in unit treatment processes that provide an opportunity to reduce risk from chemicals and/or pathogens) and associated monitoring techniques are needed for technology operation and performance verification for either pathogen or chemical control. This project would identify: (1) possible CCPs (and monitoring techniques) needed for emerging technologies, (2) best practices or standard methods needed to integrate CCPs, and (3) data needed to verify the operation and performance of new and emerging technologies.

- **Project #36: Center to Test and Validate New Potable Reuse Technologies.** A technology validation center would help in testing and validating new technologies for potable reuse. This project would develop an approach or plan to establish a centralized testing facility (or facilities) for technology validation and testing for the reuse industry.

<u>Development of New Sensors and/or Monitoring Tools</u>

- **Project #37: Online CEC Sensors.** The increased use of sensors appropriate for detecting specific CECs, groups/classes of CECs, or biological activity of CECs would improve the ability to monitor treatment performance, water quality, and water quality changes, as well as provide more confidence in potable reuse for regulators and the public. This project would develop a database of appropriate CECs and indicators and/or surrogates to monitor, with corresponding online sensors, and include: (1) a sensor data management plan, (2) best practices for sensor deployment and interpretation, and (3) a plan to incentivize the commercialization of new sensors.

- **Project #38: New Monitoring Approaches for Technology Verification**. New monitoring tools would improve confidence in potable reuse. This project would propose new monitoring approaches (e.g., bioassays, sensors, non-targeted analyses) and the means to integrate them into a treatment technology verification process and technology validation testing.

<u>Development of New Treatment Technologies</u>

- **Project #39: Next Generation Treatment Technologies.** New treatment technologies are needed that improve the current suite of technologies. This project (or suite of projects) would develop new technologies that address the following areas of interest: (1) improved public health; (2) lowering costs to improve treatment in lower-income communities meeting environmental justice goals; (3) low energy, natural treatment-based approaches; (4) non-RO technology to achieve similar treatment goals; (5) improved RO to use less water and energy; (6) technology to treat brine and recover more water; and (7) zero liquid discharge technologies.

Additional Topics Discussed

Workshop participants brought up the question of who would provide the funding and/or resources necessary for technology validation.

Breakout Session 2-4: Reliability and Robustness for CEC Control in Potable Reuse

Group Leaders: Brian Pecson (Trussell Technologies) and Scott Couch (State Water Resources Control Board)

Overview

Reliability is the ability to consistently protect public health, and it is acknowledged that DPR can only be implemented if it does not jeopardize public health. Two main groups of contaminants are of interest in potable reuse settings: pathogens and chemicals. Pathogens are considered an "acute" threat because they have an immediate health effect when consumed. Because the threat of pathogens is constant, the protection provided by treatment must also be constant. As a result, pathogen control is the most critical aspect of DPR. Most chemicals, at the concentrations found in wastewaters, are considered "chronic" threats, meaning that health effects are typically seen over longer timescales as the result of chronic exposure. Given this situation, the *average* lifetime exposure is more important for chemicals than brief periods of exceedances. For DPR, suggestions for specific public health criteria for both pathogens and chemicals were included in a recent publication (WERF 11-02).

One strategy to help achieve treatment reliability is the prevention of failures. Redundancy in treatment helps prevent failures and has been incorporated in many regulatory strategies with the concept of the "multiple barrier approach." Redundancy is important for pathogen control to ensure that the failure of one barrier does not result in system failure. Instead, redundant barriers serve as buffers to treatment failures.

A different strategy is used for controlling the wide universe of chemicals. Experience has shown that no single barrier can effectively control all chemicals of concern, so a *diversity* of barriers is employed. This breadth of treatment is termed "robustness." A robust treatment train may employ multiple barriers, including biological degradation, physical removal, physical destruction, and chemical oxidation. Together, redundancy and robustness prevent failures and, thereby, promote reliability.

Historically, chemical removal, including CECs, and possible health effects have been studied at the following potable reuse projects:

- **Montebello Forebay (Los Angeles, CA).** This project involves surface spreading of tertiary treated recycled water. Studies have documented contaminant removals through a robust treatment train, including SAT (which plays an important role in the treatment and control of organic chemicals). Multiple studies, from the 1970s to the present, have shown the effectiveness of this system in controlling CECs. The treatment train, including SAT, is a robust barrier for trace organic chemicals.

- **Groundwater Replenishment System (Orange County, CA).** This project differs from spreading projects in that it places higher reliance on engineered treatment schemes. The FAT train – including RO and UV/ AOP – evolved over time to provide increasing levels of robustness. This enhanced robustness was needed to address a growing body of knowledge on CEC control.

CECs are a concern for all potable reuse applications (i.e., groundwater recharge; surface water augmentation, and DPR). The key to control these trace organic chemicals is a multiple barrier treatment train that provides reliability through robustness. Several treatment processes should be employed to address the variety of chemical constituents. It will be important to develop new and novel treatment processes that can serve as additional or more robust barriers.

Current research is looking at improving CEC control. For example, WateReuse Research Foundation Project WERF 12-12 is investigating enhancing SAT for potable reuse. Ozonation prior to SAT transforms bulk organic matter into smaller pieces for improved SAT performance and TOC removal. Under WERF 14-12, a state-of-the-art DPR pilot plant is being used to demonstrate how a combination of treatment redundancy and enhanced monitoring techniques can reliably achieve potable reuse treatment objectives. As a result, enhanced treatment can be shown to be cost-effective for achieving reliability, public health protection, and water quality benefits and can mitigate the next unknown chemicals.

Research Priorities

Ongoing research is looking at CEC control for many forms of potable reuse, including indirect potable reuse (IPR) and DPR. Longstanding IPR projects have shown the importance of robustness in the control of CECs. Including robustness in treatment trains: (1) has the potential to increase the quality and capacity of SAT, (2) allows us to consider DPR, and (3) provides protection against the next CEC of concern.

Topics that require additional information include the following research priorities:

- **Project #40: Enhanced Monitoring of CECs.** Surrogates for the removal and/or production of CECs are needed to facilitate unit process design/operations and validate overall treatment performance. Evaluate new/emerging surrogates for CEC removal, including for the following treatment trains: ozone and BAC; RO; and UV/AOP. Develop methods for site-specific applications. Develop non-selective assays for CECs (i.e., less-selective receptors), perhaps building off those used in other industries.

- **Project #41: Identification of Unknowns.** Treatment trains providing a high degree of robust treatment can reduce effluent TOC levels down to very low levels. Efforts to identify the remaining components in the TOC of these effluents would provide important information on unknowns.

- **Project #42: Assess Environmental Impacts of CECs.** The development of new CEC treatment processes may have unintended impacts on the environment. The environmental impacts of CECs are understudied and not well understood. How do evolving CEC treatment processes (e.g., brine) impact the environment and is there a need to alter BMPs to pick up potential impacts? Assess environmental impacts of brine discharges (and CECs) on aquatic species. Assess the impacts of more concentrated wastewater effluent discharges to the environment relative to pre-water recycling conditions.

- **Project #43: Evaluation of CEC Robustness.** Document the relative robustness of unit processes and treatment trains in the removal of CECs in potable reuse applications. Compile existing data and write a white paper on the robustness of different unit processes and trains.

Table 1: List of Projects Resulting from the Breakout Sessions

Project No.	Project Title
	1-1. Chemical Testing
01	Evaluate CECs of Health Concern
02	Recycled Water Impacts upon Aquatic Life
03	Health Risks Associated with Irrigating Crops with Recycled Water
04	Indicator Monitoring
05	Standard Methods for CEC Analysis
06	Transformation of CECs during Treatment
07	CEC Reporting Limits
08	Validation on Online Sensors for CECs
09	Tools to Predict the Replacement of Reverse Osmosis (RO) Membranes
10	Optimizing Source Control for CEC Removal
11	CEC Monitoring Program Guidance
	1-2. Bioanalytical Screening
12	Selection of Endpoints to Monitor CECs in Recycled Water
13	Interpretation Framework for Cell Bioassay Results
14	Standardization of Methods and Technology Transfer
15	Multiplexing Cell Bioassay Technologies
	1-3. Applications of Bioassays for Recycled Water
16	Assess the Universe of Bioassays and Universe of Chemicals of Interest
17	Develop Standard Operation Procedures for Sample Preparation and Quality Assurance/Quality Control (QA/QC) for Bioassays for Use in Potable Reuse Applications
18	Benchmark Bioassay Techniques across and within Treatment Systems, and Compare to Other Water Sources
19	Develop a Work Flow Toolbox – What Do You Do with Bioassay Results (e.g., a "Hit" or "False Negative")?
20	Communication Plan for Bioassays
	1-4. Non-Targeted Analysis
21	Develop and Standardize Non-Targeted Analysis (NTA) Tools and Protocols
22	Identify Transformation Products and Other Unknowns
23	Characterize Source Water Quality

Project No.	Project Title
24	Update Indicator Lists for Targeted Monitoring
	2-1. Source Control, Operations, Maintenance, and Training for DPR
25	Assess How the Quality of Secondary Treated Effluent Impacts the Selection of the Type and Level of Treatment Needed to Produce Recycled Water for Potable Reuse Applications
26	Develop a Guidance Manual for Implementing the Hazard Analysis Critical Control Point (HACCP) Framework for Assessing and Managing the Risk of Contaminants in Recycled Water
27	Develop Training Manuals and Curricula for Operators within the Direct Potable Reuse Context
28	Develop Reliable Sensors to Alert Operators of Treatment Excursions
	2-2. Assessing CEC Performance of Currently Used Technologies
29	CEC Removal Comparative Analysis
30	Evaluate the Removal of CECs by Ozone/Biological Activated Carbon (BAC) Treatment
31	Standardize Operational Practices for CEC Removal by Advanced Oxidation Processes (AOPs)
32	Concentrate Treatment
33	Categorize and Prioritize CECs
	2-3. Emerging Technologies for Recycled Water Treatment
34	Validation Program for New and Emerging Technologies
35	Critical control points (CCPs) to Verify Control of Pathogens and Chemicals
36	Center to Test and Validate New Potable Reuse Technologies
37	Online CEC Sensors
38	New Monitoring Approaches for Technology Verification
39	Next Generation Treatment Technologies
	2-4. Reliability and Robustness for CEC Control in Potable Reuse
40	Enhanced Monitoring of CECs
41	Identification of Unknowns
42	Assess Environmental Impacts of CECs
43	Evaluation of CEC Robustness

Table 2: Projects Descriptions Developed from the Research Needs Identified in the Breakout Sessions

The above list of projects that were developed from the identified research needs that were identified in the breakout sessions. The research needs were refined and meeting organizers developed project descriptions for 36 potential research projects. These project descriptions were used in a post-workshop survey to identify the highest priority research needs. The project number indicated in this table is a project identifier and is not related to rank or importance.

Project	Project Description
	CHEMICAL TESTING
01	**Evaluate CECs of Health Concern**. The list of CECs has grown exponentially as we learn more about their potential to exist in the environment, but not much is known about the levels of CECs in drinking water that would correspond to a health concern (i.e., what is the "safe" or acceptable concentration of CECs?). This project would use tools from WRRF-05-005 on "Identifying Pharmaceuticals/ Personal Care Products of Most Health Concern/Persistence through Water Treatments Used for Indirect Potable Reuse" to evaluate CECs of health concern in drinking water.
02	**Recycled Water Impacts upon Aquatic Life.** Recent research has given us the tools to measure the removal of many contaminants and compounds over the course of the treatment process. This project would investigate how aquatic life could be affected by exposure to recycled water, comparing different treatment types and end uses to determine relative risk.
03	**Health Risks Associated with Irrigating Crops with Recycled Water**. A common use for recycled water is to irrigate food crops. This project aims to determine if any risk to human health exists when recycled water is used on food crops, comparing possible exposure for crops (1) grown underground or aboveground and (2) crops processed before consumption.
04	**Indicator Monitoring**. It is important to identify a suite of indicators that correlate with the occurrence and removal of CECs that could be of human health concern in potable reuse treatment systems. Indicator monitoring will serve as a verification of the performance of the system. Although past studies and regulatory guidance have suggested indicator compounds, new research has been conducted and the lists of compounds (for different applications) must be updated. For performance verification indicators, revisit Attachment A: Tables 1, 2, and 6 from the Recycled Water Policy to bring in new research/data to update and correlate groups of compounds to assess, based on different treatment processes to demonstrate the effectiveness of the process.
05	**Standard Methods for CEC Analysis**. New analysis methods are continually being developed for CECs, but there is a great need to standardize these methods. This project will evaluate candidate methods of analysis for CECs that could become standard industry methods, looking for the most efficient and cost-effective options to achieve the necessary detection limits. Then, round robin analysis will be conducted on the same set of samples to determine the consistency and dependability of the methods in different laboratories.

Project	Project Description
06	**Transformation of CECs during Treatment**. One concern is the potential transformation of chemical constituents during the treatment process. This project would examine (1) the transformation potential for common CECs during processes like oxidation, biological activated carbon, and soil aquifer treatment and (2) potential health risks of the transformation products.
07	**CEC Reporting Limits.** With increased monitoring capabilities and sensitivities of advanced instrumentation (i.e., lower and lower detection limits) comes increased concerns over the potential health risks of CECs at very low concentrations; therefore, it is critical to determine how sensitive testing must be to maintain the protection of public health, based on the range of “safe” (acceptable) concentrations of compounds in drinking water. This project would determine the required method reporting limits for key CECs, which are independent of the limit of detection.
08	**Validation on Online Sensors for CECs.** Online sensors are an increasingly important part of the monitoring system for potable reuse, used to ensure the treatment process is operating within appropriate parameters. Research is needed to correlate CEC removal with monitoring data from online sensor systems (e.g., data for surrogate parameters). This project will validate sensors to be used for correlation with CEC detection and/or removal.
09	**Tools to Predict the Replacement of Reverse Osmosis (RO) Membranes.** It is critical to keep the treatment train running consistently, but it can be difficult to predict the appropriate time to replace RO membranes in advance of failure. This project will develop tools (e.g., trend analysis or log removal) to predict the need for the replacement of RO membranes before that need becomes acute.
10	**Optimizing Source Control for CEC Removal.** The source water for a particular area plays a large role in the contaminants present at the beginning of the treatment train, as well as the treatments required to remove those contaminants. This project will look at the impact of source control on the presence of CECs and how source control programs can be optimized for CEC removal.
11	**CEC Monitoring Program Guidance.** This project will produce a guidance document for utilities and water agencies on the development of a voluntary CEC monitoring program. It will also include information (e.g., state-of-the-science report) on the relationships between chemical data and bioassay results, and how these data may be interpreted.
	BIOANALYTICAL SCREENING
12	**Selection of Endpoints to Monitor CECs in Recycled Water.** This research area was identified as a top research priority by all the breakout groups. Participants recognized that cell bioassay endpoints linked to adverse health effects may be used as indicators of potential long-term impacts on humans and aquatic wildlife. They proposed to investigate the relationships between existing cell bioassay endpoints and adverse effects at the organism and population level to identify and validate the most useful cell bioassays for CEC monitoring in recycled water. The use of non-specific cell bioassays (e.g., acute toxicity, cell death) was also suggested as a surrogate measure of CEC removal efficiency. Participants discussed the need to conduct pilot studies that evaluate the usefulness of these bioassays in detecting known and unexpected CECs in waters produced from various treatment technologies.

Project	Project Description
13	**Interpretation Framework for Cell Bioassay Results.** This topic was also endorsed by the majority of workshop participants. The consensus was that careful interpretation and extrapolation of cell bioassay results must be conducted to ensure that there is no misperception from the public regarding the quality of recycled water. Research projects applying cell bioassays to various treatment plants should be conducted to establish baseline responses. Linkage studies (i.e., analysis of the relationship between *in vitro* cell bioassay responses and biological/health effects in animals) should also be performed and the results used to establish clear thresholds of concern and corresponding management actions. Bioassay monitoring results should be integrated with current (e.g., targeted chemistry, total organic carbon) and new (e.g., non-targeted chemistry) CEC removal monitoring techniques.
14	**Standardization of Methods and Technology Transfer.** Workshop participants discussed the need for standardization with appropriate quality assurance/quality control to ensure that cell assays are run correctly and results are accurate. With appropriate training, it is possible for water agencies and treatment facilities to establish and run cell bioassays in-house. The capital cost necessary to equip the laboratory to carry out cell bioassay analyses should not be significant for those who have an existing microbiology laboratory; therefore, workshops and training sessions should be set up for these laboratories, and part of the training should include round-robin blinded analyses to evaluate individual laboratory performance. Additionally, periodic inter-laboratory validation studies should be carried out to ensure that bioassay standards are met.
15	**Multiplexing Cell Bioassay Technologies.** Projects funding the development of multiplexed bioassay endpoints (i.e., using cell lines containing receptors for several desired biological pathways) were suggested to reduce time and cost.
	APPLICATIONS OF BIOASSAYS FOR RECYCLED WATER
16	**Assess the Universe of Bioassays and Universe of Chemicals of Interest.** Based on the needs and applications associated with potable reuse, investigate and evaluate: • The range of bioassays (including health endpoints of concern). Develop a list of specific endpoints that is meaningful and part of a larger program to monitor CECs. • The range of chemicals or classes of chemicals of potential importance from a bioassay point-of-view. Determine a process and develop the drivers for determining a limited set of bioassays for potable reuse. One driver is the likelihood of developing bioassays for potable reuse applications.
17	**Develop Standard Operation Procedures for Sample Preparation and Quality** Assurance/Quality Control (QA/QC) for Bioassays for Use in Potable Reuse Applications. For bioassays for use in potable reuse, develop standardize procedures addressing sample preparation and QA/QC. Develop, test, and revise specific standard operating procedures. Classes of chemicals that are not likely to be isolated and concentrated (i.e., perchlorate and volatile organic compounds) should be better described and alternatives considered. Field validation is necessary.

Project	Project Description
18	**Benchmark Bioassay Techniques across and within Treatment Systems, and Compare to Other Water Sources.** Bioassays need to address specific endpoints and have the potential to provide meaningful information. For example, how can bioassays be part of the larger CEC monitoring program? Bioassays for potable reuse and nonpotable applications would be needed. Develop an appropriate approach and test plan to (1) assess biological activity within potable reuse treatment systems, and (2) benchmark advanced treatment recycled water with other water sources. If a broad array of bioassays is used, a project of this size and scope will provide a more structured and broader base for identifying potential health hazards than a collection of individual assays. It must be a well-designed study with a sufficient number of systems to provide a meaningful benchmark for treatment.
19	**Develop a Work Flow Toolbox – What Do You Do with Bioassay Results** (e.g., a "Hit" or "False Negative")? Develop a "work flow" or set of "treatment, monitoring, or management" procedures or steps to follow when addressing the results of bioassays, including positives, false positives, and false negatives. Quality assurance/quality control information would inform this exercise. These steps would address where in the treatment train the results are associated with. Would these results trigger other analyses or follow-on activities? Address treatment questions (e.g., does the hit decrease across treatment?) and monitoring questions (e.g., would other monitoring be triggered?).
20	**Communication Plan for Bioassays.** A communication plan for internal and external outreach would address the needs associated with the interpretation of results, follow-up on results, screening versus compliance monitoring, public understanding, and regulatory requirements. Communicating the purpose and results of bioassays will be critical to the understanding, usefulness, and acceptance of these methods. Bioassays are new in the recycled water arena and will be potentially difficult and challenging to explain. Communication would take different forms based on the purpose, such as: (1) specific communication instructions for following up on results is needed for internal use; (2) communication requirements will differ where the analyses are used for screening purposes or compliance purposes; (3) communication with certain groups (i.e., regulators, the public) needs definition; and (4) a critical area is communicating the interpretation of results. A project is needed to develop procedures and best practices for this communication.
	NON-TARGETED ANALYSIS
21	**Develop Non-Targeted Analysis (NTA) Tools and Standardizing Protocols**. Whereas the instrumentation currently available for NTA is capable of discriminating among thousands of CECs in a single sample, information on CECs detectable in water matrices remains scarce (largely due to the lack of robust, standardized data management and analysis tools designed to deal with the copious amounts of multidimensional data generated by NTA). As more groups embrace and develop NTA as a diagnostic tool, it will be critical to harmonize strategies and standardize methods, including data analysis, to realize its full potential; therefore, efforts to develop and standardize end-to-end NTA protocols focused on addressing recycled water issues was recognized as the critical first step toward applying NTA as a research tool and, eventually, for more routine diagnosis in operational recycled water facilities. Participants strongly endorsed this topic as the highest research priority in this category.

Project	Project Description
22	**Identify Transformation Products and Other Unknowns.** Participants agreed that the largest, most diverse, and potentially most problematic group of unknown CECs are transformation products produced during treatment (e.g., by advanced oxidation processes), which are missed by conventional targeted monitoring methods. Participants felt that non-targeted analysis could be developed to identify transformation products at different stages of treatment, including the analysis of reject from reverse osmosis (RO) membranes (i.e., "RO reject" or "brine"). The latter option would serve as a worst-case scenario for ambient exposure and would form the basis of a comprehensive library of transformation products and other CECs to inform other facets of recycled water treatment, including the research and development of alternative treatment processes.
23	**Characterize Source Water Quality**. Many participants expressed concern over the treatability of recycled water in the face of changing source water quality, both over time and across geographies. The groups recognized the potential for non-targeted analysis (NTA) to assess changing source water quality, taking advantage of its fingerprinting capability. Source water fingerprints generated by NTA could be compared across treatment facilities and at different time scales to help determine if treatment design and operations are sufficiently robust for variations in source water quality. NTA could also serve as a safety net against unanticipated contaminants; participants agreed that NTA would make a useful early warning system when used in conjunction with other monitoring tools (i.e., targeted analysis, screening cell assays).
24	**Update Surrogate Lists for Targeted Monitoring.** The success and efficiency of targeted monitoring relies on indicator chemicals (or "surrogates") that best mimic the fate of larger groups of residual chemicals known to occur in recycled water. Current indicators (e.g., carbamazepine, sucralose) may be phased out and/or replaced by newer generation products, while alternative treatment processes are being validated and incorporated into treatment train; therefore, a need exists to periodically update the lists of surrogates used to validate treatment designs and to optimize process control measures. With its ability to provide chemical identifications and fingerprints, non-targeted analysis could be applied to inform the selection of appropriate surrogates, including transformation product candidates, more efficiently than currently available surrogate identification methods.
	SOURCE CONTROL, OPERATIONS, MAINTENANCE, AND TRAINING FOR
25	**Assess How the Quality of Secondary Treated Effluent Impacts the Selection of the Type and Level of Treatment Needed to Produce Recycled Water for Potable Reuse Applications.** The initial step in this project would be to characterize the quality of a wide range of secondary treated effluent samples, specifically related to pathogen and chemical occurrence. The second part of the project would be to identify the type and level of treatment, based on the quality of secondary treated effluent, required to produce recycled water that meets drinking water quality standards.
26	**Develop a Guidance Manual for Implementing the Hazard Analysis Critical Control Point (HACCP) Framework for Assessing and Managing the Risk of Contaminants in Recycled Water.** Assess and manage the risk associated with CECs and other chemical and microbial contaminants during treatment that takes into account the source of the water and combination of individual processes selected for use at the advanced water treatment system. Develop a "how-to manual" for implementing a HACCP management system to assess and manage the risk of CECs

Project	Project Description
	in recycled water on a site-specific basis.
27	**Develop Training Manuals and Curricula for Operators within the Direct Potable Reuse Context.** Conduct a review of critical information for training recycled water facility operators and develop training manuals and curricula. The organization that develops the training materials and curricula would continue to update and maintain these materials.
28	**Develop Reliable Sensors to Alert Operators of Treatment Excursions.** Sensors should be developed for use at the interface of the wastewater treatment plant and advanced water treatment facility to inform operators of events that could impact the quality of advanced treatment product water. The sensors could also be used to alert operators to issues with upstream treatment performance or events that may have occurred in the collection system that could impact water quality.
	ASSESSING CEC PERFORMANCE OF CURRENTLY USED TECHNOLOGIES
29	**CEC Removal Comparative Analysis.** What is the level of success of CEC removal by different wastewater treatment technologies and how can these systems be modified to optimize CEC removal? Conduct a comparative analysis of key CECs and the effectiveness of the most common wastewater treatment technologies, including determining actions to optimize these treatments.
30	**Evaluate the Removal of CECs by Ozone/Biological Activated Carbon (BAC) Treatment.** How effective is ozone/BAC treatment for the removal of CECs and as a pretreatment method for microfiltration/reverse osmosis? Are there appropriate surrogates for BAC operations? What are the cost and treatment benefits relative to other treatment trains? Identify appropriate online surrogates for ozone/BAC operations. Determine the cost and benefits relative to alternate treatment trains.
31	**Standardize Operational Practices for CEC Removal by Advanced Oxidation Processes (AOPs).** The industry would benefit from standardized operational practices to optimize performance and CEC/organic matter removal (resilience) for AOP systems. Develop a guidance manual standardizing practices and optimizing performance across different utilities for AOP (like the existing ultraviolet disinfection guidelines).
32	**Concentrate Treatment.** As technology develops to allow us to remove more impurities during the treatment process, the management of the resulting concentrate (including CECs, breakdown products, and salts) becomes a more critical process. Identify and categorize constituents, including breakdown products, present in the concentrate and summarize the objectives for and potential treatment technologies for treating concentrate.
33	**Categorize and Prioritize CECs.** As detection methods have been developed and improved, the list of CECs has grown to include a wide variety of compounds with a potential range of human health impacts. In addition, the term "CECs" includes many different types of compounds. CECs need to be placed into categories and rated for priority based on the potential severity of impacts to human health and the environment, persistence in the system, wideness of distribution, and other qualities. Doing so will (1) allow for a better understanding of the types of CECs and (2) focus future research on contaminants with the highest cause for concern.

Project	Project Description
	EMERGING TECHNOLOGIES FOR RECYCLED WATER TREATMENT
34	**Validation Program for New and Emerging Technologies.** The development of a validation program, including standardized testing protocols and related information, is needed to verify the performance of new, emerging, and innovative technologies. This project would include developing a process for establishing (1) the protocols to validate emerging technologies, (2) an onsite verification plan, and (3) a sustainability assessment (e.g., energy usage).
35	**Critical control points (CCPs) to Verify Control of Pathogens and Chemicals.** CCPs (e.g., locations in unit treatment processes) and associated monitoring techniques are needed for technology operation and performance verification for either pathogen or chemical control. This project would identify (1) possible CCPs (and monitoring techniques) needed for emerging technologies, (2) best practices or standard methods needed to integrate CCPs, and (3) data needed to verify the operation and performance of new and emerging technologies.
36	**Center to Test and Validate New Potable Reuse Technologies.** A technology validation center would help in testing and validating new technologies for potable reuse. This project would develop an approach or plan to establish a centralized testing facility (or facilities) for technology validation and testing for the reuse industry.
37	**Online CEC Sensors**. The increased use of sensors appropriate for detecting specific CECs, groups/classes of CECs, or biological activity of CECs would improve the ability to monitor treatment performance, water quality, and water quality changes, as well as provide more confidence in potable reuse for regulators and the public. This project would develop a database of appropriate CECs and indicators and/or surrogates to monitor, with corresponding online sensors, and include (1) a sensor data management plan, (2) best practices for sensor deployment and interpretation, and (3) a plan to incentivize the commercialization of new sensors.
38	**New Monitoring Approaches for Technology Verification**. New monitoring tools would improve confidence in potable reuse. This project would propose new monitoring approaches (e.g., bioassays, sensors, non-targeted analyses) and the means to integrate them into a treatment technology verification process and technology validation testing.
39	**Next Generation Treatment Technologies.** New treatment technologies are needed that improve the current suite of technologies. This project (or suite of projects) would develop new technologies that address the following areas of interest: (1) improved public health; (2) lowering costs to improve treatment in lower-income communities meeting environmental justice goals; (3) low energy, natural treatment-based approaches; (4) non-reverse osmosis (RO) technology to achieve similar treatment goals; (5) improved RO to use less water and energy; (6) technology to treat brine and recover more water; and (7) zero liquid discharge technologies.

Project	Project Description
	RELIABILITY AND ROBUSTNESS FOR CEC CONTROL IN POTABLE REUSE
40	**Enhanced Monitoring of CECs.** Surrogates for the removal and/or production of CECs are needed to facilitate unit process design/operations and validate overall treatment performance. Evaluate new/emerging surrogates for CEC removal, including for the following treatment trains: ozone and biological activated carbon; reverse osmosis; and ultraviolet disinfection/advanced oxidation processes. Develop methods for site-specific applications. Develop non-selective assays for CECs (i.e., less-selective receptors), perhaps building off those used in other industries.
41	**Identification of Unknowns.** Treatment trains providing a high degree of robust treatment can reduce effluent TOC levels down to very low levels. Efforts to identify the remaining components in the total organic carbon of these effluents would provide important information on unknowns.
42	**Assess Environmental Impacts of CECs.** The development of new CEC treatment processes may have unintended impacts on the environment. The environmental impacts of CECs are understudied and not well understood. How do evolving CEC treatment processes (e.g., brine) impact the environment and is there a need to alter BMPs to pick up potential impacts? Assess environmental impacts of brine discharges (and CECs) on aquatic species. Assess the impacts of more concentrated wastewater effluent discharges to the environment relative to pre-water recycling conditions.
43	**Evaluation of CEC Robustness.** Document the relative robustness of unit processes and treatment trains in the removal of CECs in potable reuse applications. Compile existing data and write a white paper on the robustness of different unit processes and trains.

Post Workshop Survey Results Ranking Across Themes

After the workshop, an online survey was administered to identify research priorities from the material discussed during the facilitated afternoon breakout discussions. The survey was administered twice: once to workshop attendees and once to non-attendees. Twenty-seven workshop attendees and 31 non-attendees participated in the survey. Full results of both surveys can be found in Appendix D.

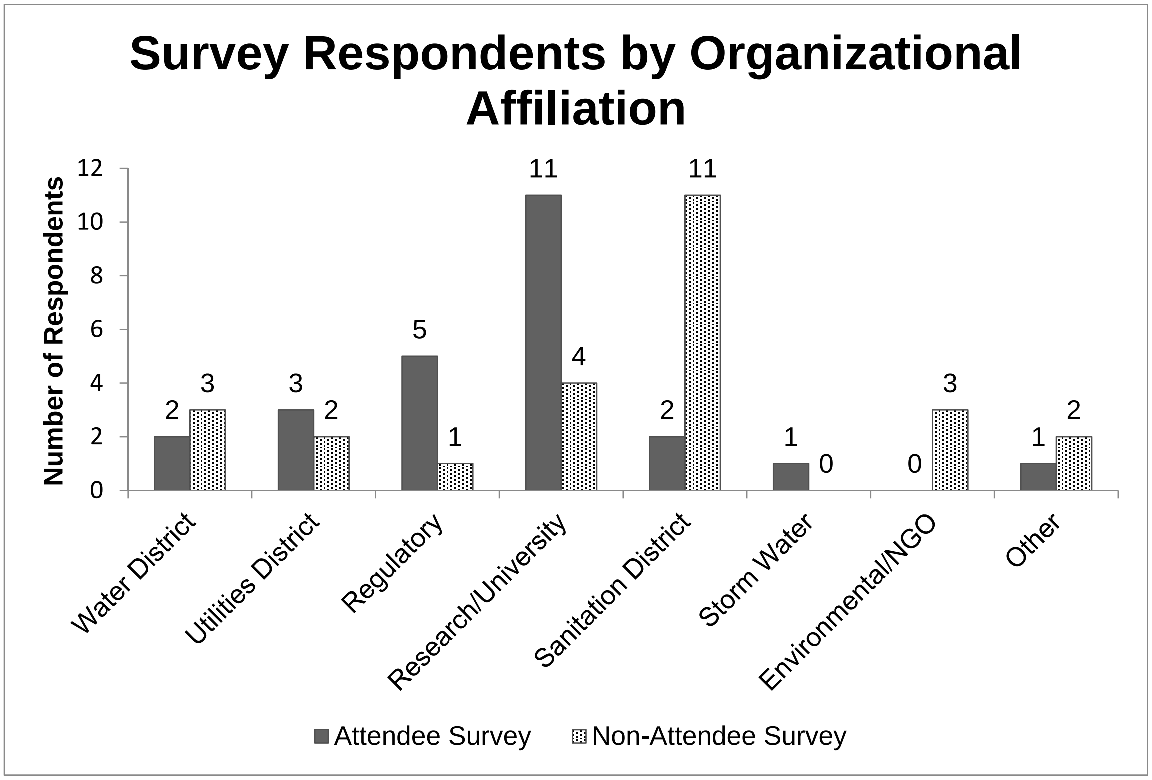

Figure 1: Survey Respondents by Organizational Affiliation

Results for workshop attendees and non-attendees were often markedly different. This may reflect knowledge shared at the workshop of the relative merit of the different research themes. It may also be indicative of the proportions of various professional sectors represented by each survey. For example, Figure 1 shows that over 40 percent of respondents to the survey of attendees self-identified as affiliated with a research or university organization. In contrast, over 40 percent of respondents to the survey of non-attendees self-identified as affiliated with a sanitation district. These sector differences between surveys and correspondingly different survey results can aid in finding common research priorities across sectors, and in understanding the relative importance of specific research priorities for different constituencies.

First, survey respondents were asked about the relative importance of the eight breakout session themes for potable, and then non-potable recycled water projects in California.

Survey Question 1: Rank the thematic research topics in order of highest priority (1) to lowest priority (8). Designating a thematic topic as the highest priority means funding projects in this topic area will furthest advance the expansion and development of potable recycled water projects in California.

Survey Results for Question 1:

Thematic Topics	Workshop attendee average rank	Non-attendee average rank
Assessing currently used technologies for CEC treatment and removal	1	1
Chemical Testing	2	4 (tie)
Bioanalytical screening	3	7
Reliability and resiliency of treatment systems	4	2
Source control, operations, maintenance, and training	5	4 (tie)
Applications of bioassays for recycled water	6	8
Assessing emerging technologies for CEC treatment and removal	7	3
Non-targeted constituent analysis	8	6

For potable recycled water projects in California, it was a high priority for both workshop attendees and non-attendees to assess currently used technologies for CEC treatment and removal. Likewise, both workshop attendees and non-attendees ranked assessing the reliability and resiliency of treatment systems highly. This reflected a broader sentiment among workshop participants that it is a higher priority to optimize existing technologies than to seek out new technologies in the treatment and removal of CECs for potable reuse applications.

Survey Question 2: Rank the thematic research topics in order of highest priority (1) to lowest priority (8). Designating a thematic topic as the highest priority means funding projects in this topic area will furthest advance the expansion and development of non-potable recycled water projects in California.

Survey Results for Question 2:

Thematic Topics	Workshop attendee average rank	Non-attendee average rank
Chemical Testing	1	3
Assessing currently used technologies for CEC treatment and removal	2	1
Bioanalytical screening	3	7
Source control, operations, maintenance, and training	4	4
Applications of bioassays for recycled water	5	8
Reliability and resiliency of treatment systems	6	2
Non-targeted constituent analysis	7	6
Assessing emerging technologies for CEC treatment and removal	8	5

For non-potable reuse applications, chemical testing ranked highly among both workshop attendees and non-attendees as a research priority, demonstrating a desire to increase scientific knowledge of the toxicological as well as ecological impacts of CECs, in addition to identification of indicator compounds that correlate with CEC removal in treatment processes and standardization of laboratory analysis methods.

Similar to the results for potable reuse applications, all survey respondents ranked assessing currently used technologies for CEC treatment and removal as a high priority and assessing emerging technologies for CEC treatment and removal as a low priority.

The results for workshop attendees and non-attendees differed substantially. For example, reliability and resiliency of treatment systems was ranked as a low priority for non-potable reuse applications by workshop attendees, while non-attendees ranked it very high. Likewise, bioanalytical screening was ranked highly by workshop attendees, but was a low priority for non-attendees.

Post Workshop Survey Results Ranking Specific Projects

Survey respondents were asked about the relative importance of the 36 potential priority projects identified in the breakout sessions. Although 43 potential projects were identified in the breakout sessions, the list was consolidated to 36 potential projects for inclusion in the post-workshop survey.

Survey Question 3: How important is the research project in the advancement of expanding recycled water in California?

Survey Results for Question 3:

Project No.	Project Description	Average Rank (Attendees)	Average Rank (Non-attendees)
1	**Evaluate CECs of Health Concern**. This project would investigate how human health could be affected by the levels of CECs in drinking water (i.e., what is the "safe" or acceptable concentration of CECs?).	1	3
28	**Categorize and Prioritize CECs.** This project will place CECs into categories of priority based on the potential severity of impacts to human health and the environment, persistence in the system, wideness of distribution, and other qualities.	2	13
2	**Evaluate CECs for Ecological Health.** This project would investigate how aquatic life could be affected by exposure to CECs in product and waste streams from recycled water production, including concentrate from reverse osmosis.	3	18
36	**Evaluate and Update List of Surrogates for CEC Monitoring.** This project will evaluate the use of current surrogates and identify additional surrogates that correlate with the occurrence and removal of CECs in recycled water.	4	2
4	**Standard Methods for CEC Analysis**. This project will evaluate, select and validate methods that could become industry standards, looking for cost-effective options to achieve the necessary reporting limits.	5	29
11	**Interpretive Framework for Cell Bioassay Results.** This project would develop a framework to translate cell bioassay results to support decision making by scientists, engineers and managers.	6	17
10	**Identify Bioassay Endpoints for Monitoring of Recycled Water.** This project would identify cell bioassay endpoints that would be useful as screening indicators of potential	7	19

Project No.	Project Description	Average Rank (Attendees)	Average Rank (Non-attendees)
	impacts to humans and aquatic wildlife.		
14	**Assess the Universe of CECs and Relevant Bioassays for Recycled Water.** This project would establish a process to prioritize CECs of relevance to recycled water and develop the drivers for determining a set of bioassays for screening recycled water quality.	8	12
24	**Comparative Analysis of CEC Removal.** This project will conduct a comparative analysis of key CECs and the effectiveness of the most common wastewater treatment technologies, including determining actions to optimize these treatments.	9	7
5	**Chemical testing for Transformation Products of CECs & Other Unknowns**. This project would examine the transformation potential for common CECs during processes like oxidation, biological activated carbon, and soil aquifer treatment using chemical testing methods and then identify the potential health risks of the transformation products	10	30
23	**Develop Reliable Sensors for Operations Control.** This project will develop sensors that could be used to alert operators to issues with treatment performance or events that may have occurred that could impact water quality.	11	8
9	**Optimizing Source Control for CEC Removal.** This project will look at the impact of source control on the presence of CECs and how source control programs can be optimized for CEC removal.	12	5
25	**Evaluate Removal of CECs by Ozone/Biological Activated Carbon (BAC) Treatment.** This project will determine the effectiveness of ozone/BAC for removing CECs and as a pretreatment method for membrane filtration (MF)/RO	13	1
27	**Concentrate Characterization and Treatment.** This project will identify and categorize constituents, including breakdown products, present in the concentrate from reverse osmosis (RO) and summarize objectives for treatment technologies for treating concentrate.	14	22
26	**Standardize Operational Practices for CEC Removal by Advanced Oxidation Processes (AOPs).** This project will develop a guidance manual standardizing practices and optimizing performance for AOPs (e.g. existing UV disinfection guidelines).	15	6
18	**Identify Transformation Products and Other Unknowns.** This project will utilize NTA to identify transformation products at different stages of treatment, including reverse osmosis (RO) concentrate.	16	10
20	**Source Water Quality and Treatment Design Considerations**. This project will characterize pathogens and CECs in secondary treated effluent, and identify the type and level of treatment required to produce recycled water for potable use.	17	9
30	**Monitoring Approaches and Critical Control Points (CCPs) to Verify Control of Pathogens and Chemicals.**	18	26

Project No.	Project Description	Average Rank (Attendees)	Average Rank (Non-attendees)
	This project would identify CCPs and monitoring techniques, including new tools (e.g. bioassays, sensors, non-targeted analysis) needed for new or emerging technologies.		
15	**Establish Benchmark Bioassay Techniques for Water Sources and CEC Removal Using Various Treatment Systems.** This project would benchmark recycled water with other water sources using multiple bioassays. The project would also use of bioassays to evaluate the efficacy of CEC removal using various treatment systems.	19	21
33	**Identification of Unknowns.** This project will identify the remaining components in the total organic carbon (TOC) in recycled water facility effluents (”product water”).	20	27
22	**Develop Training Materials for Recycled Water Facility Operators.** This project will identify the critical information needed to properly train recycled water facility operators, and will develop training manuals and curricula.	21	16
12	**Develop Standard Operating Procedures and QA/QC for Cell Bioassays.** This project will develop SOPs that cover all facets of bioassay measurement (sample preparation, conductance of bioassays, reporting). The project would provide guidance and training for water agencies to run cell bioassays in-house.	22	23
16	**Develop a Work Flow Toolbox for Bioassay Results.** This project would develop a work flow consisting of treatment, monitoring, or management procedures to follow interpreting bioassay results.	23	31
34	**Evaluate Robustness of Treatment Processes for the Removal of CECs.** This project will document the relative robustness of unit processes and treatment trains in removing CECs in potable reuse applications.	24	14
35	**CEC Monitoring Program Guidance.** This project will produce a guidance document for utilities and water agencies on the development of a voluntary CEC monitoring program.	25	32
3	**Health Risks Associated with Irrigating Crops with Recycled Water**. This project will determine what risks, if any, to human health exist when recycled water is used to irrigate food crops.	26	25
19	**Non-targeted Fingerprinting of Source Water Quality**. This project will generate source water fingerprints using NTA across treatment facilities and at different time scales and develop an early warning system that uses NTA in conjunction with other monitoring tools (i.e., targeted analysis, screening cell assays).	27	34
6	**CEC Reporting Limits.** This project would determine the required method reporting limits for key CECs, which are independent of the limit of detection.	28	28
21	**Develop a Guidance Manual for Assessing and Managing Risks of Contaminants in Recycled Water.** This project will develop a “how-to manual” for implementing a HACCP management system to assess and manage the risk	29	15

Project No.	Project Description	Average Rank (Attendees)	Average Rank (Non-attendees)
	of CECs in recycled water on a site-specific basis.		
8	**Tools to Predict the Replacement of Reverse Osmosis (RO) Membranes.** This project will develop tools (e.g., trend analysis or log removal) to predict the need for the replacement of RO membranes before that need becomes acute.	30	4
7	**Validation of Existing Online Sensors for CECs.** This project will validate existing sensors to be used for correlation with CEC detection and/or removal.	31	24
17	**Develop NTA Tools and Standardize Protocols**. This project will harmonize strategies and standardize methods, including data analysis, for application of non-targeted analysis to recycled water.	32	11
32	**Next Generation Treatment Technologies.** This project would develop new RO and non-RO based technologies that improve treatment and that reduce energy and water usage, discharge and cost.	33	33
31	**Develop New Online Sensors for CECs**. This project would develop a database of appropriate CECs and indicators/surrogates to monitor with online sensors, and a plan to incentivize the commercialization of new sensors.	34	20
29	**Validation Program for New and Emerging Technologies.** This project would develop a process for establishing protocols to validate new and emerging technologies, and the feasibility of establishing a national or regional technology validation center(s).	35	36
13	**Multiplexing Cell Bioassay Technologies.** This project will investigate the development of bioassay endpoints using cell lines containing receptors for several desired biological pathways, with the goal of increasing measurement efficiency.	36	35

Workshop attendees placed a high priority on chemical testing projects and projects that would aid in assessing CEC performance of currently used technologies. In fact, four of the ten highest-ranked projects were in the category of chemical testing. This matched the results of the first two survey questions, in which chemical testing was ranked a high priority by workshop attendees.

Assessing CEC performance of currently used technologies was also rated highly by workshop attendees. This mirrors the previously stated priority of optimizing current technologies to the extent practicable over developing emerging technologies for expanding recycled water use in California. When viewed from the context of expanding recycled water use in California, there was consensus that existing technologies for monitoring and treatment of CECs – even for direct potable reuse – are sufficient to protect public health.

Survey Question 4: Select five projects that if funded would lead to the greatest increase in the production and use of recycled water in California.

Survey Results for Question 4:

Project Number and Description	Number of Responses (Attendees)	Number of Responses (Non-attendees)
01. Evaluate CECs of Health Concern. This project would investigate how human health could be affected by the levels of CECs in drinking water (i.e., what is the "safe" or acceptable concentration of CECs?).	10	15
02. Evaluate CECs for Ecological Health. This project would investigate how aquatic life could be affected by exposure to CECs in product and waste streams from recycled water production, including concentrate from reverse osmosis.	9	12
11. Interpretive Framework for Cell Bioassay Results. This project would develop a framework to translate cell bioassay results to support decision making by scientists, engineers and managers.	8	0
10. Identify Bioassay Endpoints for Monitoring of Recycled Water. This project would identify cell bioassay endpoints that would be useful as screening indicators of potential impacts to humans and aquatic wildlife.	7	3
03. Health Risks Associated with Irrigating Crops with Recycled Water. This project will determine what risks, if any, to human health exist when recycled water is used to irrigate food crops.	6	7
17. Develop NTA Tools and Standardize Protocols. This project will harmonize strategies and standardize methods, including data analysis, for application of non-targeted analysis to recycled water.	6	1
18. Identify Transformation Products and Other Unknowns. This project will utilize NTA to identify transformation products at different stages of treatment, including reverse osmosis (RO) concentrate.	6	3
09. Optimizing Source Control for CEC Removal. This project will look at the impact of source control on the presence of CECs and how source control programs can be optimized for CEC removal.	5	4
19. Non-targeted Fingerprinting of Source Water Quality. This project will generate source water fingerprints using NTA across treatment facilities and at different time scales and develop an early warning system that uses NTA in conjunction with other monitoring tools (i.e., targeted analysis, screening cell assays).	5	2
32. Next Generation Treatment Technologies. This project would develop new RO and non-RO based technologies that improve treatment and that reduce energy and water usage, discharge and cost.	5	8
15. Establish Benchmark Bioassay Techniques for Water Sources and CEC Removal Using Various Treatment Systems. This project would benchmark recycled water with other water sources using multiple bioassays. The project would also use of bioassays to evaluate the efficacy of CEC removal using various treatment systems.	4	0
22. Develop Training Materials for Recycled Water Facility Operators. This project will identify the critical information needed to	4	3

Project Number and Description	Number of Responses (Attendees)	Number of Responses (Non-attendees)
properly train recycled water facility operators, and will develop training manuals and curricula.		
26. Standardize Operational Practices for CEC Removal by Advanced Oxidation Processes (AOPs). This project will develop a guidance manual standardizing practices and optimizing performance for AOPs (e.g. existing UV disinfection guidelines).	4	2
04. Standard Methods for CEC Analysis. This project will evaluate, select and validate methods that could become industry standards, looking for cost-effective options to achieve the necessary reporting limits.	3	5
05. Chemical testing for Transformation Products of CECs & Other Unknowns. This project would examine the transformation potential for common CECs during processes like oxidation, biological activated carbon, and soil aquifer treatment using chemical testing methods and then identify the potential health risks of the transformation products.	3	3
06. CEC Reporting Limits. This project would determine the required method reporting limits for key CECs, which are independent of the limit of detection.	3	2
14. Assess the Universe of CECs and Relevant Bioassays for Recycled Water. This project would establish a process to prioritize CECs of relevance to recycled water and develop the drivers for determining a set of bioassays for screening recycled water quality.	3	2
20. Source Water Quality and Treatment Design Considerations. This project will characterize pathogens and CECs in secondary treated effluent, and identify the type and level of treatment required to produce recycled water for potable use.	3	6
21. Develop a Guidance Manual for Assessing and Managing Risks of Contaminants in Recycled Water. This project will develop a "how-to manual" for implementing a HACCP management system to assess and manage the risk of CECs in recycled water on a site-specific basis.	3	1
24. Comparative Analysis of CEC Removal. This project will conduct a comparative analysis of key CECs and the effectiveness of the most common wastewater treatment technologies, including determining actions to optimize these treatments.	3	7
28. Categorize and Prioritize CECs. This project will place CECs into categories of priority based on the potential severity of impacts to human health and the environment, persistence in the system, wideness of distribution, and other qualities.	3	7
34. Evaluate Robustness of Treatment Processes for the Removal of CECs. This project will document the relative robustness of unit processes and treatment trains in removing CECs in potable reuse applications.	3	8
35. CEC Monitoring Program Guidance. This project will produce a guidance document for utilities and water agencies on the development of a voluntary CEC monitoring program.	3	1
36. Evaluate and Update List of Surrogates for CEC Monitoring. This project will evaluate the use of current surrogates and identify	3	5

Project Number and Description	Number of Responses (Attendees)	Number of Responses (Non-attendees)
additional surrogates that correlate with the occurrence and removal of CECs in recycled water.		
23. Develop Reliable Sensors for Operations Control. This project will develop sensors that could be used to alert operators to issues with treatment performance or events that may have occurred that could impact water quality.	2	4
25. Evaluate Removal of CECs by Ozone/Biological Activated Carbon (BAC) Treatment. This project will determine the effectiveness of ozone/BAC for removing CECs and as a pretreatment method for membrane filtration (MF)/RO	2	2
27. Concentrate Characterization and Treatment. This project will identify and categorize constituents, including breakdown products, present in the concentrate from reverse osmosis (RO) and summarize objectives for treatment technologies for treating concentrate.	2	8
29. Validation Program for New and Emerging Technologies. This project would develop a process for establishing protocols to validate new and emerging technologies, and the feasibility of establishing a national or regional technology validation center(s).	2	6
33. Identification of Unknowns. This project will identify the remaining components in the total organic carbon (TOC) in recycled water facility effluents (”product water”).	2	2
12. Develop Standard Operating Procedures and QA/QC for Cell Bioassays. This project will develop SOPs that cover all facets of bioassay measurement (sample preparation, conductance of bioassays, reporting). The project would provide guidance and training for water agencies to run cell bioassays in-house.	1	0
30. Monitoring Approaches and Critical Control Points (CCPs) to Verify Control of Pathogens and Chemicals. This project would identify CCPs and monitoring techniques, including new tools (e.g. bioassays, sensors, non-targeted analysis) needed for new or emerging technologies.	1	2
31. Develop New Online Sensors for CECs. This project would develop a database of appropriate CECs and indicators/surrogates to monitor with online sensors, and a plan to incentivize the commercialization of new sensors.	1	4
07. Validation of Existing Online Sensors for CECs. This project will validate existing sensors to be used for correlation with CEC detection and/or removal.	0	2
08. Tools to Predict the Replacement of Reverse Osmosis (RO) Membranes. This project will develop tools (e.g., trend analysis or log removal) to predict the need for the replacement of RO membranes before that need becomes acute.	0	3
13. Multiplexing Cell Bioassay Technologies. This project will investigate the development of bioassay endpoints using cell lines containing receptors for several desired biological pathways, with the goal of increasing measurement efficiency.	0	0
16. Develop a Work Flow Toolbox for Bioassay Results. This project would develop a work flow consisting of treatment, monitoring, or	0	0

Project Number and Description	Number of Responses (Attendees)	Number of Responses (Non-attendees)
management procedures to follow interpreting bioassay results.		

The fourth survey question asked about projects that would lead to the greatest increase in recycled water use in California, which related both to filling scientific knowledge gaps as well as instilling public confidence in recycled water use. It followed, therefore, that the evaluation of toxicological and ecological effects of CECs ranked highly, along with further development and increasing understanding and application of bioassays and non-targeted analyses.

Recommendations

The State Water Board will continue to collaborate with NWRI, SCCWRP, WE&RF, and other research agencies to bring together scientific experts to share the most current information in recycled water research. In addition, the State Water Board plans to use the results of this workshop to aid in the allocation of Proposition 1 grant funds for recycled water research, and specifically, research on CECs. These ongoing collaborative efforts will continue to inform the State Water Board on emerging research, and aid in advancing the production and use of recycled water in California while protecting water quality.

Acknowledgements

This report was completed by the National Water Research Institute (NWRI), Southern California Coastal Water Research Project Authority (SCCWRP), Water Environment & Reuse Foundation (WE&RF), and the California State Water Resources Control Board (State Water Board). Claire Waggoner served as the State Water Board manager on this effort, and Laura McLellan aided in preparation of this report.

The State Water Board would like express appreciation to Jeff Mosher of NWRI, Steve Weisberg of SCCWRP, and Melissa Meeker and Julie Minton of WE&RF for their efforts, input, and coordination in making this workshop possible, and to all workshop attendees, whose input and participation contributed to the overall success in meeting the goals identified for this workshop. The State Water Board would also like to thank Dr. Shane Snyder of the University of Arizona, Mike Wehner of the Orange County Water District, Dr. Michael Denison of UC Davis, Dr. Lee Ferguson of Duke University, Dr. Rhodes Trussell and Dr. Brian Pecson of Trussell Technologies, Dr. Ben Stanford of Hazen and Sawyer, Andy Salveson of Carollo Engineers, Dr. Karl Linden of University of Colorado, Boulder, Alvine C. Mehinto and Keith Maruya of SCCWRP, and Scott Couch and Claire Waggoner of the State Water Board for their insightful presentations, thoughtful facilitation, and contributions to a productive workshop.

Appendix A: Meeting Agenda

CALIFORNIA Water Boards

Recycled Water Research Workshop: Monitoring and Treatment Performance for Constituents of Emerging Concern

EDMUND G. BROWN JR.
GOVERNOR

MATTHEW RODRIQUEZ
SECRETARY FOR
ENVIRONMENTAL PROTECTION

State Water Resources Control Board

Tuesday October 27th, 2015
Day 1 – Monitoring for CECs

Meeting Goals:

- To have a discussion among Water Board, drinking water, wastewater, and storm water agency managers, and research organizations on the strategies for addressing constituents of emerging concern (CECs) in recycled water.
- Identify and prioritize CEC monitoring and treatment research activities that will ensure water supplies from recycled water are protective of public health and the environment.

8:30 am	Welcome, Charge, and Introductions	Board Member Steven Moore and Victoria Whitney State Water Board Steve Weisberg SCCWRP
8:50 am	Overview: State of the science of CEC monitoring.	Shane Snyder University of Arizona
9:30 am	Topic 1: Chemical testing	Mike Wehner, Orange County Water District
10:00 am	**BREAK**	
10:15 am	Topic 2: Bioanalytical screening	Mike Denison UC Davis
10:45 am	Topic 3: Applications of bioassays for recycled water	Shane Snyder University of Arizona
11:15 am	Topic 4: Non-targeted analysis	Lee Ferguson Duke University
11:45 am	Instructions for afternoon Breakout Sessions: - 4 groups - Rotation between the 4 topics	Jeff Mosher, National Water Research Institute (NWRI)
12:00 noon	**Lunch (on site)**	

1:00 pm	Breakout Session #1: Go to the room matching the first letter on your name tag code (bottom right corner)	Rooms A, B, C, D
1:40 pm	Breakout Session #2 Go to the room matching the second letter on your name tag code	Rooms A, B, C, D
2:20 pm	**BREAK**	
2:40 pm	Breakout Session #3 Go to the room matching the third letter on your name tag code	Rooms A, B, C, D
3:20 pm	Breakout Session #4 Go to the room matching the fourth letter on your name tag code	Rooms A, B, C, D
4:00 pm	Report Out and Wrap Up	Steve Weisberg SCCWRP

Wednesday October 28th, 2015
Day 2 – Treatment performance for CECs

Meeting Goals:

- To have a discussion among Water Board, drinking water, wastewater, and storm water agency managers, and research organizations on the strategies for addressing constituents of emerging concern (CECs) in recycled water.
- Identify and prioritize CEC monitoring and treatment research activities that will ensure water supplies from recycled water are protective of public health and the environment.

8:30 am	Transition to Day 2	Jeff Mosher NWRI
8:50 am	Overview: Assessing performance of treatment for CECs	Rhodes Trussell Trussell Technologies
9:30 am	Topic 1: Source control, operations, maintenance, and training.	Ben Stanford Hazen and Sawyer
10:00 am	**BREAK**	
10:15 am	Topic 2: Assessing CEC performance of currently used technologies	Andy Salveson Carollo Engineers
10:45 am	Topic 3: Assessment of emerging and innovative technologies and monitoring strategies.	Karl Linden U. Colorado Boulder
11:15 am	Topic 4: Reliability and resiliency	Brian Pecson Trussell Technologies

11:45 am	Instructions for afternoon Breakout Sessions: - 4 groups - Rotation between the 4 themes	Jeff Mosher NWRI
12:00 noon	**Lunch (on site)**	
1:00 pm	Breakout Session #1: Go to the room matching the first letter on your name tag code	Rooms A, B, C, D
1:30 pm	Breakout Session #2 Go to the room matching the second letter on your name tag code	Rooms A, B, C, D
2:00 pm	Breakout Session #3 Go to the room matching the third letter on your name tag code	Rooms A, B, C, D
2:30 pm	Breakout Session #4 Go to the room matching the fourth letter on your name tag code	Rooms A, B, C, D
3:00 pm	Report Out and Wrap Up	Steve Weisberg SCCWRP

Appendix B: Workshop Attendees

Last name	First Name	Organization	Email Address
Aflaki	Roshanak	City of Los Angeles	roshanak.aflaki@lacity.org
Armstrong	Jeff	Orange County Sanitation District	jarmstrong@ocsd.com
Bernados	Brian	State Water Board-DDW[1]	brian.bernados@waterboards.ca.gov
Campbell	Doug	City of San Diego Public Utilities Department	dcampbell@sandiego.gov
Chang	Cathy	Water Replenishment District of Southern California	cchang@wrd.org
Chao	Jing-Tying	State Water Board-DDW[1]	jing-tying.chao@waterboards.ca.gov
Couch	Scott	State Water Board-DWQ[2]	scott.couch@waterboards.ca.gov
Denison	Mike	UC Davis	msdenison@ucdavis.edu
Dorrington	Gina	City of Ventura	gdorrington@venturawater.net
Farahnak	Shahla	State Water Board-DWQ[2]	shahla.farahnak@waterboards.ca.gov
Ferguson	Lee	Duke University	lee.ferguson@duke.edu
Gearheart	Greg	State Water Board-OIMA[3]	greg.gearheart@waterboards.ca.gov
Gossett	Richard	IIRMES/Physis	richgossett@yahoo.com
Haddad	Serge	Los Angeles Department of Water and Power	serge.haddad@ladwp.com
Javier	Al	Eastern Municipal Water District	javiera@emwd.org
Joy	Jayne	Eastern Municipal Water District	joyj@emwd.org
Klein	Eric	San Diego County Public Works	eric.klein@sdcounty.ca.gov
Larabee	Jeannine	Santa Clara Valley Water District	jlarabee@valleywater.org
Lau	Al	Padre Dam Municipal Water District	alau@padre.org
Li	Susanna	West Basin Municipal Water District	susannaL@westbasin.org
Linden	Karl	University Colorado Boulder	karl.linden@colorado.edu
Maruya	Keith	SCCWRP[4]	keithm@sccwrp.org
Meeker	Melissa	Water Reuse Research Foundation	mmeeker@watereuse.org
Mehinto	Alvine	SCCWRP[4]	alvinam@sccwrp.org
Minton	Julie	Water Reuse Research Foundation	jminton@watereuse.org
Mosher	Jeff	National Water Research Institute	jmosher@nwri-usa.org
Mumley	Tom	San Francisco Bay RWB[5]	thomas.mumley@waterboards.ca.gov

[1] Division of Drinking Water
[2] Division of Water Quality
[3] Office of Information Management and Analysis
[4] Southern California Coastal Water Research Project
[5] Regional Water Board

Last name	First Name	Organization	Email Address
Nasaei	Elnaz	State Water Board-DWQ[2]	elnaz.nasaei@waterboards.ca.gov
Noetle	Jeff	Inland Empire Utilities Agency	jnoelte@ieua.org
Oldewage	Lars	Irvine Ranch Water District	oldewage@irwd.com
Osibodu	Fisayo	San Diego RWB[5]	olufisayo.osibodu@Waterboards.ca.gov
Owen	Doug	Water Reuse Research Foundation	doug.owen@arcadis.com
Packard	Harvey	Central Coast RWB[5]	harvey.packard@waterboards.ca.gov
Pecson	Brian	Trussell Technologies	brianp@trusselltech.com
Plumlee	Meghan	Orange County Water District	mplumlee@ocwd.com
Pramanik	Amit	Water Environment Research Foundation	apramanik@werf.org
Rosilela	Sherly	State Water Board-DDW[1]	sherly.rosilela@waterboards.ca.gov
Roy	Toby	San Diego County Water Authority	troy@sdcwa.org
Salveson	Andy	Carollo Engineers	asalveson@carollo.com
Sharp	Grant	Orange County Public Works	grant.sharp@ocpw.ocgov.com
Smith	Deborah	Los Angeles RWB[5]	deborah.smith@waterboards.ca.gov
Smythe	Hope	Riverside Regional Water Board	hope.smythe@waterboards.ca.gov
Snyder	Shane	University of Arizona	snyders2@email.arizona.edu
Thompson	Lisa	Sacramento County Regional Sanitation District	thompsonlisa@sacsewer.com
Stanford	Ben	Hazen and Sawyer	bstanford@hazenandsawyer.com
Tang	Hoan	Los Angeles County Flood Control District	htang@dpw.lacounty.gov
Tremblay	Martha	Los Angeles County Sanitation Districts	mtremblay@lacsd.org
Tremblay	Raymond	Los Angeles County Sanitation Districts	rtremblay@lacsd.org
Trussell	Rhodes	Trussell Technologies	rhodes.trussell@trusselltech.com
Waggoner	Claire	State Water Board-DWQ[2]	claire.waggoner@waterboards.ca.gov
Wass	Lonnie	Central Valley RWB[5]	lonnie.wass@waterboards.ca.gov
Wehner	Mike	Orange County Water District	mwehner@ocwd.com
Weisberg	Stephen	SCCWRP[4]	stevew@sccwrp.org
Whitney	Victoria	State Water Board-DWQ[2]	victoria.whitney@waterboards.ca.gov
Young	Michele	City of San Jose	michele.young@sanjoseca.gov

[1] Division of Drinking Water [2] Division of Water Quality
[4] Southern California Coastal Water Research Project [5] Regional Water Board

Appendix C: Speaker Biographies

 Mike Denison University of California, Davis	Dr. Mike Denison received a B.S. degree in Marine Biology from St. Francis College, a M.S. degree in Animal Physiology from Mississippi State University and a Ph.D. in Environmental Toxicology from Cornell University. After postdoctoral research in the Clinical Pharmacology Department at the Hospital For Sick Children in Toronto and the Molecular Pharmacology Department at Stanford University, he joined the Department of Biochemistry at Michigan State University as an Assistant Professor and relocated UC to Davis where he is currently a professor in the Department of Environmental Toxicology. Dr. Denison's overall research focus for the past 35 years has been directed toward understanding the molecular mechanisms by which the Ah receptor mediates the biological/toxicological actions of dioxins and related chemicals and nuclear hormone (steroid) receptors mediate the action of endocrine disrupting chemicals. In addition to his work on the biochemical and molecular analysis of the Ah receptor and steroid hormone receptors, his laboratory has a major emphasis in the development of receptor-based bioassay systems for the detection and quantitation of dioxin-like chemicals and environmental hormones (endocrine disruptors) in environmental, biological, food and commercial and consumer products. He has more than 200 publications in these areas.
 Lee Ferguson Duke University	Dr. P. Lee Ferguson is an Associate Professor of Environmental Science and Chemistry at Duke University in Durham, NC. Research in the Ferguson laboratory is focused on Environmental Analytical Chemistry. Specifically, his research group develops novel methods for trace analysis of organic and nanoparticulate contaminants in the aquatic environment. Specifically, a major thrust of research in the lab involves the application of high resolution, accurate mass (HRAM) mass spectrometry coupled with multidimensional chromatographic separations, bioaffinity isolation techniques, and online sample preparation methods to detect, identify, and quantify emerging contaminants (including endocrine disruptors, pharmaceuticals, and surfactants) in wastewater and drinking water. Another significant research thrust involves the development of sensitive trace analytical techniques for quantifying and characterizing carbon based nanoparticles in natural and engineered systems. The analytical methods developed in the Ferguson laboratory (for both nanoparticles and organic contaminants) are applied to both process-oriented environmental chemistry experiments in the field and laboratory as well as to toxicity bioassays (including whole-organism assays and molecular endpoints). The overarching goal is to gain an increased understanding of how emerging contaminants are transported, transformed and induce deleterious effects within aquatic ecosystems.

 Karl Linden University of Colorado Boulder	Dr. Karl G. Linden is a Professor of Environmental Engineering and the Mortenson Professor in Sustainable Development at the University of Colorado Boulder, USA. He has a BS from Cornell University in Agricultural and Biological Engineering and an MS and PhD from University of California at Davis in Environmental Engineering. He teaches classes on UV Processes in Environmental Systems, Sustainable Water Reuse, and Water Sanitation and Hygiene. Dr. Linden's research has investigated novel water and wastewater treatment systems, including advanced and innovative UV systems; the efficacy of UV and ozone disinfection for inactivation of pathogens; and the use of UV and advanced oxidation processes for the degradation of organic and other emerging contaminants in water and wastewater. Dr. Linden is an associate editor of Journal of Environmental Engineering and Journal of the American Water Works Association. He serves as Trustee of the Water Science and Research Division of the AWWA, and is 2013-2016 President of the International Ultraviolet Association (IUVA). He was named a 2013-2014 Fellow of the Australian Water Recycling Centre of Excellence, received the 2013 Pioneer Award in Disinfection and Public Health from the Water Environment Federation and was the WateReuse Association's 2014 WateReuse Person of the Year. Professor Linden Co-Directs the Mortenson Center in Engineering for Developing Communities at CU Boulder.
 Brian Pecson Trussell Technologies	Dr. Brian M. Pecson has a B.S. and B.A. from the University of Notre Dame, and an M.S. and Ph.D. in Civil and Environmental Engineering from the University of California at Berkeley. Dr. Pecson is a registered engineer in the state of California. Dr. Pecson has 9 years of environmental engineering experience and has authored 7 research papers. His professional experiences have focused on the reuse of wastewater and sludges, the analysis of alternative treatment processes, and the impact of treatment decisions on greenhouse gas emissions. His interests in the field of water reuse include the treatment and management of brine residuals, the suitability of recycled water for agriculture, and the development of technologies for indirect potable reuse. In addition to analyzing alternative treatment processes based on water quality criteria, Dr. Pecson is interested in understanding how these decisions affect the carbon footprint of treatment facilities. His past research experience focused on the disinfection of wastewater and sludges, with an emphasis on viruses and helminth eggs, two of the most resistant pathogen classes. These studies provided a wide breadth of experience, from low-tech treatment options (constructed wetlands, alkaline sludge stabilization) to the development of molecular detection methods.

 Andy Salveson Carollo Engineers	Mr. Andy Salveson is the Vice President, Water Reuse Chief Technologist, and Disinfection Principal at Carollo Engineers in Walnut Creek, CA. Mr. Salveson has 19 years of environmental consulting experience serving public and private-sector clients in the research and design of water and wastewater treatment systems. He is a nationally recognized expert in water reuse and disinfection, and provides Carollo's clients with guidance and expertise on the latest industry issues and technology regarding reuse. Mr. Salveson has led numerous planning, design, and research projects for various organizations, utilities, and corporations, and was honored with the 2007 WateReuse Person of the Year Award for bringing innovative technologies to market. Mr. Salveson specializes in water reuse and disinfection, treatment technology development, and water treatment technology research and investigations, including innovations in UV disinfection and new approaches to ozone treatment. Mr. Salveson is currently working on design efforts for indirect and direct potable water reuse projects in Oregon, California, New Mexico, and Texas.
 Shane Snyder University of Arizona	Dr. Shane Snyder is a Professor of Chemical & Environmental Engineering, and holds joint appointments in the College of Agriculture and School of Public Health, at the University of Arizona. He also co-directs the Arizona Laboratory for Emerging Contaminants (ALEC) and the Water & Energy Sustainable Technology (WEST) Center. For nearly 20 years, Dr. Snyder's research has focused on the identification, fate, and health relevance of emerging water pollutants. Dr. Snyder and his teams have published over 175 manuscripts and book chapters on emerging contaminant analysis, treatment, and toxicology (H-index = 55 as of September 2015). He currently serves as an editor-in-chief for the international journal Chemosphere. Dr. Snyder has been invited to brief the Congress of the United States on three occasions on emerging issues in water quality. He has served on several U.S. EPA expert panels and is currently a member of the EPA's Science Advisory Board drinking water committee. He was recently appointed to the World Health Organization's Drinking Water Advisory Panel and was a member of the US National Academy of Science's National Research Council Committee on Water Reuse. Dr. Snyder also is a Visiting Professor at the National University of Singapore and an Adjunct Professor at the Gwangju Institute of Science and Technology in South Korea.

 Ben Stanford Hazen and Sawyer	Dr. Ben Stanford is the Director of Applied Research at Hazen and Sawyer in Raleigh, NC where he manages a portfolio that has spanned over 50 research grants and also leads the company's water reuse practice group. Dr. Stanford earned his Ph.D. in Environmental Sciences and Engineering from UNC Chapel Hill and has conducted a range of studies spanning science, engineering, and public health protection for water, water reuse, and wastewater. His current work includes numerous direct and indirect potable water reuse studies and projects. He also serves as an expert advisor to AWWA, NSF, municipalities, and several other groups on emerging contaminants, cyanotoxins, chlorate/perchlorate, disinfection byproducts, and control of legionella in premise plumbing systems. Dr. Stanford has over 30 peer-reviewed publications, and was awarded the 2012 Publications Award by the American Water Works Association.
 Rhodes Trussell Trussell Technologies	The founder of Trussell Technologies, Inc., R. Rhodes Trussell, has a B.S., M.S., and Ph.D. in Environmental Engineering from University of California at Berkeley. Dr. Trussell is a registered Civil and Corrosion Engineer in the State of California with more than 40 years of experience who has authored more than 200 publications. He is recognized, worldwide, as an authority in methods and Criteria for Water Quality and in the development of advanced processes for treating water or wastewater to achieve the highest standards. He has worked on the process design for dozens of treatment plants, ranging from less than one to more than 900 mgd in capacity and has experience with virtually every physiochemical process and most biological processes as well. Dr. Trussell is available to review and advise on any complex water quality problem. He has a special interest in emerging water quality problems and reuse. Dr. Trussell served for more than ten years on EPA's Science Advisory Board, on several committees for the National Academies, including as Chair of their Water Science and Technology Board. For the International Water Association, Dr. Trussell has served on the Scientific and Technical Council, Editorial Boards, and on the Program Committee.

 Mike Wehner Orange County Water District	Mr. Mike Wehner is the Assistant General Manager at Orange County Water District (OCWD) and directly manages Water Quality and Technology programs at the District. Prior to joining OCWD in 1991, he spent 20 years with Orange County Environmental Health where he was Water Quality Program Chief. Mr. Wehner is an internationally recognized expert in water quality, public health and advanced water purification technology and has served on advisory panels for the National Water Research Institute, WaterRF, the Water Environment Research Foundation, the NRC, US EPA, CDPH, the California State Water Resources Control Board, UK Water Industry Research, Thames Water, CSIRO in Australia and the PUB in Singapore. Mr. Wehner received a Masters of Public Administration from California State University Long Beach and a B.S. in Biological Sciences from the University of California, Irvine.

Appendix D: Survey Questions and Raw Data for the Post-workshop Survey to Identify Priority Projects

Survey of Workshop Attendees

The survey was conducted online, using Survey Monkey, and had 27 respondents.

1. Rank the thematic research topics in order of highest priority (1) to lowest priority (8). Designating a thematic topic as the highest priority means funding projects in this topic area will furthest advance the expansion and development of potable recycled water projects in California.									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Score**
Assessing currently used technologies for CEC treatment and removal	4	6	5	2	6	3	1	0	5.52
Chemical Testing	6	2	4	4	7	2	0	2	5.26
Bioanalytical screening	4	2	6	2	1	4	5	3	4.48
Reliability and resiliency of treatment systems	5	4	2	2	1	3	7	3	4.44
Source control, operations, maintenance, and training	3	4	2	5	4	0	4	5	4.37
Applications of bioassays for recycled water	3	3	2	2	4	5	4	4	4.07
Assessing emerging technologies for CEC treatment and removal	1	2	3	5	3	7	3	3	3.96
Non-targeted constituent analysis	1	4	3	5	1	3	3	7	3.89

2. Rank the thematic research topics in order of highest priority (1) to lowest priority (8). Designating a thematic topic as the highest priority means funding projects in this topic area will furthest advance the expansion and development of non-potable recycled water projects in California.									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Score**
Chemical Testing	5	3	6	5	4	2	1	1	5.44
Assessing currently used technologies for CEC treatment and removal	2	0	9	4	8	2	2	0	4.89
Bioanalytical screening	5	3	4	2	2	6	3	2	4.78
Source control, operations, maintenance, and training	4	7	0	2	2	3	5	4	4.52
Applications of bioassays for recycled water	4	3	3	2	3	4	8	0	4.48
Reliability and resiliency of treatment systems	6	3	2	1	2	0	4	9	4.11
Non-targeted constituent analysis	1	6	1	4	2	3	2	8	3.89
Assessing emerging technologies for CEC treatment and removal	0	2	2	7	4	7	2	3	3.89

3. How important is the research project in the advancement of expanding recycled water in California?						
Project No.*	**Extremely Important**	**Important**	**Moderately Important**	**Somewhat Important**	**Not Very Important**	**Weighted Average**
1	12	7	5	1	0	1.80
2	12	6	4	2	1	1.96
3	7	6	5	5	2	2.56
4	7	12	5	0	1	2.04
5	6	11	6	1	1	2.20
6	3	10	8	2	2	2.6
7	2	13	3	4	3	2.72
8	3	8	10	2	2	2.68
9	7	7	8	2	1	2.32
10	10	6	5	3	1	2.16
11	13	3	5	3	1	2.04
12	2	12	8	2	1	2.52
13	1	7	5	9	3	3.24
14	10	5	6	4	0	2.16
15	8	6	4	6	1	2.44
16	3	12	5	4	1	2.52
17	5	7	5	4	4	2.80
18	9	5	5	4	2	2.40
19	8	5	4	6	2	2.56
20	6	10	4	3	2	2.40
21	6	7	6	3	3	2.60
22	7	7	5	4	2	2.48
23	4	14	4	2	1	2.28
24	6	11	5	1	1	2.17
25	6	8	8	3	0	2.32
26	7	5	10	3	0	2.36
27	7	6	9	3	0	2.32
28	9	13	2	1	0	1.80
29	3	5	9	6	1	2.88
30	4	11	6	4	0	2.40
31	1	13	5	1	5	2.84
32	3	10	5	3	4	2.80
33	4	11	7	1	2	2.44
34	6	8	6	2	3	2.52
35	4	11	5	3	2	2.52
36	10	8	6	0	1	1.96

*Corresponds to the numbers listed in Table 2.

4. Select five projects that if funded would lead to the greatest increase in the production and use of recycled water in California.	Responses
01. Evaluate CECs of Health Concern. This project would investigate how human health could be affected by the levels of CECs in drinking water (i.e., what is the "safe" or acceptable concentration of CECs?).	10
02. Evaluate CECs for Ecological Health. This project would investigate how aquatic life could be affected by exposure to CECs in product and waste streams from recycled water production, including concentrate from reverse osmosis.	9
03. Health Risks Associated with Irrigating Crops with Recycled Water. This project will determine what risks, if any, to human health exist when recycled water is used to irrigate food crops.	6
04. Standard Methods for CEC Analysis. This project will evaluate, select and validate methods that could become industry standards, looking for cost-effective options to achieve the necessary reporting limits.	3
05. Chemical testing for Transformation Products of CECs & Other Unknowns. This project would examine the transformation potential for common CECs during processes like oxidation, biological activated carbon, and soil aquifer treatment using chemical testing methods and then identify the potential health risks of the transformation products.	3
06. CEC Reporting Limits. This project would determine the required method reporting limits for key CECs, which are independent of the limit of detection.	3
07. Validation of Existing Online Sensors for CECs. This project will validate existing sensors to be used for correlation with CEC detection and/or removal.	0
08. Tools to Predict the Replacement of Reverse Osmosis (RO) Membranes. This project will develop tools (e.g., trend analysis or log removal) to predict the need for the replacement of RO membranes before that need becomes acute.	0
09. Optimizing Source Control for CEC Removal. This project will look at the impact of source control on the presence of CECs and how source control programs can be optimized for CEC removal.	5
10. Identify Bioassay Endpoints for Monitoring of Recycled Water. This project would identify cell bioassay endpoints that would be useful as screening indicators of potential impacts to humans and aquatic wildlife.	7
11. Interpretive Framework for Cell Bioassay Results. This project would develop a framework to translate cell bioassay results to support decision making by scientists, engineers and managers.	8
12. Develop Standard Operating Procedures and QA/QC for Cell Bioassays. This project will develop SOPs that cover all facets of bioassay measurement (sample preparation, conductance of bioassays, reporting). The project would provide guidance and training for water agencies to run cell bioassays in-house.	1
13. Multiplexing Cell Bioassay Technologies. This project will investigate the development of bioassay endpoints using cell lines containing receptors for several desired biological pathways, with the goal of increasing measurement efficiency.	0
14. Assess the Universe of CECs and Relevant Bioassays for Recycled Water. This project would establish a process to prioritize CECs of relevance to recycled water and develop the drivers for determining a set of bioassays for screening recycled water quality.	3

4. Select five projects that if funded would lead to the greatest increase in the production and use of recycled water in California.	Responses
15. Establish Benchmark Bioassay Techniques for Water Sources and CEC Removal Using Various Treatment Systems. This project would benchmark recycled water with other water sources using multiple bioassays. The project would also use of bioassays to evaluate the efficacy of CEC removal using various treatment systems.	4
16. Develop a Work Flow Toolbox for Bioassay Results. This project would develop a work flow consisting of treatment, monitoring, or management procedures to follow interpreting bioassay results.	0
17. Develop NTA Tools and Standardize Protocols. This project will harmonize strategies and standardize methods, including data analysis, for application of non-targeted analysis to recycled water.	6
18. Identify Transformation Products and Other Unknowns. This project will utilize NTA to identify transformation products at different stages of treatment, including reverse osmosis (RO) concentrate.	6
19. Non-targeted Fingerprinting of Source Water Quality. This project will generate source water fingerprints using NTA across treatment facilities and at different time scales and develop an early warning system that uses NTA in conjunction with other monitoring tools (i.e., targeted analysis, screening cell assays).	5
20. Source Water Quality and Treatment Design Considerations. This project will characterize pathogens and CECs in secondary treated effluent, and identify the type and level of treatment required to produce recycled water for potable use.	3
21. Develop a Guidance Manual for Assessing and Managing Risks of Contaminants in Recycled Water. This project will develop a "how-to manual" for implementing a HACCP management system to assess and manage the risk of CECs in recycled water on a site-specific basis.	3
22. Develop Training Materials for Recycled Water Facility Operators. This project will identify the critical information needed to properly train recycled water facility operators, and will develop training manuals and curricula.	4
23. Develop Reliable Sensors for Operations Control. This project will develop sensors that could be used to alert operators to issues with treatment performance or events that may have occurred that could impact water quality.	2
24. Comparative Analysis of CEC Removal. This project will conduct a comparative analysis of key CECs and the effectiveness of the most common wastewater treatment technologies, including determining actions to optimize these treatments.	3
25. Evaluate Removal of CECs by Ozone/Biological Activated Carbon (BAC) Treatment. This project will determine the effectiveness of ozone/BAC for removing CECs and as a pretreatment method for membrane filtration (MF)/RO	2
26. Standardize Operational Practices for CEC Removal by Advanced Oxidation Processes (AOPs). This project will develop a guidance manual standardizing practices and optimizing performance for AOPs (e.g. existing UV disinfection guidelines).	4
27. Concentrate Characterization and Treatment. This project will identify and categorize constituents, including breakdown products, present in the concentrate from reverse osmosis (RO) and summarize objectives for treatment technologies for treating concentrate.	2

4. Select five projects that if funded would lead to the greatest increase in the production and use of recycled water in California.	Responses
28. Categorize and Prioritize CECs. This project will place CECs into categories of priority based on the potential severity of impacts to human health and the environment, persistence in the system, wideness of distribution, and other qualities.	3
29. Validation Program for New and Emerging Technologies. This project would develop a process for establishing protocols to validate new and emerging technologies, and the feasibility of establishing a national or regional technology validation center(s).	2
30. Monitoring Approaches and Critical Control Points (CCPs) to Verify Control of Pathogens and Chemicals. This project would identify CCPs and monitoring techniques, including new tools (e.g. bioassays, sensors, non-targeted analysis) needed for new or emerging technologies.	1
31. Develop New Online Sensors for CECs. This project would develop a database of appropriate CECs and indicators/surrogates to monitor with online sensors, and a plan to incentivize the commercialization of new sensors.	1
32. Next Generation Treatment Technologies. This project would develop new RO and non-RO based technologies that improve treatment and that reduce energy and water usage, discharge and cost.	5
33. Identification of Unknowns. This project will identify the remaining components in the total organic carbon (TOC) in recycled water facility effluents (”product water”).	2
34. Evaluate Robustness of Treatment Processes for the Removal of CECs. This project will document the relative robustness of unit processes and treatment trains in removing CECs in potable reuse applications.	3
35. CEC Monitoring Program Guidance. This project will produce a guidance document for utilities and water agencies on the development of a voluntary CEC monitoring program.	3
36. Evaluate and Update List of Surrogates for CEC Monitoring. This project will evaluate the use of current surrogates and identify additional surrogates that correlate with the occurrence and removal of CECs in recycled water.	3

5. What improvements would you suggest for the next workshop?
1. Hear about the public perception issues and how that fits into the technical side.
2. Highlight some success stories regarding effective treatment of CECs
3. There was a lot of material covered in the two days. Is it possible to narrow the focus?
4. I thought the format for this workshop was very good. I cannot think of a good suggestion for improvement.
5. Great workshop.
6. Workshop was well done. Add more time at the end to answer questions like the ones in the survey on-site while it is all fresh in our minds.
7. None.
8. More dialog after the presentations rather than during the break-out discussions.
9. More overlap between discussion/breakout sessions of day 1 and 2. In the last workshop, topics discussed on day 1 were largely ignored on day 2 even though application of new tools was a relevant

topic.
10. A presentation giving an overview of where regulation is to date.
11. Thought it was an excellent mix of people and areas. Perhaps a bit more guidance in what was supposed to be derived in the breakout sessions would have been good. They would have been more productive.
12. Take this vote at the workshop. Hard to remember all of these projects.

6. What topic(s) would you like to see covered at the next Recycled Water Research Workshop?
1. More on sensors. Different types of recycled water (storm water, gray water).
2. Discussions regarding the top priority issues identified here.
3. Treatment reliability and resiliency. Response time. Water quality issues (other than CECs). Validation of technologies. Streamlining permitting. Concentrate management (including regulatory issues with concentrate in wastewater outfalls). Salinity management.
4. More on the state of the science for non-target analysis. Where and how it is currently being used and what is on the horizon.
5. Similar topics.
6. Pathogen monitoring and treatment.
7. No suggestions.
8. Bioanalytical screening tools. Non-targeted analysis for water quality assessment CEC removal and production during recycled water treatment. Effect of maintenance and operation on recycled water quality. CECs in recycled water waste streams discharged to receiving waters (e.g. RO concentrate).
9. Impact of recycled water on potable and non-potable distribution systems.
10. Impact of recycled water on potable and non-potable distribution systems.
11. Pathogens monitoring and removal of transformation products. Treatment and disposal of brine.
12. A look at CECs in source waters, the path in which CECs are introduced and what detection of them really means.

7. What type of organization are you affiliated with?	**Responses**
Water District	2
Utilities District	3
Regulatory	5
Research	11
Sanitation District	2
Storm Water	1
Other	1
Total	**25**

Survey of Non-Attendees

The survey was conducted using Survey Monkey, and had 31 respondents.

1. Rank the thematic research topics in order of highest priority (1) to lowest priority (8). Designating a thematic topic as the highest priority means funding projects in this topic area will furthest advance the expansion and development of potable recycled water projects in California.									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Score**
Assessing currently used technologies for CEC treatment and removal	8	2	4	5	6	4	2	0	5.39
Reliability and resiliency of treatment systems	7	4	7	2	4	3	1	3	5.35
Assessing emerging technologies for CEC treatment and removal	3	7	5	5	5	2	2	2	5.16
Chemical Testing	3	5	4	3	3	6	3	4	4.45
Source control, operations, maintenance, and training	4	3	3	6	4	3	4	4	4.45
Non-targeted constituent analysis	2	5	4	4	4	1	2	9	4.10
Bioanalytical screening	3	1	2	4	3	7	7	4	3.68
Applications of bioassays for recycled water	1	4	2	2	2	5	10	5	3.42

2. Rank the thematic research topics in order of highest priority (1) to lowest priority (8). Designating a thematic topic as the highest priority means funding projects in this topic area will furthest advance the expansion and development of non-potable recycled water projects in California.									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Score**
Assessing currently used technologies for CEC treatment and removal	5	5	6	5	4	4	2	0	5.42
Reliability and resiliency of treatment systems	7	8	1	2	3	4	2	4	5.16
Chemical Testing	7	1	6	5	5	1	2	4	5.00
Source control, operations, maintenance, and training	2	8	4	4	4	2	4	3	4.81
Assessing emerging technologies for CEC treatment and removal	2	2	6	6	6	4	2	3	4.48
Non-targeted constituent analysis	3	1	4	4	6	6	1	6	4.03
Bioanalytical screening	4	2	1	4	1	6	8	5	3.71
Applications of bioassays for recycled water	1	4	3	1	2	4	10	6	3.39

3. How important is the research project in the advancement of expanding recycled water in California?						
Project No.*	**Extremely Important**	**Important**	**Moderately Important**	**Somewhat Important**	**Not Very Important**	**Weighted Average**
1	15	7	2	3	1	1.86
2	11	7	6	3	1	2.14
3	4	15	5	3	1	2.36
4	8	7	6	6	1	2.46
5	11	7	7	3	0	2.07
6	3	10	8	5	2	2.75

3. How important is the research project in the advancement of expanding recycled water in California?						
Project No.*	Extremely Important	Important	Moderately Important	Somewhat Important	Not Very Important	Weighted Average
7	7	6	7	6	2	2.64
8	6	7	9	4	2	2.61
9	8	12	2	4	2	2.29
10	5	8	6	8	1	2.71
11	7	3	8	9	1	2.79
12	4	4	8	9	3	3.11
13	3	3	9	9	4	3.29
14	6	3	9	9	4	3.29
15	7	3	8	7	3	2.86
16	2	4	8	8	6	3.43
17	3	5	5	10	5	3.32
18	6	7	9	4	1	2.52
19	4	4	12	6	2	2.93
20	9	5	9	3	2	2.43
21	3	6	11	6	2	2.93
22	3	8	10	6	1	2.79
23	8	6	6	7	0	2.44
24	9	7	5	6	1	2.39
25	6	8	4	8	2	2.71
26	8	8	4	6	2	2.50
27	7	13	5	3	0	2.14
28	11	9	4	3	1	2.07
29	4	9	8	5	2	2.71
30	3	10	9	5	1	2.68
31	7	7	5	8	1	2.61
32	9	7	7	3	2	2.36
33	8	7	7	5	1	2.43
34	9	4	9	4	2	2.50
35	5	5	5	12	1	2.96
36	8	6	6	6	2	2.57

* Corresponds to Table 2.

4. Select five projects that if funded would lead to the greatest increase in the production and use of recycled water in California.	Responses
01. Evaluate CECs of Health Concern. This project would investigate how human health could be affected by the levels of CECs in drinking water (i.e., what is the "safe" or acceptable concentration of CECs?).	15
02. Evaluate CECs for Ecological Health. This project would investigate how aquatic life could be affected by exposure to CECs in product and waste streams from recycled water production, including concentrate from reverse osmosis.	12
03. Health Risks Associated with Irrigating Crops with Recycled Water. This project will determine what risks, if any, to human health exist when recycled water is used to irrigate food crops.	7

4. Select five projects that if funded would lead to the greatest increase in the production and use of recycled water in California.	Responses
04. Standard Methods for CEC Analysis. This project will evaluate, select and validate methods that could become industry standards, looking for cost-effective options to achieve the necessary reporting limits.	5
05. Chemical testing for Transformation Products of CECs & Other Unknowns. This project would examine the transformation potential for common CECs during processes like oxidation, biological activated carbon, and soil aquifer treatment using chemical testing methods and then identify the potential health risks of the transformation products.	3
06. CEC Reporting Limits. This project would determine the required method reporting limits for key CECs, which are independent of the limit of detection.	2
07. Validation of Existing Online Sensors for CECs. This project will validate existing sensors to be used for correlation with CEC detection and/or removal.	2
08. Tools to Predict the Replacement of Reverse Osmosis (RO) Membranes. This project will develop tools (e.g., trend analysis or log removal) to predict the need for the replacement of RO membranes before that need becomes acute.	3
09. Optimizing Source Control for CEC Removal. This project will look at the impact of source control on the presence of CECs and how source control programs can be optimized for CEC removal.	4
10. Identify Bioassay Endpoints for Monitoring of Recycled Water. This project would identify cell bioassay endpoints that would be useful as screening indicators of potential impacts to humans and aquatic wildlife.	3
11. Interpretive Framework for Cell Bioassay Results. This project would develop a framework to translate cell bioassay results to support decision making by scientists, engineers and managers.	0
12. Develop Standard Operating Procedures and QA/QC for Cell Bioassays. This project will develop SOPs that cover all facets of bioassay measurement (sample preparation, conductance of bioassays, reporting). The project would provide guidance and training for water agencies to run cell bioassays in-house.	0
13. Multiplexing Cell Bioassay Technologies. This project will investigate the development of bioassay endpoints using cell lines containing receptors for several desired biological pathways, with the goal of increasing measurement efficiency.	0
14. Assess the Universe of CECs and Relevant Bioassays for Recycled Water. This project would establish a process to prioritize CECs of relevance to recycled water and develop the drivers for determining a set of bioassays for screening recycled water quality.	2
15. Establish Benchmark Bioassay Techniques for Water Sources and CEC Removal Using Various Treatment Systems. This project would benchmark recycled water with other water sources using multiple bioassays. The project would also use of bioassays to evaluate the efficacy of CEC removal using various treatment systems.	0
16. Develop a Work Flow Toolbox for Bioassay Results. This project would develop a work flow consisting of treatment, monitoring, or management procedures to follow interpreting bioassay results.	0
17. Develop NTA Tools and Standardize Protocols. This project will harmonize strategies and standardize methods, including data analysis, for application of non-	1

4. Select five projects that if funded would lead to the greatest increase in the production and use of recycled water in California.	Responses
targeted analysis to recycled water.	
18. Identify Transformation Products and Other Unknowns. This project will utilize NTA to identify transformation products at different stages of treatment, including reverse osmosis (RO) concentrate.	3
19. Non-targeted Fingerprinting of Source Water Quality. This project will generate source water fingerprints using NTA across treatment facilities and at different time scales and develop an early warning system that uses NTA in conjunction with other monitoring tools (i.e., targeted analysis, screening cell assays).	2
20. Source Water Quality and Treatment Design Considerations. This project will characterize pathogens and CECs in secondary treated effluent, and identify the type and level of treatment required to produce recycled water for potable use.	6
21. Develop a Guidance Manual for Assessing and Managing Risks of Contaminants in Recycled Water. This project will develop a "how-to manual" for implementing a HACCP management system to assess and manage the risk of CECs in recycled water on a site-specific basis.	1
22. Develop Training Materials for Recycled Water Facility Operators. This project will identify the critical information needed to properly train recycled water facility operators, and will develop training manuals and curricula.	3
23. Develop Reliable Sensors for Operations Control. This project will develop sensors that could be used to alert operators to issues with treatment performance or events that may have occurred that could impact water quality.	4
24. Comparative Analysis of CEC Removal. This project will conduct a comparative analysis of key CECs and the effectiveness of the most common wastewater treatment technologies, including determining actions to optimize these treatments.	7
25. Evaluate Removal of CECs by Ozone/Biological Activated Carbon (BAC) Treatment. This project will determine the effectiveness of ozone/BAC for removing CECs and as a pretreatment method for membrane filtration (MF)/RO	2
26. Standardize Operational Practices for CEC Removal by Advanced Oxidation Processes (AOPs). This project will develop a guidance manual standardizing practices and optimizing performance for AOPs (e.g. existing UV disinfection guidelines).	2
27. Concentrate Characterization and Treatment. This project will identify and categorize constituents, including breakdown products, present in the concentrate from reverse osmosis (RO) and summarize objectives for treatment technologies for treating concentrate.	8
28. Categorize and Prioritize CECs. This project will place CECs into categories of priority based on the potential severity of impacts to human health and the environment, persistence in the system, wideness of distribution, and other qualities.	7
29. Validation Program for New and Emerging Technologies. This project would develop a process for establishing protocols to validate new and emerging technologies, and the feasibility of establishing a national or regional technology validation center(s).	6
30. Monitoring Approaches and Critical Control Points (CCPs) to Verify Control of Pathogens and Chemicals. This project would identify CCPs and monitoring techniques, including new tools (e.g. bioassays, sensors, non-targeted analysis) needed for new or emerging technologies.	2

4. Select five projects that if funded would lead to the greatest increase in the production and use of recycled water in California.	Responses
31. Develop New Online Sensors for CECs. This project would develop a database of appropriate CECs and indicators/surrogates to monitor with online sensors, and a plan to incentivize the commercialization of new sensors.	4
32. Next Generation Treatment Technologies. This project would develop new RO and non-RO based technologies that improve treatment and that reduce energy and water usage, discharge and cost.	8
33. Identification of Unknowns. This project will identify the remaining components in the total organic carbon (TOC) in recycled water facility effluents ("product water").	2
34. Evaluate Robustness of Treatment Processes for the Removal of CECs. This project will document the relative robustness of unit processes and treatment trains in removing CECs in potable reuse applications.	8
35. CEC Monitoring Program Guidance. This project will produce a guidance document for utilities and water agencies on the development of a voluntary CEC monitoring program.	1
36. Evaluate and Update List of Surrogates for CEC Monitoring. This project will evaluate the use of current surrogates and identify additional surrogates that correlate with the occurrence and removal of CECs in recycled water.	5

5. What type of organization are you affiliated with?	Responses
Water District	3
Utilities District	2
Regulatory	1
Research/University	4
Sanitation District	11
Storm Water	0
Public/Interested Party	0
Environmental/NGO	3
Other	2
Total	**26**