Scope of Work Document as prepared by Hazen and Sawyer, P.C.
Critical Control Point Assessment to Quantify Robustness and Reliability of Multiple Treatment Barriers of a DPR Scheme
(WRRF-13-03)

Attached here will be the Scope of Work Document as prepared by the Contractor. The "**Scope of Work Document**" shall be defined as a short written document that clearly describes the Project scope and the duties and responsibilities of the Contractor. The Scope of Work Document may be a derivative work of the Project Proposal with any updates made since.

The Scope of Work for this project includes the following work objectives, divided into the specific tasks and sub-tasks listed below:

(1) **Conduct a hazard assessment to identify health risks, identify water quality objectives, and identify critical control points** for both full advanced treatment (FAT) of MF/UF-RO-UV/H_2O_2-Cl_2 and the non-membrane O_3-BAC-GAC-UV-Cl_2. This will utilize a thorough literature review of previous research as well as full scale operating plant experience and operating data and will incorporate much of the work completed to date for project WateReuse-11-02. A key element of this work will be the inclusion of maintenance data from operating plants and identification of likely failure points within each of those processes based on that data. Our approach also included the assembly of a HACCP team and 2-day workshop to fully vet the water quality objectives, CCPs, and final list of chemical and microbial indicators and surrogates.

(2) **Conduct Challenge Studies using both bench scale, pilot scale and importantly full scale operating plant**. Our approach will incorporate the extensive amount of existing full-scale and pilot-scale data to develop the range of contaminant concentrations under normal modes and failure modes of operation. It is critical that ample data be collected and sorted to support the work of Task 3, thus the use of existing data is required. Where needed, additional full-scale, pilot-scale, and bench-scale challenge testing will be conducted at pilot sites in Arizona and elsewhere with laboratory analysis conducted by Shane Snyder at University of Arizona (the same lab currently supporting WateReuse-11-01 and WateReuse-11-02) to augment the findings of Task 1.

(3) **Use Monte Carlo** analysis to develop a probabilistic risk assessment to characterize, quantify, and communicate the risk of failing to meet treated water quality targets. Additional work will build upon the risk analysis to develop operation and response procedures as well as to provide insight into design standard guidelines.

The specific tasks and subtask are listed here, with full descriptions on the following pages:

Task 1: Conduct Hazard Assessment for Key Unit Operations and Determine CCPs
Subtask 1-A: Literature Review of Source Water Hazards
Subtask 1-B: Review of Hazardous Events and Modes of Failure
Subtask 1-C: Risk Assessment and CCP Selection Workshop
Task 2: Conduct Bench/Pilot/Full-Scale Challenge Test Studies

Task 3: Monte Carlo Risk Analysis to Support Design, Operation, and Response
Subtask 3-A: Monte Carlo Risk Analysis
Subtask 3-B: Workshop #2, Standard Operation and Response Procedures, and Design Standard Guidelines
Task 4: Prepare Guidance Document and Final Report

The specific tasks to be completed under this contract and Scope of Work are listed below.

Task 1: Conduct Hazard Assessment for Key Unit Operations and Determine CCPs

We will work with the Foundation staff and PAC to determine what unpublished data from existing projects such as WateReuse-09-03 might be available and useful to augment our assessment of the literature. This communication will begin before the kick-off meeting and will continue as a dialog throughout the project.

Secondly, and in keeping with HACCP principles, the project team will assemble a multi-disciplinary HACCP team to assist in the delivery of the project outcomes, including participation in two workshops described in the appropriate subtasks of this proposal. This team will be comprised of all the members of the project team, which includes experience of indirect potable reuse plant management and design, as well as experts in the field of recycled water quality research for public health. In addition to the project team, we will also work closely to gain operational experience and insight by engaging with operational personnel from water recycling plants in California including Orange County Water District, West Basin Municipal District, Scottsdale Water Campus in Arizona, and the Australian Water Recycling Center of Excellence (letters of support included in this proposal).

Once these administrative tasks are complete, the following Subtasks will be conducted as part of this effort:

Subtask 1-A: Literature Review of Source Water Hazards

The first principle of HACCP is to conduct a hazard assessment. Guidance from the draft California Reuse Regulations, the Australian Guidelines for Water Recycling, and the approach incorporated in the recent State of the Science report on potable reuse will be used to demonstrate the process of risk assessment and selection/prioritization of contaminants of concern or their appropriate indicators and surrogates. In addition, known risks from literature and other similar applications will be included in the risk assessment.

Our scope includes investigating data from a range of operating recycled water facilities in the United States, Australia, and Namibia to identify key microbial and chemical risks and failures that may lead to their presence in finished water. Operational sites that will provide data to support our team's efforts in this study include:

- Orange County Water District Groundwater Replenishment Scheme, CA, USA (FAT)
- West Basin Municipal District Edward C Little Recycling Facility, CA, USA (FAT)
- Scottsdale Water Campus, AZ, USA (FAT)

- Gerringong Water, NSW, Australia (Ozone – Biological Activated Carbon)
- Fairfield Water Recycling Plant, NSW, Australia (Microfiltration-Reverse Osmosis – Cl_2).
- Anonymous Water Recycling Scheme, Australia (name withheld) (FAT)
- Goreangab Water Recycling Plant, Windhoek, Namibia (Ozone- Biological Activated Carbon-GAC)

In addition to the full-scale operating data, the team will review current literature and emerging trends to identify any additional parameters of interest that may not have been considered in the example plants. There is a significant amount of water quality data available for water recycling schemes such as those requested in the RFP including from the following WateReuse Research Foundation Projects, of which our team members have been an integral part and/or on the PAC: 08-05, 08-08, 10-11, 11-01, 11-02, and 13-10. Project 13-10 is an ongoing study with the City of Hollywood, FL that includes 12 months of operational data with an ozone-BAC potable water reuse pilot system including data from over 200 regulated and unregulated contaminants monitored throughout the study. This project will provide a massive data set to support the Monte Carlo analysis. These documents and data sets, in addition to other published manuscripts regarding water quality related to each process, will be assembled and reviewed as part of this task.

Subtask 1-B: Review of Hazardous Events and Modes of Failure

In addition to the hazards presented in source water, the team will conduct a study of literature and incorporate operational data from full-scale facilities to determine likely hazardous events and modes of operational failure at the treatment barriers.

Data will be gathered from literature, as well as a review of operating history of participating water recycling facilities. Where available, a detailed review of operational maintenance records will be used to identify particular points of failure for each type of process or combination of processes. The data review will focus on both planned maintenance, in order to identify equipment or instrumentation that may have a high maintenance requirement, as well as unplanned maintenance where equipment may not have a high reliability.

In support of this review, our project team will have access to work completed under the "Australian Water Recycling Centre of Excellence Goal 3" project on the resilience of potable reuse schemes (http://www.australianwaterrecycling.com.au/current-projects.html). The data collected from this study are of direct importance for the Monte Carlo risk analysis to be conducted in Task 3. A database of all mechanical components has already been developed based on review of the As-Built P&ID's. Information on time on-line (utility) and product compliance history (quality) has been tabulated from operating records. Actual maintenance records have been reviewed to determine mean time to failure (MTTF) and mean time to repair (MTTR) for each component. Process-specific Weibull functions are being developed from data collected from each plant.

Information from the database will be used to determine system resilience (including availability and equipment criticality, costs and spares, etc.) using a Monte Carlo-based risk-based approach built on real failure and maintenance information. The development of failure scenarios was based on a critical review of documented incidents of failure in drinking water systems including 62 confirmed cases of pathogen outbreaks in developed countries over the period 2003-2010 with identification of what component of the system failed and why. The work has identified specific institutional, mechanical and operational errors that have led to water contamination. A suite of scenarios, based on these events, is being simulated to assess the probability and consequence of similar mechanical, operational and institutional failures in a potable reuse scheme.

Therefore, our Project Team will review the data and outputs from the "Australian Water Recycling Centre of Excellence Goal 3" study, including use the risk analysis and Monte Carlo simulated data to support our own risk analysis described in the remainder of this proposal.

Subtask 1-C: Risk Assessment and CCP Selection Workshop

After gathering data from the literature and operational facilities, the HACCP team will convene a workshop to complete a formal hazard risk assessment and determine critical control points for both the FAT and non-membrane processes.

We will construct representative process flow diagrams, then verify the process flow diagram using a logical decision tree. The process flow diagrams will be developed with detailed knowledge gathered from full scale plants where either the entire process train for FAT or non-membrane is used, or parts of the process are used.

The project team will convene a critical control point analysis workshop whereby the HACCP team will conduct a hazard identification by working through each process step of both the full available treatment and non-membrane process trains. Hazards will be categorized as microbial, chemical, and physical, with some sub-categorization of chemicals into relevant sub groups based on families of chemicals or analytical groups. The risk, treatment objective, and/or water quality goal associated with each identified hazard will be assessed using a scoring approach that rates both the likelihood and consequence of the hazardous event, relative to defined water quality objectives or treatment objectives. As a part of the hazard analysis, the HACCP team will identify control measures that would eliminate or reduce the hazard to an acceptable level.

Following the risk assessment, the HACCP team will develop a set of critical control points (CCPs). For each CCP, a measurable parameter will be identified for process monitoring (e.g., surrogates such as conductivity, TOC, trans-membrane pressure, turbidity, UVT). Given the general, broadly applicable scope of this project, specific critical limits will not be applied, but instead ranges from literature will be established.

Task 2: Conduct Bench/Pilot Level Challenge Test Studies

The purpose of Task 2 is to fill data gaps identified in Task 1, to provide a verification step in the selection of critical control points, and to provide the data necessary to conduct a Monte Carlo risk analysis in Task 3. There are at least two full scale challenge tests that we propose to conduct as a part of this study in order to provide additional data to support the use of the CCPs, and also to provide data for the Monte Carlo analysis (as outlined in the Proposal document). As part of this task, we are proposing limited full scale testing at the Scottsdale Water Campus to determine the impact of o-ring failure (e.g., rolled o-rings, missing/broken o-rings) on the sensitivity of pressure decay test as a critical control point for membrane filtration. Full scale testing of reverse osmosis membrane processes will also be conducted to determine the sensitivity of o-ring and interconnector failures. An additional benefit of the test at Scottsdale will be the ability to compare the different impact of o-ring failure from standard 8" diameter membrane systems compared to newer generation 16" diameter membranes. Additional pilot-scale and/or bench-scale tests will also be needed to fill in any remaining gaps and will be conducted at University of Arizona.

Task 3: Conduct Monte Carlo Risk Analysis and Develop Standard Design Approaches, Operational Procedures, and Response Strategies

Subtask 3A – Monte Carlo Risk Analysis

A risk analysis will be performed to characterize the risk of failing to meet satisfactory final water quality objectives as determined in Workshop #1. In order to develop an appropriate model for Monte Carlo simulation, both identified treatment trains (FAT and non-membrane systems) will require characterization of anticipated variability (and uncertainty) in source water composition, as well as variability (and uncertainty) in operational performance of individual treatment barriers. The necessary data for these requirements will be derived from a combination of existing literature and plant performance data (Task 1) as well as from the gaps addressed in the bench/pilot level challenge studies (Task 2).

Following established procedures, probability density functions (PDFs) will be derived for parameters known to be determining factors of final water composition. These include source water compositions and some specific treatment barriers, depending on the type of contaminant (pathogen, dissolved chemical). In most cases, individual treatment steps will be characterized for their variable performance in contaminant removal, but in some cases (e.g. DBPs), processes may lead to increased formation. In all cases, PDFs will be developed initially as cumulative distribution functions (CDFs), which have a number of advantages including the ability to effectively account for censored data (data < limit of detection) in a rigorous and statistically sound manner (Khan & McDonald, 2010). Such censored data present a common complicating factor for many water quality datasets (Figu).

Fitting of data to CDFs will be undertaken using @RISK v6 software (Palisade Corporation, 2013). This will allow for a wide variety of PDF-types to be assessed (e.g., Normal, Gamma, Weibull). However, previous studies have revealed lognormal CDFs are typically very well suited to water quality data. Furthermore, this choice is well supported by Central Limit Theorem. As such, lognormal CDFs will generally be favored for water quality data, but standard numerical tests (e.g. Anderson-Darling, Kolmogorov–Smirnov, chi-squared) and graphical tests (e.g. assessment of linearity of lognormal probability plots) will be applied to test 'goodness of fit' in all cases.

Since some advanced water treatment processes (e.g., reverse osmosis membranes) are very effective for contaminant removal it can be difficult to detect measurable effluent (in this case ‘permeate’) concentrations, required for the development of process removal CDFs. In some such cases, concentrate (brine) streams can be monitored and performance CDFs established by overall mass-balance.

Where possible, CDFs will be constructed from extensive datasets, thereby capturing a broad range of variable operational conditions. Furthermore, challenge testing undertaken to inform CDF development will be designed to capture a broad range of operational conditions.

Monitoring data from (potential) CCPs will also be subject to distribution analysis and fitted to appropriate CDFs using @RISK software and our full- and pilot-scale data. This will capture both the inherent variability in the monitoring data, as well as the underlying uncertainty in the measurement.

Monte-Carlo simulation analysis will initially be undertaken to assess the relationship between the measured CCP variability and observed variability in water composition. This will facilitate the determination of which parameters are in-fact sensitive to changes in CCP monitoring results, whether the relationship is linear and whether this holds across the range of CCP variability. A larger Monte-Carlo simulation will be used to combine the sources of variability and uncertainty across an entire treatment train, as well as throughout the entire range of CCPs being monitored to control the performance of that train. This will be used to determine the overall treatment process variability and the effectiveness of the CCPs in managing it. These Monte-Carlo simulations will be undertaken using @RISK software with 10,000 simulation iterations.

Subtask 3-B: Workshop #2, Standard Operation and Response Procedures, and Design Standard Guidelines

This workshop will not be included as part of this Scope of Work per recommendations from the PAC and the Foundation. However, the Project Team will convene a webinar with the PAC and HACCP team to discuss the results of the project and to provide any summary recommendations that may be helpful in defining Design Standard Guidelines and Standard Operation and Response Procedures.

Based on the work conducted in subtask 3A, and with involvement of the HACCP team, a set of standard operational responses will be prepared for each of the critical control points. This will take the form of both intended system control action, as well as operations response to a critical control failure. These will take the form of an easy to reference flow chart approach adapted from a similar HACCP plan operated system in Australia. The CCP response follows a logical progression of “if, then” scenarios, designed to ensure the safety and reliability of the treated water. Our team has extensive experience in developing such response plans and will include a general plan for both full available treatment and non-membrane based DPR facilities.

Finally, using the information collected in all previous tasks, a set of standard design guidelines for each CCP will be prepared as a part of the outcome of this study. These guidelines will focus specifically on outcomes of this study to enhance the robustness, reliability and operability of each CCP from the standpoint of protection of public health. It will focus both on key process barriers that are identified as CCPs, with specific detail of monitoring equipment and instrumentation. In addition, maintenance and calibration recommendations will also be provided.

Task 4: Prepare Guidance Document and Final Report

The Final Report, Response Plan, and Design Standard Guidelines will be deliverables provided to the PAC and the Foundation for review towards the end of the project. Pending feedback from the PAC and the Foundation, these documents can be provided as a single deliverable or can be split into two separate deliverables, with the Final Report also containing the Guidance Document. We plan on submitting a draft outline of the final report for PAC review within the first two quarters of the project.