WateReuse Research Foundation
Proposal Cover Sheet

RFP # Tailored Collaboration

Title: Building-Scale Treatment for Direct Potable Water Reuse & Intelligent Control for Real Time Performance Monitoring

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Total WRRF Funds Requested: $ 100,000

Total SFPUC Cash Contribution: $ 324,670

Other Funding: $100,000

In-Kind Total: $101,830

Total Project Budget: $626,500

ABSTRACT

This proposed research project is intended as a collaborative effort between the SFPUC and WRRF, and potentially other organizations, such as Water Research Foundation (WRF) and the US Bureau of Reclamation (USBR). The SFPUC is seeking equal contribution from WRRF and WRF ($100,000 each), and the budget detailed in this proposal reflects the funding requests. The SFPUC has previously submitted a funding proposal to USBR for $200,000; however, we have not received a response at the time of this submittal. Therefore, the proposed budget assumes that USBR funding is not forthcoming. If USBR funding is made available at a future date, those funds would be used to extend the duration of our demonstration and conduct a power analysis and increase sampling, beyond the current scope. If WRF funds are not available, the project is still viable and the SFPUC remains committed to its implementation. We expect all funding sources to be known in May 2016, before we enter into funding agreements. As a research project intended to provide valuable information to the industry regarding the efficacy and reliability of treatment processes for Direct Potable Reuse (DPR), we value a partnership with WRRF for the credibility it lends to this research, and hope that you will support this project.

Overview and Objectives. DPR starts with raw wastewater and ends with purified water that is protective of public health. This project will use innovative building-scale treatment, proven purification processes, real time online monitoring, and advanced analytical tools to demonstrate water quality and public health protection in real time. The proposed project will help fill an important research gap, providing data on the technical viability of building-scale treatment. We recognize that economic and operational feasibility will also need to be addressed in the future. The advanced purification system for DPR will be sited at the San Francisco Public Utilities Commission Headquarters Building, where an existing Living Machine® System treats the building's wastewater to non-potable reuse standards. After performance data is collected, effluent from the purification treatment train will blended with the living machine effluent for toilet flushing in the building.

Technical Approach and Anticipated Results. The treatment train will use the existing tertiary treatment system, followed by ultrafiltration (UF), reverse osmosis (RO), and ultraviolet light with an advanced oxidation process (UV AOP) to produce purified water. State-of-the-art advanced analytics, including bioassays and non-target analyses, will be used in conjunction with Critical Control Point (CCP) monitoring to prove the safety of the purification facility. Finally, the viability of DPR will be demonstrated while educating the public on the importance and safety of potable water reuse through online and print materials, tours, and presentations proposed as part of this project.

Submitting Organization and Budget. The San Francisco Public Utilities Commission (SFPUC) is submitting this proposal in collaboration with Carollo Engineers. The research effort is being led by Principal Investigators Paula Kehoe and Manisha Kothari at the SFPUC and Co-Principal Investigator Andrew Salveson, PE at Carollo Engineers. A contribution of $100,000 is requested from WateReuse Research Foundation and $100,000 is requested from the Water Research Foundation. The total project budget is $626,500, composed of $324,670 cash contribution from SFPUC, and in-kind contributions totaling $101,830.

UNDERSTANDING OF THE PROBLEM

Advanced treatment of wastewater for direct potable reuse (DPR) is operational at one facility in the United States, the Colorado River Municipal Water District's Raw Water Production Facility in Big Spring Texas. Ongoing research of that facility is demonstrating the production of a high quality water that is protective of public health (Steinle-Darling *et al.,* 2015). These results demonstrated the effective use of multiple barriers for reduction of trace pollutants and pathogens. While providing high quality water, the "Big Spring" facility relies upon monitoring systems designed for indirect potable reuse (IPR) applications. Nationally, the National Water Research Institute (NWRI) recently published a 173-page "how to" document on DPR, titled *Framework for Direct Potable Reuse* (NWRI, 2015). ***Central to this document was the use of precise and accurate monitoring technologies for public health protection in DPR applications***. Within California, an extensive research program (>$6M), the California DPR Initiative, has been undertaken to define the necessary level of treatment for a DPR project in California, and inform the discussion of DPR nationally. The Division of Drinking Water (DDW) is part of this Initiative, providing third party review of all research as they consider the possibility of regulating DPR in California. Even with the success of "Big Spring," with the development of clear guidelines for safe DPR implementation, and with extensive funding for research, the public and regulatory concern over "unknown unknowns" remains. What is that next pollutant? How do we find it? Are trace levels of pollutants harmful? The State Water Resources Control Board recently conducted an expert workshop to lay the groundwork for tracking down these questions (SWRCB, 2015). ***The expert workshop team recommended the use of non-target analysis (NTA) and bioassays to better grasp the significance of the "unknown unknowns."***

These key research needs, the ability to document real time precise and accurate monitoring technologies and the use of advanced analytics to understand the impact of the "unknown unknowns," are the primary objectives of this proposed research project. There is a secondary value of this project, which is the integration of DPR methodologies into building-scale treatment. Although building-scale treatment would require much more research and evaluation, this project would contribute data to the industry and to regulators that would help inform that future discussion. The proposed project would use the existing constructed wetlands with tertiary treatment that harvests wastewater from the building and treats it to non-potable water reuse standards, and then purify the water to potable standards. The treated water would be tested and then blended with the tertiary treated water for onsite toilet flushing.

In total, the goals of the demonstration are:

- Demonstrate innovative building-scale treatment of wastewater for DPR.
- Procure purification processes that produce potable water in accordance with health criteria established in National documents (NWRI, 2015).
- Use leading edge online analytical techniques to demonstrate the performance of each treatment process.
- Use advanced analytical monitoring to understand the potential impact of unknown trace level pollutants.
- Clearly document the costs of a potential future DPR system for utilities in California.
- Educate regulators and community members about the safety of properly engineered potable water reuse treatment systems.

This ambitious project will span one year, and includes a substantial work effort which is supported by funding from the San Francisco Public Utilities Commission (SFPUC) and Carollo Engineers.

TECHNICAL APPROACH

1.0 Building-Scale Treatment for Non-Potable Water Reuse

This project starts with raw wastewater, harvested from the 13-story, 900 employee SFPUC headquarters building. The advanced, ecologically based tertiary treatment system currently collects and treats wastewater for non-potable reuse inside the structure. The tertiary treatment system can treat a maximum flow of 5,000 gallons per day. As shown in Figure 1, the system consists of primary treatment and flow equalization followed by a wetland system, denitrification, polishing and disinfection and a reclaimed water reservoir. The system has proven capable of treating raw wastewater with a small physical footprint, appropriate to an urban setting.

The value of de-centralized wastewater treatment cannot be overstated. Water can be treated and used within one watershed, eliminating the need for sewers, pump stations, and wasted conveyance energy. Demonstrating advanced purification of the reclaimed water to potable water standards is possible and safe may lead to a radical revolution in the water industry.

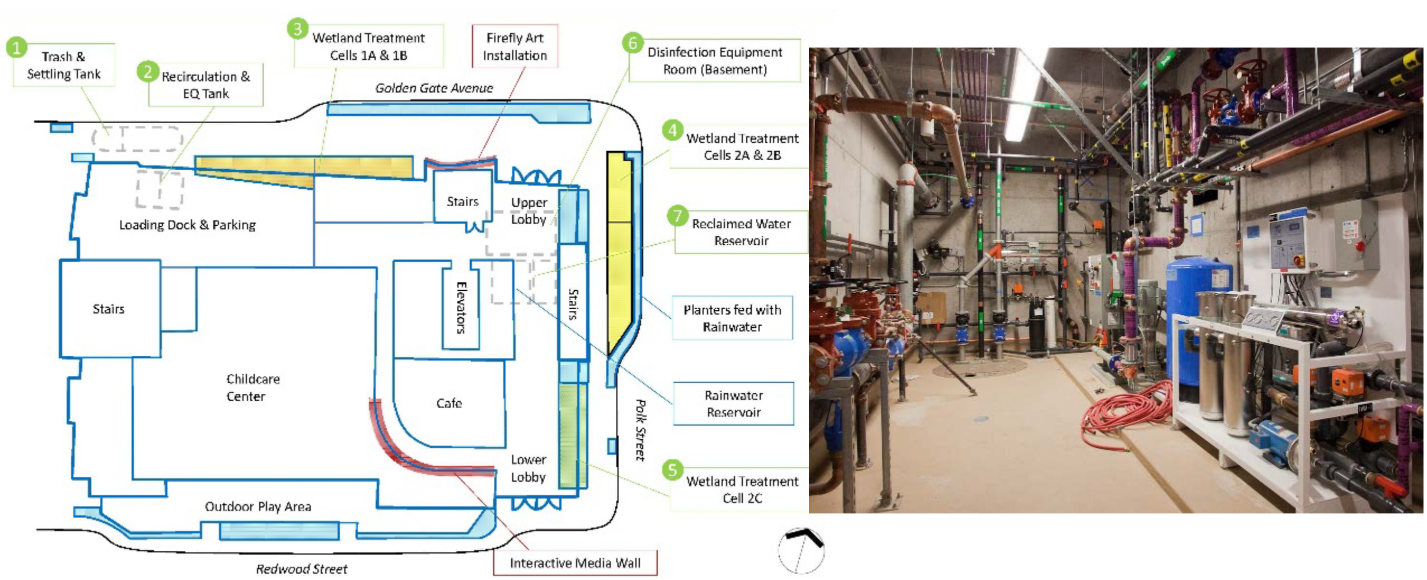


Figure 1. Wetland Treatment Schematic and Photo of Disinfection Room at SFPUC

2.0 Purification Processes for Potable Water Reuse

There are numerous treatment trains that could be used for potable water reuse. Within California, the particular processes that could be employed for this type of project are more limited (CDPH, 2014). In particular, IPR projects in California that include 100 percent purified water (no dilution) and do not benefit from surface spreading (soil aquifer treatment), must have reverse osmosis (RO) and advanced oxidation processes (AOP) within the treatment train. Using these two processes as a starting point, and relying upon the NWRI Framework for Direct Potable Reuse (NWRI, 2015), the purification process proposed for this treatment train are ultrafiltration (UF), RO, ultraviolet light (UV) AOP, and an engineered storage buffer (ESB) with free chlorine during storage (Figure 2, shown on the next page). These processes will provide multiple barriers to both pollutants and pathogens, as shown in Table 1 on the next page. When coupled together, the proposed processes meet all pathogen and pollutant requirements for potable water reuse as defined by CDPH (2014).

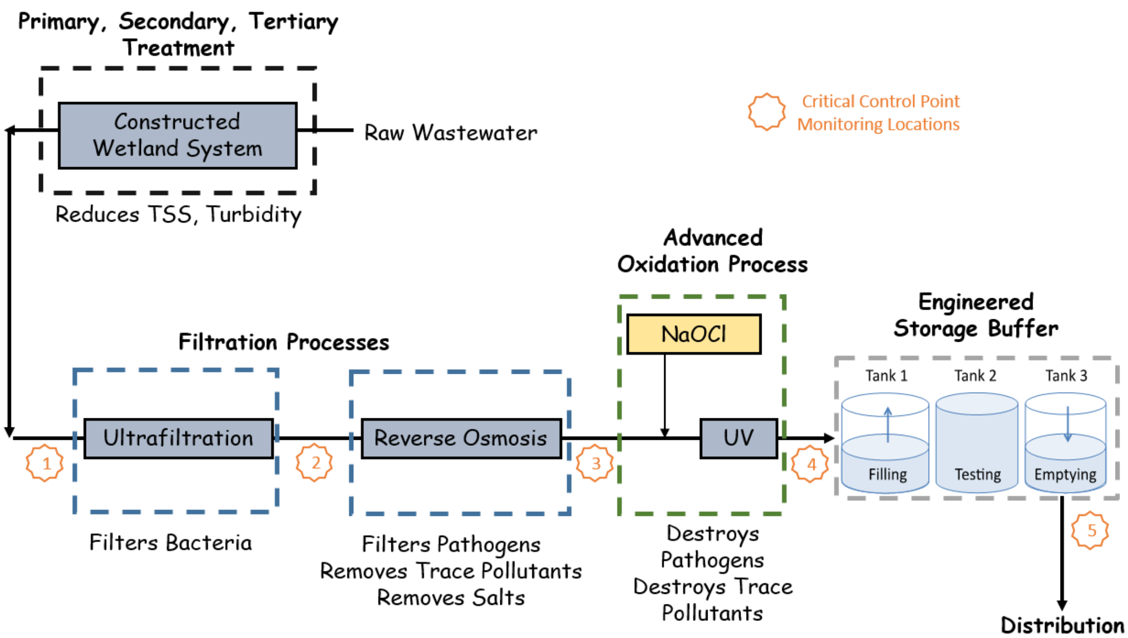


Figure 2. Proposed Advanced Treatment Train for Direct Potable Reuse

Table 1. Use of Multiple Barriers for Purification

	Bulk Organic Removal	Trace Organic Removal	Virus Removal	Protozoa Removal	Bacteria Removal
Primary, Secondary, and Tertiary Treatment	●	●	●	●	●
UF	●	–	–	●	●
RO	–	●	●	●	●
UV AOP	–	●	●	●	●
ESB with free chlorine	–	Partial	●	Partial	●

This proposed treatment train will have online monitoring at critical control points (CCPs), as detailed further on below.

Ultrafiltration

Recent work with Clean Water Services (CWS) (Oregon), as part of DPR demonstration testing, indicates that a well-functioning UF (0.01 μm nominal pore size) can attain 4.7-log reduction of seeded virus (CWS, 2014) without chemical use (such as alum or polymer) ahead of the membrane. Equivalent or greater reduction of protozoa can be assumed based upon this data, and is directly supported by NSF (2012). Furthermore, MF or UF membrane integrity testing (MIT), confirms system performance and demonstrates how MIT data can be used to track and ensure continued membrane performance (CWS, 2014). Therefore, both MF and UF membranes can be relied upon for 4+ log reduction of protozoa.

Reverse Osmosis

The RO is the primary treatment process that addresses the removal of total dissolved solids (TDS), hardness, and trace levels of organic and inorganic contaminants. The RO trains also help to remove trace organic compounds, total organic carbon (TOC), and pathogens from the tertiary effluent.

Studies have found virus removal by RO to be from 3 to >6-log (Reardon *et al.*, 2005, NRMMC/EPHC/NHMRC 2008, CWS 2014). Equal or greater removal is expected for protozoa. Unfortunately, RO process performance for pathogen rejection is not governed by the ability of an intact membrane to reject pathogens; it is governed by the ability to monitor process integrity (Reardon et al., 2005 and Schäfer et al., 2005). The monitors currently used, electrical conductivity (EC) meters and total organic carbon (TOC) meters, can measure 99 percent or less removal of both parameters through the RO process. Recently, the DDW granted 1.5 log reduction credit for all pathogens for RO (WRD, 2013), based upon a requirement to continuously monitor TOC reduction across RO. Alternative technologies, such as online fluorescent dye monitoring, have been shown to have higher accuracy in assessing membrane efficiency (3+ log based upon new research as part of Water Research Foundation project 4536), with other research showing similar results (Kitis et al., 2003; Henderson et al., 2009; Pype et al., 2013). Using traditional monitoring technology, we recommend using the 1.5-log reduction value for all pathogens for RO at this time.

UV AOP

In the event of pathogens passing through RO, the UV process provides for a high level of disinfection. NDMA, with a DDW notification level (NL) of 10 ng/L, can pass through RO at low concentrations (typically 20 to 100 ng/L), requiring destruction by UV photolysis (Sharpless and Linden, 2003). Therefore, it is common to set the UV dose at 800+ millijoule per square centimeter (mJ/cm^2). This high UV dose photolyzes NDMA as well as many other smaller chemicals that may have passed through the RO train. Adding H_2O_2 before the high dose UV, typically in the range of 3 to 5 mg/L, results in the generation of hydroxyl radicals throughout the UV process. This turns the treatment into an AOP. Hydroxyl radicals are nonselective and break down most chemicals with which they come in contact, destroying a range of trace level pollutants.

At a dose of 800+ mJ/cm^2, as would be applied for this project, the high UV dose will result in 6+ log reductions of all target pathogens (USEPA, 2006; Hijnen et al., 2006; Rochelle et al., 2005), including *Cryptosporidium*, *Giardia*, and adenovirus. Higher reductions are theoretically possible, but the DDW allows only a maximum of 6-log reduction credits per any one treatment technology (CDPH, 2014).

ESB with Free Chlorine

DPR forgoes the environmental buffer in lieu of an Engineered Storage Buffer (ESB, Tchobanoglous *et al.*, 2011). The ESB would be applied for any DPR application in California.

Eliminating the environmental buffer leads to the loss of several benefits, including contaminant reduction, dilution, and, perhaps most importantly, time to detect and respond to a treatment failure. Recent potable reuse reports suggest that these are limitations that can be overcome. These studies include the WateReuse Research Foundation's 2011 report entitled "Direct Potable Reuse: A Path Forward" (Tchobanoglous et al., 2011), the National Research Council's 2012 report entitled "Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater" (NRC, 2012), the Australian Academy of Technological Sciences and Engineering's 2013 report entitled "Drinking Water through Recycling: The benefits and costs of supplying direct to the distribution system"

(ATSE, 2013), and the WateReuse Research Foundation Project 11-10, Application of Risk Reduction Principles to Direct Potable Reuse (Salveson et al., 2014). They suggest that a higher level of treatment at the Advanced Water Treatment (AWT) facility can compensate for the treatment and dilution provided by the groundwater aquifer or surface water reservoir. The ESB can be designed to provide time to hold and test the treated water to ensure its safety before distribution. No further treatment is added in the ESB (except, perhaps further contact time), and therefore no log-removal credits for pathogens should be expected from this treatment process.

The ESB provides several key benefits over the environmental buffer. For communities without available environmental buffers such as rivers or aquifers (which are often in the most dire need), water reuse is still a possibility with ESBs. Second, ESBs eliminate the need for costly pumps and pipes to and from environmental buffers. Much of the treated water is also lost in the environmental buffer, either washed downstream or dispersed through an aquifer. Finally, advanced treated water is typically higher in quality than groundwater or surface water. Environmental sources can be easily contaminated with runoff and other influences. Keeping the treated water separate from these sources can lower contamination and decrease further treatment costs.

For this project, the ESB would follow the recommendations in Salveson et al. (*in press*) for ESB application. For each unit process and its associated monitoring method, a failure and response time (FRT) is defined. The process FRT is the maximum possible time between when a failure occurs and when the system has reacted such that the final product water quality is no longer affected. The FRT is a sum of the sampling interval, the sample turnaround time (TAT), and the system reaction time, as shown in Figure 3 on the next page. For a unit process monitored by a traditional sampling technique, the sampling interval may range from continuous online monitoring to periodic sampling. In this pilot project, key process monitoring will be done online determine the minimum acceptable FRT for this type of advanced treatment system.

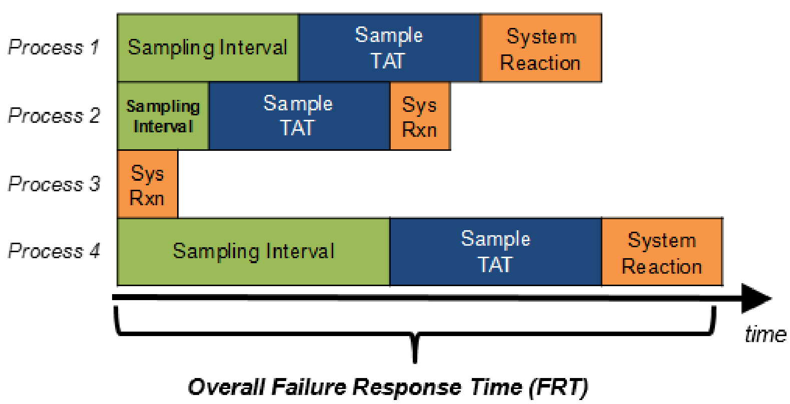


Figure 3. Determination of Failure and Response Time for ESB

In addition to the FRT value of the ESB, the ESB provides for substantial disinfection treatment by free chlorine. A future ESB would have free chlorine dosing and be controlled to maintain a target free chlorine *Ct* sufficient to attain 3-log for *Giardia* and 4-log for viruses, based upon a 4 hour contact time with a 1 mg/L free chlorine residual, with an RO permeate pH of 6. The pathogen credits are based upon the 1990 SWTR Guidance Manual (USEPA, 1990).

3.0 Monitoring Technologies

Conventional potable reuse trains have repeatedly met EPA drinking water standards, as documented by long term compliance with California regulations by the Orange County Water District, among many others. Demonstration testing of similar advanced treatment trains has shown similar performance (CWS, 2014; Trussell, 2013). Emerging pollutants will be evaluated for this project, focusing on the following trace level pollutants:

- A suite of pharmaceuticals and personal care products (PPCPs)
- A suite of perfluorinated compounds (PFCs)
- NDMA
- NDMA formation potential
- THM and HAA formation potential
- Fluorescence

Pathogens will also be evaluated for this project, documenting with grab sampling the pathogen levels after secondary treatment and thus allowing an analysis of sufficient reduction of such pathogens through the purification processes. Pathogens (and surrogate organisms) to be evaluated include: male specific and somatic coliphage, *enterococci*, *E. coli*, total coliform, *Giardia*, *Cryptosporidium*, enterovirus, and norovirus.

The ability for these processes to produce high quality water in accordance with regulations is not in question. <u>What this project looks to define is the ability to continuously monitor the performance of the advanced treatment systems in real time.</u> This will be done through the use of precise and accurate metering of the critical control points in the purification process. To that end, we have secured the use of two ZAPs LiquID stations to perform such monitoring, as shown in Table 2, on the next page. These parameters will be used to demonstrate process by process performance; as follows:

- **UF -** UF filtrate turbidity and *E. coli* concentrations will closely track UF performance. These continuous measurements will be paired with daily pressure decay test (PDT) results to provide real-time confidence in protozoa and bacteria removal performance.
- **RO -** TOC values collected pre and post RO allow for clear determination of a conservative surrogate for pathogen removal by RO as well as consistent reduction in TOC. TOC values will be paired with online electrical conductivity (EC) to verify TOC performance values.
- **UV AOP -** Destruction of total chlorine across UV systems has now been shown to correlate directly with UV dose, which then correlates directly to pathogen removal and destruction of pollutants such as NDMA (work in press). Free chlorine measurements and UV absorbance (UVA) can be used to develop a "chlorine weighted UV dose," which has recently been shown to correlate directly with destruction of trace pollutants by UV AOP (work in press).
- **ESB -** Free chlorine residual after the ESB will be used to calculate a Ct and show disinfection credit in accordance with EPA standards.

Table 2. Online Real Time Monitoring for Demonstration Project

Measurement	Post UF	Post RO	Pre UV	Post UV
Chloramines	●		●	●
Free Chlorine	●		●	●
E. coli	●			
TOC	●	●		
UVA			●	●
Turbidity	●			

The information from the ZAPs systems will be logged for the duration of the 6-month demonstration and used to evaluate overall reliability in system performance. These values will also be used to monitor system performance remotely, available 24/7/365.

The research will take one further step, the investigation of the "unknown unknowns." While hundreds of chemicals have been detected in water, thousands more likely occur at very low concentrations but have not yet been detected. Chemical surrogates and indicators are often used to gauge the efficacy and efficiency of a particular treatment process and/or multibarrier train (Yu et al., 2015; Merel et al., 2015; Anumol et al., 2015; Gerrity et al., 2012). However, these measures do not provide any reference to biological effects and thus do not account for the potential additive or synergistic effects of chemical mixtures. Bioassay-based monitoring complements chemical analysis by providing a comprehensive assessment of the mixture of substances present in a particular water sample (Escher et al., 2014). A limitation of bioassays is the ability to determine what substance, or substances, were responsible for the bioactivity observed. Therefore, non-targeted analysis (NTA) will also be performed using high-resolution mass spectrometry (HRMS) with both gas chromatography (GC) and liquid chromatography (LC) interfaces for volatile and non-volatile organic compounds, respectively. National experts convened in California recently to examine two promising techniques for such investigation (SWRCB, 2015). In that two-day workshop, the expert group concluded that these two methods, non-target analysis (NTA) and bioassays, should be paired.

In order to accomplish both the bioassays and NTA methods proposed below, we will use 4L of water (approximately one gallon) for each sample. Technically, two liters of water is required; however, we recommend providing additional water for replicates (3) to improve statistical accuracy of the NTA work, and allows for repeat analyses if necessary. Two one-liter samples will be extracted using a comprehensive two-SPE system previously shown to capture the majority of organic contaminants occurring in water systems (Escher et al. 2014; Jia et al., 2015). Positive controls for bioassays will be used for matrix spikes to ensure acceptable recovery (greater than 70 percent) of bioactive substances.

Assays selected were those recently demonstrated to address relevant endpoints, displayed significant activity using water samples, and were reliable in multiple laboratories (Escher et al., 2015).

1) Non-specific Toxicity: Cytotoxicity. Cytotoxicity will be assessed using the MTS assay. The MTS reagent will be purchased from Promega (CellTiter 96® AQueous One Solution Cell Proliferation Assay, #G3580). MTS (tetrazolium) is bioreduced by cells in culture into a colored formazan product that is soluble in tissue culture medium, and this conversion is presumably accomplished by NADPH or NADH produced by dehydrogenase enzymes in metabolically active cells. Assays are performed by adding a small amount of the MTS Reagent directly into culture wells, incubating for 2 hours, and then recording the absorbance at 490 nm with a 96-well plate reader.

2) Specific (Receptor-mediated) Toxicity: Glucocorticoid Receptor (GR) and Estrogen Receptor (ER). Estrogens and glucocorticoids have been reported to occur widely in WWTP effluents (Escher et al., 2014; Snyder et al. 2001; Stavreva et al., 2012). Based on previous testing of multiple ER and GR assays, our team has elected to use the Invitrogen platform as it also was selected by the State of California funded project on which Snyder is a Co-PI. The ER/GR assay uses GeneBLAzer® HEK 293T cells which contain an estrogen receptor/glucocorticoid receptor (ER/GR) ligand-binding domain/Gal4 DNA binding domain chimera stably integrated into the GeneBLAzer® UAS-*bla* HEK 293T cell line. GeneBLAzer® UAS-*bla* HEK 293T contains a beta-lactamase reporter gene under control of a UAS response element stably integrated into HEK 293T cells. Fluorescence Resonance Energy Transfer (FRET) substrate that generates a ratiometric reporter response and dual-color (blue/green) reading is used to minimize experimental noise. The ER and GR assay will help to identify potential for endocrine disruption effects caused by estrogenic and glucocorticoid hormones, respectively, as well as contaminants that mimic these hormones.

3) Xenobiotic Metabolism: Aryl Hydrocarbon Receptor (AhR). A well-known example of a xenobiotic receptor is the arylhydrocarbon receptor (AhR), which responds to exposure to dioxin-like chemicals. The AhR assay has been used to gauge remediation of PCB and dioxin in environmental spill scenarios (Giesy et al., 2002). For the proposed research, rat hepato-carcinoma cells (H4IIE-luc) which have been stably transfected with the luciferase gene under control of the AhR will be used (Giesy et al., 2002; Sanderson et al., 1996; Jarosov et al., 2012).

4) p53 reporter gene. The p53 protein is known for its major role in the prevention of cancer. It acts as a tumor suppressant, recognizing damaged DNA and triggering DNA repair. This pathway also plays a role in cell cycle arrest and apoptosis. Our team has chosen to use the CellSensor *p53RE-bla HCT-116* cell line, which operates very similarly to GeneBLAzer® HEK 293T cells, to represent stress response. The CellSensor *p53RE-bla HCT-116* cell line contains a p53 receptor ligand-binding domain/Gal4 binding domain, as well as a beta-lactamase reporter gene under control of a UAS response element. CCF4-AM substrate will be used to measure fluorescence, as it emits a green in the absence of betalactamase and blue in the presence. The primary difference between the CellSensor *p53RE-bla HCT-116* cell line and to GeneBLAzer® HEK 293T cells is that the p53 cell line uses human colorectal carcinomacells, where the ER/GR cell lines use human embryonic kidney cells. The p53 assay will help determine the quality of the water since the ability of a cell to repair itself may be more sensitive than actual damage done.

NTA of unknown compounds will be performed using the latest generation quadrupole-time-of-flight (QTOF) mass spectrometers. The LC-QTOF will use an aliquot of methanol extracts prepared for bioassay and analyzed using both positive and negative electrospray ionization (ESI). These extracts will also be analyzed by GC-QTOF by injection of the methanol extracts and analyzed with electron impact ionization. Samples will be analyzed in auto-MS/MS mode in both instruments, where instruments record all the mass to charge ratios (m/z). Between acquisitions of MS spectra, the instrument is programmed to isolate the most abundant ions and fragment them to acquire their corresponding MS/MS spectra. These analyses generate large amounts of data, which will be processed using software specifically designed for this purpose.

Using the QTOF data, our team is able to statistically “fingerprint” different water qualities based on their mass profile. In previous preliminary studies, our team has demonstrated that HRMS could discriminate water exposed to different treatments or different doses of the same oxidant. Resulting HRMS data is evaluated initially through heatmaps, revealing multiple classes of compounds such as recalcitrant, those removed, and transformation products (including intermediates). Each sample profile will be paired both with water treatment variable and with bioassay results. Therefore, while bioassays indicate if a treatment leads to an increase or decrease in toxicity, QTOF data will provide information on which compounds or group of compounds correlate statistically to the biological observation.

The second value of this approach consists in being able to identify compounds of interest among the list of molecular features. For example, if sample toxicity increases after a specific treatment, the transformation products formed by such treatment will be isolated from the molecular features enclosed in the sample profile for further identification. Based on their high resolution mass spectra, transformation products will be searched against libraries of compounds available in Dr. Snyder's laboratory. While some of these products may not be registered in the library, a first identification of chemical formula can be proposed based on the accurate mass. Such molecular formula would then be further evaluated based on MS/MS spectra. In addition, these data produce a lasting electronic record of what substances were present, thus if a new contaminant is identified, these spectra can be retroactively mined to determine if the substance was present and its relative abundance.

For this initial research, the NTA and bioassay analysis will be taken across the treatment train as detailed in the Scope of Work. These two tools, when used in combination, will present a powerful picture of water quality through different levels of treatment over the duration of the study. These tools will supplement the previously detailed analysis for regulated and unregulated pollutants and pathogens and begin to answer the questions about the "unknown unknowns" frequently raised by opponents to water reuse projects.

4.0 Data Analysis

Three distinct sets of data will be collected. What those data are, and how they will be utilized, is defined below:

- **Online Data -** online data will be logged and performance probability distribution functions (PDFs) will be created, which document the statistical reliability of each process to provide the desired results (for pathogen and pollutant reduction)
- **Grab Sample Data -** trace pollutant data will be collected and compared against industry standards, and then used to compare pollutant levels with the results from the advanced analytics. Pathogen data will be used to set a baseline of pathogen levels in the purification feed water, and then document the levels of reduction of those pathogens to the new potable water supply, clearly documenting compliance (or lack thereof) with published health standards (CDPH, 2014; NWRI, 2015).
- **Advanced Analytics -** NTAs and bioassays will be paired together and compared/contrasted with the trace pollutant data.

Scope of Work

Task 1: Project Management

As Principal Investigator (PI) for this project, Manisha Kothari, will serve as the contact PI on this project and work closely with PI Paula Kehoe. As such, Ms. Kothari and Ms. Kehoe will be responsible for overall project management, including oversight of Carollo as the contractor, communication with WRF and WRRF, and review of the technical progress of the research and ensure that results are applicable to the water community. Ms. Kothari and Ms. Kehoe, in conjunction with Carollo, will monitor the progress of the research through review of progress reports, participation in project calls and face-to-face meetings, and review of all project final deliverables.

The Co-PI for this project, Andrew Salveson, will manage the day-to-day and long-term objectives of this project. That includes the review and guidance of Carollo staff in the performance of their duties and the coordination of subconsultant team members. The project management responsibilities extend to the management of the project budget and the billings. Finally, project management includes quality assurance/quality control, which is a period review of project progress from outside the core project team by experts in the relevant field(s).

Schedule: N/A.

Deliverables: The management team will be available for weekly check-in calls for the duration of the project. Any issues that arise during the management of this project will be documented in progress reports. Further details of communication with WRF and WRRF and of the dissemination of this work are outlined in the Communication Plan.

Task 2: Site Preparation

Small modifications will be made to the existing tertiary treatment system. These changes will require coordination efforts with the building staff, minor equipment adjustments, and piping modifications.

Task 3: Purification Facility Design and Construction

For potable water reuse, the project team will select and install a series of advanced processes to purify the Tertiary treatment system effluent and to monitor the water quality online. The proposed technologies to be applied are ultrafiltration (UF), reverse osmosis (RO), ultraviolet light disinfection (UV) with sodium hypochlorite addition to result in an advanced oxidation process (AOP), with a final treatment/storage step using an engineered storage buffer (ESB). Online monitoring includes turbidity, *E. coli*, total organic carbon (TOC), electrical conductivity (EC), total and free chlorine, and ultraviolet transmittance (UVT). These online monitoring parameters will be done by the ZAPs LiquiD, as shown in Table 3 below.

Table 3. Online Monitoring Parameters

Measurement	Post UF	Post RO	Pre UV	Post UV
Chloramines	●		●	●
Free Chlorine	●		●	●
E. coli	●			
TOC	●	●		
UVA			●	●
Turbidity	●			

For this Task, the project team will do the following:

- Select and rent (or purchase) small-scale advanced treatment processes (as listed above), with capacities in the range of 1 to 3 gpm[1].
- Select and purchase online monitoring processes (as listed above).
- Start up the purification and monitoring systems

[1] The current plan is to rent UF and RO systems and purchase small UV and ESB treatment systems. For monitoring systems, the project team will need to purchase online monitoring equipment.

- Collect and store all online data in a centralized control system, allowing for later analysis.
- Summarize all process, monitoring, and startup procedures in a TM.

Schedule: Selection of equipment, installation of equipment, and startup of equipment would be expected to start within 30 days of the receipt of grant funding and will be completed within 4 months of the notice to proceed.

Deliverables: A TM will be completed in draft form that details the treatment and monitoring processes as well as any details related to operation and startup. The TM will document the purification treatment train meets all pathogen and pollutant requirements for potable water reuse as required by CDPH. The TM will also document the costs of equipment procurement, installation, and expected analytics to understand the costs of DPR treatment at the building scale.

Task 4: Direct Potable Water Reuse Performance Demonstration

To date, no potable water reuse system (indirect or direct), provides a comprehensive real-time monitoring of overall performance. For potable water reuse, the treatment targets include virus, protozoa, bacteria, total organic carbon, salts, and trace level pollutants. This project will build a treatment system that tracks and records performance of each system, and most importantly of the entire system for the removal of pathogens and pollutants. This will be the first real-time "smart" potable water reuse treatment system, operating for 6 consecutive months, which will be used to demonstrate the long term reliability of advanced water purification processes.

To that end, we have broken up the 6-month demonstration into the following work efforts.

Operation. The facility will be run continuously for 6 months. The system will be run automatically, with twice-weekly inspections and calibration of online devices.

Conventional Parameters, PPCPs, Pathogens, and Advanced Analytics. Over the 6-month timeframe, the system will be continuously monitored using the online technologies discussed previously. This online monitoring will be supplemented by three different analytical chemistry approaches, as shown in the bullets and Table 4 on the next page.

- **Conventional Parameters:** TOC (twice monthly), ATP (weekly), turbidity, UVA, total and free chlorine (twice weekly).
- **CECs[2]:** pharmaceuticals and personal care products (PPCPs), perfluorinated compounds (PFCs), NDMA, NDMA FP, THM/HAA FP, and fluorescence EEM, all monthly. This work will be done by (monthly) work will be done by the Dr. Eric Dickenson at the Southern Nevada Water Authority.
- **Pathogens:** male specific and somatic coliphage, enterococci, *E. coli*, total coliform, *Giardia*, *Cryptosporidium*, enterovirus, and norovirus. Biological analysis will be done (monthly) by Dr. Rick Danielson at BioVir.
- **Advanced Analytics:** non-target analysis and bioassays. Advanced analytics will be done (monthly) by Dr. Shane Snyder at the University of Arizona.

[2] The CEC list and pathogen list are identical to WaterRF 4536 and WateReuse Research Foundation 14-16, which are both run by this current project team.

Table 4. Online Monitoring - Analytical Chemistry Approaches

Measurement	Tertiary Effluent	Post UF	Post RO	Post UV
Conventional Parameters		●	●	●
CECs		●	●	●
Pathogens	●			
Advanced Analytics		●	●	●

Schedule: Testing will be done periodically over a 6 month time period.

Deliverables: Prior to the start of testing, a test protocol will be developed which includes detailed sampling methods, lab testing methods, and quality control. Conventional parameters will be compared against similar DPR demonstrations (CWS, Big Springs, TX), while CECs and pathogens will be compared to established health criteria standards (NWRI 2015). The Advanced Analytic testing will demonstrate the feasibility of monitoring the unknown toxicity of DPR treatment trains. These novel results will evaluated for the first time to demonstrate the safety of DPR. All results will be compiled in the draft report as described below and may be published via research journals to share the state of the art with academics, regulators, and the public.

Task 5: Public Communication and Outreach

Multiple outreach efforts, provided by Data Instincts, will be developed as part of the demonstration project.

Development of Online Materials

Data Instincts and RMC will develop dedicated web pages to describe the demonstration project and engage the public about this research effort, as well as Direct Potable Reuse more broadly. The web interface will include updates on the demonstration project as it is proceeding.

Development of Print Materials

This task will include the development of various forms of print media to supplement online material on the demonstration project. It will include a pocket brochure describing the demonstration project, as well as fact sheets for various audiences, information on Frequently Asked Questions, and the preparation of pre- and post- tour surveys to help measure the effectiveness of the demonstration project.

Virtual Tour

A video production that provides a virtual tour of the pilot demonstration, the virtual tour will be showcased online and will provide information on the objectives and processes associated with the demonstration project.

Digital Wall

The SFPUC Headquarter building includes a large public space / café at its entry level. A large digital wall provides a venue for information to be displayed in a large and very visible format to people working in and visiting the building. The wall is also visible from public streets outside. In this task, we will prepare and display key messages and images to convey about the demonstration project and Direct Potable Reuse.

Develop/Distribute Educational Materials

The objective of this task is to create specific educational materials and disseminate them to targeted audiences including schoolchildren, media, public officials, and special groups.

Schedule: The outreach work would begin prior to the start of testing and run through the completion of the project.

Deliverables: Final report, survey results, and any other outreach materials will be shared with the funding agencies. The final report will document the outreach campaign efforts, survey results, and will provide documentation of public acceptance. Project results will be submitted for peer-review publications and conference proceedings.

Task 6: Project Communication and Reporting

The project team will prepare quarterly reports for the duration of this project, one draft report, and one final report. At a minimum, the project team will meet with the Project Advisory Committee (PAC) and Research Advisory Committee (RAC), the WRF and WRRF research managers in person. Additional meetings can be conducted remotely on a monthly basis as needed.

Schedule: Reporting will be done throughout the duration of the project, with quarterly reports done after the first three months of work and done every three months thereafter. An on-site project meeting will occur at the start of the 6 month DPR testing period. One draft report and one final report will be completed after the end of the 6 month demonstration period. Near the completion of the project, one member of the project team will travel to Denver to present the results to Reclamation staff.

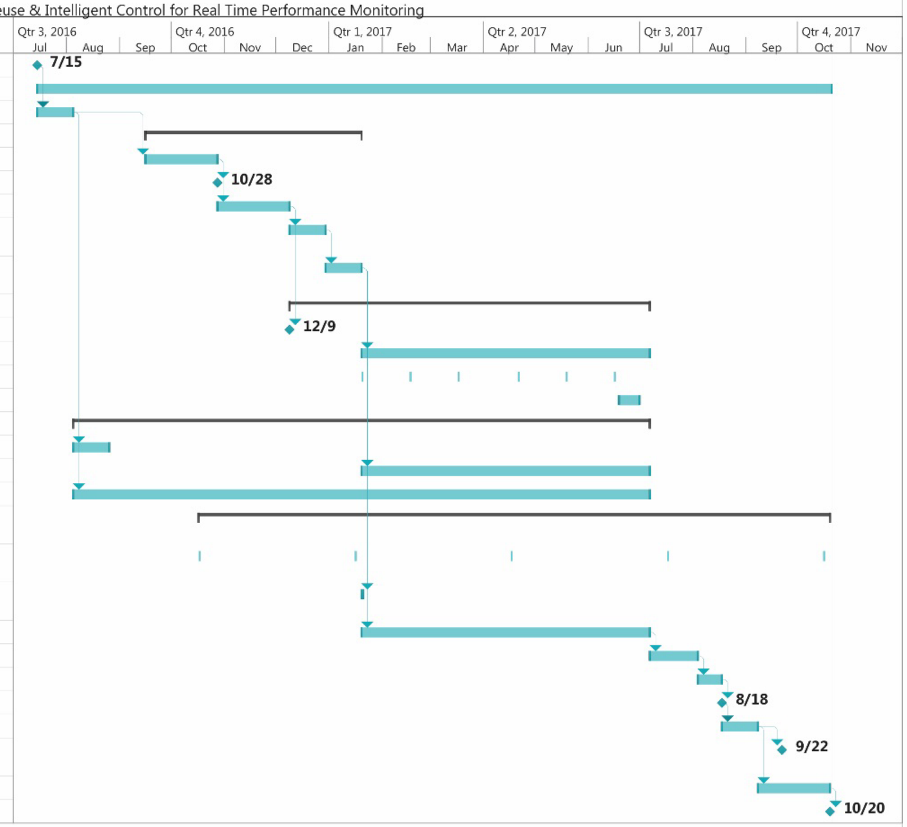
Deliverables: Quarterly reports, one draft report, and one final report, and one on-site project meeting with the advisory committees and WRF/WRRF research managers. The report will compile the results of all tasks, including operational startup, detailed analytic sampling methods, conventional and analytic results, and work through the public outreach campaign.

RESEARCH WORK PLAN AND SCHEDULE

The work to be carried out in the demonstration study is described in task descriptions of the Scope of Work Section. The project schedule, including all major tasks and subtasks, is shown below. The schedule details the elapsed time for the entire pilot testing project. Estimates of equipment delivery dates, pilot construction and commissioning, and dates of all deliverables are included. The total project duration is expected to be 15 months.

Building Scale Treatment for Direct Potable Water Reuse & Intelligent Control for Real Time Performance Monitoring

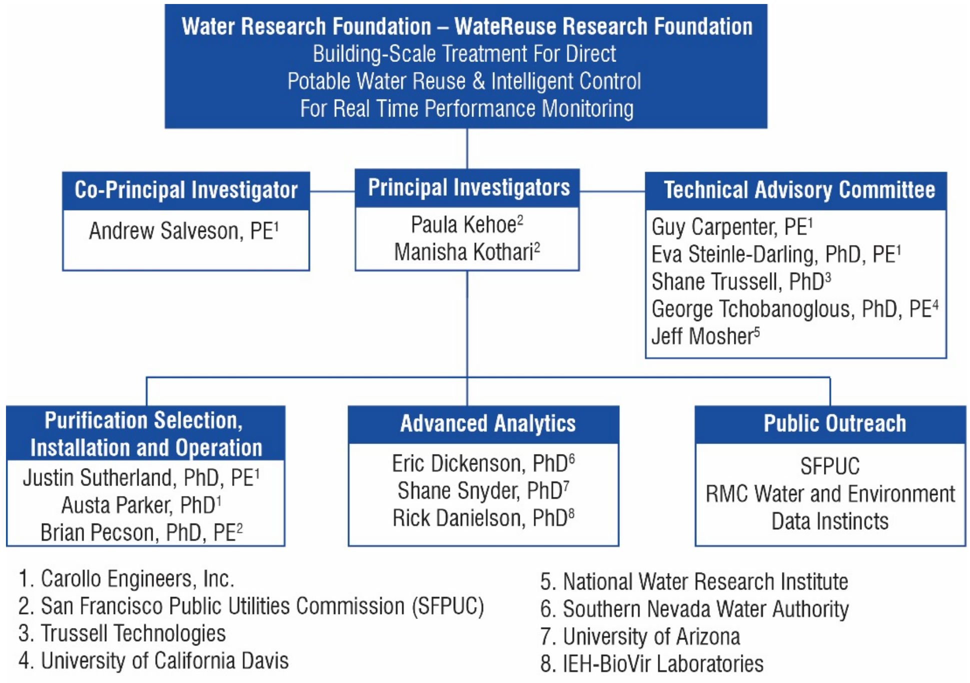
ID	Task Name	Duration	Start	Finish	Predecessors
1	DPR Demonstration	0 days	Fri 7/15/16	Fri 7/15/16	
2	**Task 1: Project Management**	331 days	Fri 7/15/16	Fri 10/20/17	
3	**Task 2: Site Preparation**	15 days	Fri 7/15/16	Thu 8/4/16	1
4	**Task 3: Purification Facility Design and Construction**	**90 days**	**Fri 9/16/16**	**Thu 1/19/17**	
5	Purchase UF/RO/UV AOP from Suppliers	30 days	Fri 9/16/16	Thu 10/27/16	3FS+30 days
6	Submit Treatment and Monitoring TM	0 days	Fri 10/28/16	Fri 10/28/16	5
7	Deliver UF/RO/UV AOP to Site	30 days	Fri 10/28/16	Thu 12/8/16	5
8	Advanced Purification Pilot Installation, Testing, and Commissioning	15 days	Fri 12/9/16	Thu 12/29/16	7
9	Advanced Monitoring/Intelligent Control Installation, Testing, and Commissioning	15 days	Fri 12/30/16	Thu 1/19/17	8
10	**Task 4: DPR Performance Demonstration**	**150 days**	**Fri 12/9/16**	**Thu 7/6/17**	
11	Submit Test Protocol	0 days	Fri 12/9/16	Fri 12/9/16	7
12	DPR Pilot Operation	6 mons	Fri 1/20/17	Thu 7/6/17	9
13	**Advanced Analytics**	**106 days**	**Fri 1/20/17**	**Fri 6/16/17**	
20	Decommission and Site Clean-Up	10 days	Mon 6/19/17	Fri 6/30/17	13
21	**Task 5: Public Outreach**	**240 days**	**Fri 8/5/16**	**Thu 7/6/17**	
22	Install Banners	15 days	Fri 8/5/16	Thu 8/25/16	3
23	Provide Educational Tours	6 mons	Fri 1/20/17	Thu 7/6/17	9
24	Create/Maintain Demonstration Website	12 mons	Fri 8/5/16	Thu 7/6/17	3
25	**Task 6: Project Communication and Reporting**	**264 days**	**Mon 10/17/16**	**Fri 10/20/17**	
26	**Prepare and Submit Progress Reports**	**261 days**	**Mon 10/17/16**	**Mon 10/16/17**	
32	Onsite Project Meeting with Advisory Committees/Research Managers	1 day	Fri 1/20/17	Fri 1/20/17	9
33	Compile Pilot Plant Data	6 mons	Fri 1/20/17	Thu 7/6/17	9
34	Prepare Draft Report	20 days	Fri 7/7/17	Thu 8/3/17	33
35	Internal Review of Draft Report	10 days	Fri 8/4/17	Thu 8/17/17	34
36	Submit Draft Report to WRF/WRRF for Review	0 days	Fri 8/18/17	Fri 8/18/17	35
37	WRF/WRRF Review of Report	15 days	Fri 8/18/17	Thu 9/7/17	36
38	Presentation to Advisory Committess/Research Managers	0 days	Fri 9/22/17	Fri 9/22/17	37FS+10 days
39	Prepare Final Report	30 days	Fri 9/8/17	Thu 10/19/17	37
40	Submit Final Report to WRF/WRRF	0 days	Fri 10/20/17	Fri 10/20/17	39



Project: DPR Demonstration
Date: Thu 4/7/16

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

MANAGEMENT PLAN



The proposed project is intended as a collaboration between SFPUC, WRRF, and WRF. Both WRRF and WRF are being asked to participate as equal partners. Should WRRF or WRF wish to have specific deliverables tied to their cash contributions, the team can provide such a breakout.

SFPUC will be responsible for overall project management, coordination, and communications with WRRF and WRF, and facilitation with the research team. Carollo will be the technical leader for this project. We have assembled a team of professionals experienced in municipal reuse and leading-edge water technology.

Key Team Members

Paula Kehoe – Principal Investigator

Paula Kehoe is the Director of Water Resources for the San Francisco Public Utilities Commission (SFPUC). She is responsible for diversifying San Francisco's local water supply portfolio through the development and implementation of conservation, groundwater, and recycled water programs. Paula spearheaded the landmark legislation allowing for the collection, treatment, and use of alternate water sources for non-potable end uses in buildings and districts within San Francisco.

Manisha Kothari – Principal Investigator

Manisha Kothari is a Project Manager with the Water Resources Division of the San Francisco Public Utilities Commission. Manisha represents the SFPUC in the planning of water reuse projects that the SFPUC is developing through regional partnerships in order to diversify its water supply portfolio and meet future demands. She works with water agencies throughout the Bay Area to evaluate and develop recycled water and desalination opportunities for San Francisco's customers. Manisha has over 10 years of experience managing infrastructure projects from concept to implementation.

Andrew Salveson, PE – Co-Principal Investigator

Andy Salveson has 22 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, including IPR and DPR. Mr. Salveson provides guidance and expertise on state-of-the-art technologies on the latest industry issues regarding reuse, including extensive projects for the Water Research Foundation and WateReuse Research Foundation related to Potable Reuse. Andy was named to a national panel of 7 experts to develop national guidance on Direct Potable Reuse (NWRI Framework for

Direct Potable Reuse) and was named to a panel of experts to develop potable water reuse for the World Health Organization.

Justin Sutherland, PhD, PE – Purification Selection, Installation, and Operation

Dr. Justin Sutherland is a member of Carollo's Research Group with 16 years of experience in applied research, bench- and pilot-scale process design and testing. He has extensive experience in water reuse. He served as Project engineer for the Texas Water Development Board-funded project, "Testing Water Quality in a Municipal Wastewater Effluent Treated to Drinking Water Standards." He was responsible for the review of historical RO performance data and sampling water quality (EDC, pharmaceuticals, etc.) around the MF, RO, and AOP processes at the Direct Potable Reuse Plant and led a pilot scale evaluation of a direct integrity monitor (Nalco's Trasar technology) for potable reuse RO systems.

Eric Dickenson, PhD – Advanced Analytics

Dr. Dickenson serves as R&D project manager for the Southern Nevada Water Authority. His experience includes the fate of emerging contaminants (e.g., EDCs and pharmaceuticals) in natural systems (e.g., aquifer recharge, riverbank filtration) and conventional and advanced engineered systems (e.g., RO, nanofiltration, GAC, ozone, AOP, MBR). Additionally he is experienced in the utilization of state-of-the-art characterization methods for natural and effluent organic matter for water quality characterization and optimization of disinfection processes.

Shane Snyder, PhD – Advanced Analytics

Dr. Snyder is a Professor of Chemical and Environmental Engineering at the University of Arizona. He holds a PhD in Environmental Toxicology and Zoology and a BA in Chemistry. He is a microconstituents expert who participated in the "Blue Ribbon Panel" for the California Water Resources Control Board to consider Constituents/Contaminants of Emerging Concern in Recycled Water. He is also Co-director of the Arizona Laboratory for Emerging Contaminants, a state-of-the-art analytical facility that identifies and quantifies emerging contaminants, such as pharmaceutical compounds, endocrine disrupting compounds, and nanoparticles.

Rick Danielson, PhD – Advanced Analytics

Dr. Danielson has a broad background in environmental health microbiology including: the development and application of bio-technology (PCR, ELISA, monoclonal antibodies, plasmid analysis, etc.); microbiological risk assessment; environmental virology and parasitology (certified USEPA Principal Analyst for protozoans and viruses); providing information and consultation on agents of bioterrorism; expert testimony in environmental microbial contamination cases; and, the establishment of certified environmental microbiological testing laboratories. He is a lecturer of microbiology at the U.C. Berkeley School of Public Health (1993 to present) and has served on several national public health (US FDA & NMFS, ASTM) and research review committees (WERF, AWWA, Sea Grant, USDA).

COMMUNICATION PLAN

The proposed research will benefit the drinking water, wastewater, and reuse industries through demonstration of safe DPR treatment processes. Regulators, utilities, and the public will have access to both the physical demonstration facility and the analytic results and key outcomes that show the process performance throughout the treatment train. The proposed outreach options to communicate the results of the research include the following:

Periodic Technical Progress Reports

Periodic technical progress reports and a Draft Final Report will be prepared and submitted for ongoing review by the WRRF and WRF, and their respective Advisory Committees. It is estimated that up to six progress reports, occurring every 3 months, will be submitted during the duration of the pilot testing. The reports will be letter-style and will include a Technical Summary, summary of the completed activities, activities in progress, and a calculation of the estimated percent of completed work. The Technical Summary will include descriptions of the materials and methods, results, and discussion of the results.

Conference Presentations

Conference presentations will be used as an interim outreach activity prior to submission of the final report to WRRF and WRF. Several conferences are planned as a forum to disseminate research results to utilities and technical audiences within the reuse industry. The selected conferences for presentation include those targeted to the water reuse industry, such as the annual WQTC and WRRF conferences as well as ACE and the WRF annual conference.

Final Report

This report will be submitted to the WRF and WRRF upon completion of the project. The report will include a description of the research project including research materials and methods, results, discussion, conclusions, and recommendations to meet the objectives for each task outlined in the technical section.

Webcast

Upon completion of the project, the Principal and Co-Principal Investigators will develop and deliver a webcast disseminating the project findings to participants within the water industry, particularly public and private utilities. Recommendations and implementation strategies will also be discussed. The webcast will be scheduled within 6 months of the publication of the project report. This webcast will be targeted to both WRRF and WRF subscribers and other stakeholders.

Project Meetings

SFPUC and Carollo will participate in one intermediate project meeting with the Advisory Committees and the WRRF/WRF research managers. Team members may attend via webinar. This meeting will be held at SFPUC's Headquarters and include a visit to the pilot plant site.

QUALITY ASSURANCE/QUALITY CONTROL

Quality Assurance and Quality Control (QA/QC) are necessary aspects of any research project, and particularly so for this project as it pertains to the protection of public health. The test plan proposed for this effort includes duplicate sampling of advanced analytics (CECs, fluorescence, non-target analysis, and bioassays) in six different sampling events. The project team will work closely with certified laboratories running accepted standard methods to ensure data precision and accuracy (defined below). Method Detection limits (MDLs) will be used to determine the statistical significance of any detectable response.

Three certified laboratories will be performing the analysis in this project and will be responsible for internal QA/QC for each sampling parameter.

- Southern Nevada Water Authority (SNWA) will be providing analysis for: Contaminants of Emerging Concern (CECs), Total Organic Carbon (TOC), and Fluorescence (EEM).

- BioVir Laboratories will provide all pathogen analysis, including Phage, Enteroccoci, E. coli , Total Coliform, Giardia, Cryptosporidium, Enterovirus, and Norovirus.
- University of Arizona will perform advanced analytics using bioassays, Gas Chromatography Non-Target Analysis (GC-NTA), and Liquid Chromatography Non-Target Analysis LGC-NTA).

Precision

The precision of duplicate samples is assessed by calculating the relative percent difference (RPD) according to:

$$RPD = \frac{|S - D|}{\frac{(S + D)}{2}} \times 100\%$$

where,

S = Sample concentration and

D = Duplicate sample concentration.

If calculated from three or more replicates, the precision is determined using the relative standard deviation (RSD):

$$RSD = \frac{SD}{Average} \times 100\%$$

where,

SD = Standard deviation for the replicate samples.

Sample Replicates

The demonstration facility will run for a minimum of 6 months, with online monitoring of a range of parameters, daily inspection of online equipment, and with monthly or more frequent sampling for a wide range of offline laboratory analysis (see Table 5 on the next page). Routine sampling is expected with Turbidity, UVA, total and free chlorine being tested bi-weekly. ATP and TOC will be tested more frequently, once per week and twice per week, respectively. Online monitoring tools (Turbidity, UVA, Total and Free Chlorine, TOC, *E. coli*) will verify performance conditions and provide additional confidence in the laboratory analysis.

Table 5. Replicates and Associated Number of Sampling Events

Sample Location	Parameter to Analyze	Frequency of Sampling Events	Number of Sampling Events
Tertiary Influent	Pathogens[1]	Monthly	6
UF Effluent (RO Influent)	Turbidity, UVA, Total Chlorine, Free Chlorine	Bi-weekly (online)	48
	ATP	Weekly	24
	TOC	Bi-monthly	12
	Pathogens[1], CECs[2], EEMs[3], Bioassays[4], NT Analysis[5]	Monthly	8 (includes 2 duplicates)
		Monthly	4
RO Effluent (UV AOP Influent)	Turbidity, UVA, Total Chlorine, Free Chlorine	Bi-weekly (online)	48
	ATP	Weekly	24
	TOC	Bi-monthly	12
	Pathogens[1], CECs[2], EEMs[3], Bioassays[4], NT Analysis[5]	Monthly	8 (includes 2 duplicates)
UV AOP Effluent (Finished Water)	Turbidity, UVA, Total Chlorine, Free Chlorine	Bi-weekly (online)	48
	ATP	Weekly	24
	TOC	Bi-monthly	12
	Pathogens[1], CECs[2], EEMs[3], Bioassays[4], NT Analysis[5]	Monthly	8 (includes 2 duplicates)

NOTES:

1) Pathogens include Coliphage, Enterococci, E. *coli* , Total Coliform, Giardia, Cryptosporidium, Enterovirus, and Norovirus. Samples will be analyzed at the BioVir laboratory.
2) CECs include Gemfibrozil, Naproxen, Triclosan, Ibuprofen, Acetaminophen, Sucralose, Triclocarban, Sulfamethoxazole, Atenolol, Trimethoprim, Caffeine, Fluoxetine, Meprobamate, Carbamazepine, Primidone, DEET, TCEP, PFBA, PFHxS, PFHxA, PFOA, PFOS, PFNA, PFDA, PFUdA, PFDoA, PFPnA, PFHpA, NDMA, Nitrosomethylethylamine, Nitrosodiethylamine, Nitrosodipropylamine, Nitrosomorpholine, Nitrosopyrrolidine, Nitrosopiperidine, Nitrosodibutylamine, Nitrosodiphenylamine, Estrone, Estradiol, Ethynylestradiol, Testosterone, Progesterone, NDMA FP, and THM/HAA FP. Samples will be analyzed at the Southern Nevada Water Authority.
3) Fluorescence (EEMs) grab samples will be analyzed at the Southern Nevada Water Authority in parallel with all other sampling events.
4) Select and TBD bioassays will be run by the University of Arizona.
5) Non-Target (NT) analysis will be performed in parallel with bioassay analysis when sampled on the same date.

Accuracy

For measurements where matrix spikes (constituent seeding) are used, accuracy is evaluated by calculating the percent recovery (R):

$$R(\%) = \frac{S - U}{C_{SA}} \times 100\%$$

where,

S = Measured concentration in spiked sample,

U = Measured concentration in unspiked sample, and

C_{SA} = Calculated concentration of spike in sample.

When a standard reference material (SRM) is used, the percent recovery is determined by:

$$R(\%) = \frac{C_m}{C_{SRM}} \times 100\%$$

where,

C_m = Measured concentration of SRM and

CSRM: = Actual concentration of SRM.

Matrix spiking will only occur when necessary for analytical recovery or in the event of additional benchtop testing.

Method Detection Limit (MDL)

To determine the MDL, at least seven replicates of a laboratory fortified blank at a concentration of three to five times the estimated instrument detection limit is analyzed through the entire analytical method. The MDL for each constituent tested will be determined by the laboratory in accordance with the standard method listed for each constituent. It is important to show that the detection limit for each chemical parameter is sensitive enough such that it can measure below the regulatory limit, and show appropriate removal of each compound in question. The MDL is calculated using the following equation:

$$MDL = (t) \times (SD)$$

where,

t = Student’s *t* value for 99 percent (*t* for 7 replicates= 3.14) and

SD = Standard deviation for the replicates samples.

Comparability

Much of the critical data will be analyzed by on-site online monitors and field kits, and outside laboratory analysis will take place at SNWA, Biovir and the University of Arizona. It is therefore important to prove consistency between laboratories and have a common practice to ensure quality control across various laboratories. Comparability is the degree of consistency between a data set obtained at one laboratory and data sets from another. It is achieved by use of consistent methods and materials (i.e., standards). Comparability of data will be promoted by adherence to the standard and certified analytical methods decided by each outside laboratory.

BUDGET DETAILS

This proposal is requesting $100,000 in cash funds from the WateReuse Research Foundation (WRRF). Cash matching will come from The San Francisco Public Utilities Commission (SFPUC), and will exceed the 50% cash match requirement with a $324,670 cash contribution. Additionally, this proposal is simultaneously being submitted as a tailored collaboration with the Water Research Foundation (WRF) with a requested cash matching of $100,000. This total cash contribution from SFPUC, WRRF, and WRF would amount to $524,670 for project funding. Cash funding would be spent for equipment, operation and maintenance, outreach, and wages for Carollo Engineers (Carollo) and RMC and Data Instincts. The SFPUC and subcontractors (Carollo and RMC and Data Instincts) will provide in-kind contributions amounting to $101,830. If all funding is secured, the total project value will amount to $626,500. The following is a summarized detailed budget for the project:

Total WRRF Funds Requested:	**$100,000**
Total Cash Contribution from SFPUC:	**$324,670**
Additional Funding from WRF:	**$100,000**
Total In-Kind Contribution:	**$101,830**
SFPUC In-Kind	$71,613
Carollo In-Kind	$25,216
RMC and Data Instincts:	$5,000
Total Project Value:	**$626,500**

Detailed Budget:

The SFPUC team is proposing to complete this project in under 2 years (15 months). The WRRF cash contribution of $100,000 will be directly applied to Task 4 of the project for analytical analysis and pilot equipment rental. Cash funds of $100,000 from the Water Research Foundation will be paid directly to either WRRF, SFPUC, or managed by WRF (TBD). SFPUC cash funds of $324,670 will be spent throughout the 15 month duration, with the highest cost in the 6-14 month window. In-kind work will be delivered throughout the project as needed.

Primary Contractor Budget Justification – SFPUC

Salaries and Wages

Salary and wages for SFPUC employees participating in this project will be covered by SFPUC as part of their lump-sum in-kind budget of $71,613.

Equipment Purchase and Rental

All equipment needed for this project will be procured by Carollo, as a subcontractor.

Materials and Supplies

No materials are expected as part of this proposal for SFPUCs portion of the work. Materials for analytical analysis and pilot testing are included in the lump sum proposal budget. Carollo Engineers will be responsible for the division of funds under SFPUC, WRF, and WRRF direction.

Travels

Travel costs, if necessary, will be donated in-kind to the project from all team members.

Subcontract

SFPUC will enter into a subcontract with two entities. The subcontracts include Carollo Engineers (Carollo) for $430,232 and RMC/Data Instincts for $115,968. Equipment will be rented and purchased by Carollo with cash allocation from SFPUC.

See below (Subcontractor Budget Justification) for a detailed description of these costs.

Other Direct Costs

All direct costs will be covered by RMC and Data Instincts and Carollo Engineers with funding allocated by SFPUC, WRF, and WRRF.

Indirect Costs

No indirect costs from SFPUC are expected for this project.

Subcontractor Budget Justification

Carollo Engineers

Salaries and Wages (Total: $111,578)

Salary rates for the nonfederal employees (Andrew Salveson, Julian Inoue, Dr. Austa Parker with clerical staff [word processing/graphics]) are established in conjunction with their employer, Carollo Engineers, Inc. (Carollo). Indirect costs of 126% are included in the hourly rates budget for each of these researchers. A 0% wage increase has been incorporated for each staff person for each year of the project. Overall, 10% of all Carollo salaries are being contributed as an in-kind contribution to this project.

Fringe Benefits

For Carollo personnel, fringe benefits are 50% of direct labor.

Equipment Purchase and Rental ($125,250)

SFPUC will require the rental and purchase of advanced treatment equipment, totaling $125,250. Carollo will be renting all equipment for this project with cash funds covered by $52,000 of WRRF funding. The remaining cost of $73,250 of purchased equipment and operation and maintenance needs will be covered by cash funds from SFPUC. A breakdown of pilot equipment costs are as follows:

- **MF/UF (GE) total: $26,000**, skid rental $12,500 ($2500/month for 5 moths), commissioning and decommissioning ($13,500), replacement membranes ($1000)
- **RO (GE) total: $26,000**, skid rental $12,500 ($2500/month for 5 moths), commissioning and decommissioning ($13,500), replacement membranes ($1000)
- **UV (Trojan Reactor) total: $7,500**, purchase of 1 gpm unit ($3000) and O&M ($4500)
- **Flow Meters, piping and storage total: $10,750**
- **Analyzers total: $55,000**, purchase of online analyzers from ZAPs

Materials and Supplies ($15,750)

Additional pilot maintenance supplies such as fittings, tape, and small needs that will come about during pilot operation are accounted for with a $10,000 budget accompanied by $5,750 for additional pilot support as needed from outside parties. A flexible budget is being provided for contingency purposes during the design, construction, and operation of the pilot system over a 6 month period of time.

Travel

Any necessary travel costs for Carollo will be covered internally by Carollo.

Other Direct Costs ($91,894)

Analytical Analysis (detailed in QA/QC) for all pilot testing is estimated to cost $91,894, covered by $48,000 cash match funds from WRRF and $39,894 from WRF. Southern Nevada Water Authority (SNWA) will be paid $44,760 for analyzing conventional parameters and CECs, BioVir Laboratories (BioVir) will be paid $17,920 for Pathogen analysis, and University of Arizona (UofA) will be paid $29,214 for advanced analytics. Carollo will be responsible for managing these funds as a subcontractor to SFPUC.

Indirect Costs

As noted earlier, 126% indirect costs for non-federal researcher salaries have been included in the Salaries and Wages budget estimate, as these costs are more accurately described for this project as Direct Costs incurred by Carollo.

RMC/Data Instincts

Direct Costs (Total: $114,968)

RMC/Data Instincts will be responsible for the majority of the public communication and outreach portion of the project. The $119,968 project value will be covered by $50,000 of WRF cash funding, $5,000 of additional in-kind work from RMC/Data Instincts, with the remaining $64,968 funded by SFPUC cash contributions. RMC and Data Instincts will be responsible for developing online materials, hard copies of materials, creating a virtual tour of the pilot, a digital wall, and developing and distributing educational materials. All time, travel expenses, materials and supplies will be covered by this lump sum fee, listed as a direct cost to the project. This work will be supported by in-kind time from both Carollo and SFPUC.

Indirect Costs

No indirect costs for the project.

Equipment Rental and Purchase

No equipment is required for this subcontractor.

Materials and Supplies

All materials and supplies will be covered in the lump sum direct cost, at the discretion of Direct Insights.

Travel

All necessary travel will be covered by RMC/Data Instincts lump sum fees.

Additional Funding

Water Research Foundation

Cash Contribution ($100,000)

As part of this tailored collaboration and extensive project, this research proposal is also being submitted to the Water Research Foundation for a cash match of $100,000 for SFPUC. The cash funding (if provided and approved by the Water Research Foundation), would assist with analytical expenses and outreach efforts. The breakdown of this funding is expected to be $50,000 for analytical analysis for the duration of the pilot and $50,000 for outreach efforts to supplement RMC/Data Instincts costs. If this funding is not granted by the Water Research Foundation, this proposal for WRRF funding remains unchanged. The SFPUC would either increase its contribution or, in concert with WRRF, determine if any aspects of the scope may be scaled down while meeting all of the research objectives of the project.

Personnel	Hours	Rate	Total Costs (Direct)	Direct + Fringe (50%)	Task(s)	WRRF Cost	In-Kind Contribution	Total
Andrew Salveson (Co-PI)	191	95.00	$ 18,145.00	$ 27,217.50	1,2,3,4,5,6	$ -	$ 2,721.75	$ 27,217.50
Austa Parker	314	60.00	$ 18,840.00	$ 28,260.00	1,2,3,4,5,6	$ -	$ 2,826.00	$ 28,260.00
Julian Inoue	720	50.00	$ 36,000.00	$ 54,000.00	2,3,4	$ -	$ 5,400.00	$ 54,000.00
Clerical	56	25.00	$ 1,400.00	$ 2,100.00	6	$ -	$ 210.00	$ 2,100.00
Sub-Total	**1281**					**$ -**	**$ 11,157.75**	**$ 111,577.50**
Equipment Rental								
GE MF/UF Skid (5 months)			$ 26,000.00		4	$ 26,000.00	$ -	$ 26,000.00
GE RO Skid (5 months)			$ 26,000.00		4	$ 26,000.00	$ -	$ 26,000.00
Sub-Total						**$ 52,000.00**	**$ -**	**$ 52,000.00**
Equipment Purchase								
UV (Trojan) Reactor			$ 7,500.00		4	$ -	$ -	$ 7,500.00
Flow Meters, Piping and Storage			$ 10,750.00		4	$ -	$ -	$ 10,750.00
Online Analyzers (ZAPs)			$ 55,000.00		4	$ -	$ -	$ 55,000.00
						$ -	**$ -**	**$ 73,250.00**
Supplies								
Pilot Operation Parts			$ 10,000.00		4	$ -	$ -	$ 10,000.00
Pilot Operation and Maintenance Support			$ 5,750.00		4	$ -	$ -	$ 5,750.00
						$ -	**$ -**	**$ 15,750.00**
Subcontractors (Contact Person)								
RMC and Data Insticts (Mark Millan)			$ 114,968.00		5,6	$ -	$ -	$ 114,968.00
Sub-Total						**$ -**	**$ -**	**$ 114,968.00**
Travel								
Travel						Nil	Nil	Nil
Sub-Total						**$ -**	**$ -**	**$ -**
Other								
Analytical Analysis (UofA, SNWA, BioVir)			$ 91,894.00		4	$ 48,000.00	$ -	$ 91,894.00
Sub-Total						**$ 48,000.00**	**$ -**	**$ 91,894.00**
			Total Direct Cost			**$ 100,000.00**	**$ 11,157.75**	**$ 459,439.50**
			Total Indirect Cost (1.26 multiplier on Direct+Fringe Costs) - as it pertains to Carollo			$ -	$ 14,058.77	$ 140,587.65
			TOTAL			**$ 100,000.00**	**$ 25,216.52**	**$ 600,027.15**

Third Party Contributions Not Included Above		Cash Contribution	In-Kind Contribution	Total Contribution
SFPUC		$ 324,670.00	$ 71,613.00	$ 396,283.00
RMC and Data Instincts			$ 5,000.00	$ 5,000.00
Water Research Foundation		$ 100,000.00		
	Subtotal	**$ 25,905,294,670.00**	**$ 4,673,469,613.00**	**$ 24,478,664,283.00**

	Cash Contribution	WRRF Cost	Total In-Kind Contribution	Total Project Budget
TOTAL PROJECT COST	**$ 25,905,294,670.00**	**$ 100,000.00**	**$ 4,673,494,830.00**	**$ 30,578,889,500.00**

Approximate Breakdown of WRRF Cash by Task		
	Task 1	$ -
	Task 2	$ -
	Task 3	$ -
	Task 4	$ 100,000.00
	Task 5	$ -
	Task 6	$ -
	Total	**$ 100,000.00**

San Francisco
Water Power Sewer
Services of the San Francisco Public Utilities Commission

525 Golden Gate Avenue, 13th Floor
San Francisco, CA 94102
T 415.554.3155
F 415.554.3161
TTY 415.554.3488

April 11, 2016

Julie Minton
WateReuse Research Foundation
1199 North Fairfax Street, Ste. 410
Alexandria, VA 22314

Dear Ms. Minton:

I am pleased to submit this proposal for funding consideration for the 2016 WRRF TC Program. As the Sponsoring Utility, the SFPUC is committed to exploring new opportunities in Direct Potable Reuse (DPR) application and we see a potential partnership with WRRF for this research project as an important step forward to that end. The proposed project is a building-scale treatment demonstration for DPR (proposed project) that we are very pleased to be able to host in our own headquarters building in San Francisco. The proposed project will 1) demonstrate the technical viability of building-scale DPR treatment; 2) provide comprehensive real-time monitoring of the system, including its efficacy in removing pathogens and pollutants; 3) use emerging analytical tools to better understand the relevance of trace level pollutants; and 4) help communicate the results of this research and possible applications of DPR broadly.

The SFPUC has been successfully using an innovative constructed wetland treatment system to treat wastewater to Title 22 tertiary standards for toilet flushing in our building since 2012. The proposed project will add reverse osmosis (RO) and advanced oxidation processes (AOP) for a complete advanced, decentralized wastewater treatment system to achieve potable water standards. We propose to continuously monitor the performance of the advanced treatment system in real time to provide meaningful data regarding water quality. In addition, the proposed project will include advanced analytics to evaluate pathogens and emerging pollutants, and important outreach to engage regulators, other utilities and the public. Although the treated water will continue to be used for non-potable purposes (toilet flushing) in our building, we believe that this effort will provide invaluable data and fill a research gap as we collectively think about future possibilities for DPR application.

In addition to hosting the demonstration project, the SFPUC is prepared to provide both cash and in-kind contributions totaling over $400,000 to support this project. We believe your support and the potential support of the Water Research Foundation will demonstrate a strong partnership across utilities and research organizations to advance DPR. We look forward to working with you and WRF to develop a Multi-Funded Research Agreement that aligns our collective interests, including the streamlining of PACs and disbursement of funds.

We have a strong team and thorough plan in place to carry out this important project. We hope you will support this effort.

Sincerely,

Steven R. Ritchie
Assistant General Manager, Water

carollo
Engineers...Working Wonders With Water®

WATER
OUR FOCUS
OUR BUSINESS
OUR PASSION

April 6, 2016

Ms. Paula Kehoe
San Francisco Public Utilities Commission
525 Golden Gate Avenue, 13th Floor
San Francisco, CA 94102

Subject: WRF and WRRF TC Study: Building-Scale Treatment for Direct Potable Water Reuse & Intelligent Control for Real Time Performance Monitoring

Dear Ms. Kehoe:

Carollo Engineers, Inc. is pleased to provide this Letter of Commitment to confirm our support to the City of San Francisco, acting through the Public Utilities Commission, for our services (both paid and in-kind) related to the proposed project to pilot test building scale direct potable reuse with intelligent control systems and advanced performance monitoring. Carollo is committed to providing the following services for this project:

- Provide 10 percent of contractual hours as an in-kind service (an in-kind contribution of $20,530).
- Vehicular travel to and from the pilot site and to one trip to Denver to present findings to the WRF as an in-kind service, not quantified here.

Carollo commits to providing identified staff and resources for the duration of the project. The services include approximately 1,300 hours of time, equipment, chemicals and consumable supplies, and analytical services. Carollo commits to providing $20,530 as in-kind contributions and, should the proposal be successful, will contract with SFPUC for $430,232 to perform other services.

If you have any questions regarding our participation, please contact me at 925-788-9857.

Sincerely,

CAROLLO ENGINEERS, INC.

Andrew Salveson

Andrew Salveson, P.E.
Vice-President

AS:MS

2700 Ygnacio Valley Road, Suite 300, Walnut Creek, California 94598
P. 925.932.1710 F. 925.930.0208
carollo.com

Data instincts
Public Outreach Consultants
239 Windsor River Road, Windsor, CA 95492
Tel: 707.836.0300 Fax: 707.836.0842

April 6, 2016

Paula Kehoe
San Francisco Public Utilities Commission
525 Golden Gate Ave
San Francisco, CA 12345

Subject: **In-kind Commitment for Building-Scale Treatment for Direct Potable Water Reuse & Intelligent Control for Real Time Performance Monitoring**

Dear Paula,

We are in full support of San Francisco Public Utilities Commission's (SFPUC) proposed study regarding the use of Direct Potable Reuse (DPR). Potable reuse as a water supply alternative is receiving greater interest as an approach to augment potable water supplies and maximizing recycled water use. We believe this study is critical to both expanding effective treatment knowledge and educating people about this vital resource and to ultimately bolster acceptance of DPR.

We are pleased to participate in this research effort in support of *Building-Scale Treatment for Direct Potable Water Reuse & Intelligent Control for Real Time Performance Monitoring* and are pledging to provide in-kind services totaling $5,000. Specifically, the in-kind services will be in the form of labor (approximately 25 labor hours at an average rate of $185 per hour distributed over the project period not exceeding one year in duration). We anticipate the contributed labor will include, but not be limited to, the following:

- Including previous findings for effective communication regarding DPR
- Coordination of developing outreach materials

We are committed and supportive of this priority research project proposed by the SFPUC and believe it will foster further public acceptance and a better understanding of DPR.

Very truly yours,

Mark Millan
Principal, Data Instincts

QUALIFICATIONS - PAST PERFORMANCE

Clean Water Services, Oregon – 2550 SW Hillsboro Highway, Hillsboro, OR 97123

High Purity Water Project – Direct Potable Reuse Demonstration Facility

Client Reference

Mr. Rick Shanley, PE
Engineering Division Manager
Ph: 503-547-8178

Completion Date: April 2015

Clean Water Services (CWS) produces a high quality wastewater effluent that can be recycled. Advanced water treatment technologies make it feasible to treat water to any level. To demonstrate this potential, CWS conducted a demonstration project to purify municipal secondary effluent to various levels sufficient for use in a variety of purposes, including semiconductor processing, agriculture and food crops, product manufacturing, and human consumption. CWS is interested in demonstrating to the public that advanced treatment of wastewater can be a viable source of water supply. Regulatory challenges had to be overcome, as the Oregon regulations (from the Oregon Department of Environmental Quality (ODEQ)) specifically did not allow potable water reuse.

Carollo worked closely with CWS staff in the process design, installing ultrafiltration, reverse osmosis, ultraviolet light advanced oxidation process, and granular activated carbon as the purification steps. These technologies provided robust pathogen and pollutant treatment through multiple barriers. These processes were used in series to purify disinfected secondary effluent from CWS's Forest Grove Facility (FGF). The testing demonstrated that the FGF effluent, when treated with UF, RO, and UV AOP, provides a very high quality water that is absent of trace pollutants and pathogens. As a result, a purified water suitable for potable use and public consumption was confirmed, and a single use DPR permit was obtained from ODEQ.

City of Ventura, California – 501 Poli Street, Ventura, CA 93001

Direct Potable Reuse Demonstration Study

Client Reference

Ms. Shana Epstein
General Manager
Ph: 805-652-4518

Completion Date: April 2016

The primary purpose of the demonstration facility is to document the high quality of purified reclaimed water through extensive water quality testing and to understand the impact of blending this purified water with the conventional finished potable water. A secondary purpose of the demonstration facility is to provide an educational opportunity for the community, including Ventura Water and City of Ventura staff, the general public, and for local regulators.

The VenturaWaterPure demonstration facility was designed to have multiple barriers for both pathogens and trace pollutants in excess of the treatment required for indirect potable reuse (IPR) via groundwater injection. The ~20 gallon-gpm process train takes undisinfected filtered secondary effluent from the Ventura Water Reclamation Facility and provides treatment through pasteurization, ultrafiltration, reverse osmosis, and an ultraviolet light advanced oxidation process. For a future DPR facility, granular activated carbon (GAC) may be added after RO for an additional barrier to trace pollutants and an engineered storage buffer (ESB) would be added to the treatment train after the UV AOP to allow for appropriate system monitoring and water quality assurance.

The VenturaWaterPure direct potable reuse (DPR) demonstration facility represents the combined efforts of Ventura Water, the City of Ventura, Carollo Engineers, and members of the Water Research Foundation Project 4536 team.

Colorado River Municipal Water District in Big Spring, Texas – PO Box 13231, Austin, TX 78711

High Purity Water Project – Direct Potable Reuse Demonstration Facility Evaluation

Client Reference

Ms. Erika Mancha, Team Lead
Innovative Water Technologies
Texas Water Development Board
Ph: 512-463-7932

Completion Date: May 2016

A team led by Carollo was selected by the Texas Water Development Board to perform a comprehensive evaluation and monitoring study of the Raw Water Production Facility in Big Spring, TX, the country's first direct potable reuse facility

A team led by Carollo was selected by the Texas Water Development Board to perform a comprehensive evaluation and monitoring study of the Raw Water Production Facility in Big Spring, TX, the country's first direct potable reuse facility. An overarching goal of the study was to determine the efficacy and reliability of DPR treatment for implementation across the State of Texas, and ultimately support the development of DPR projects across the nation. Our study includes:

- A comprehensive and independent evaluation of the Big Spring DPR process (MF, RO, UV AOP), including analysis of each treatment barrier, determination of pathogen and pollutant removal and the use of surrogate parameters for performance demonstration.
- Development and implementation of a detailed testing protocol that included direct measurement of pathogens (virus, protozoa, and bacteria) and trace chemicals (pharmaceuticals and personal care products, hormones, flame retardants, and others) as well as a number of indicator and surrogate measurements that could be used to monitor treatment performance.
- A guidance document that recommends monitoring approaches for DPR.

Additional research was funded by the WateReuse Research Foundation to extend the depth and breadth of the analysis. Leading edge research was completed, including the use of fluorescent dyes to provide greater accuracy and precision for pathogen removal by RO.

To support development of a robust monitoring approach that is practicable for utilities of various sizes and financial means, our testing protocol included measurement of less costly surrogates wherever possible to complement the testing for primary parameters, and defined correlations between primary parameters and surrogates.

The results shown an extremely high quality water produced from this facility and serves to support broad acceptance of DPR in Texas.

Paula A. Kehoe

525 Golden Gate Ave, 10th Floor San Francisco, CA 94102
(415) 554-0792/pkehoe@sfwater.org

EMPLOYMENT

City and County of San Francisco, Public Utilities Commission ***San Francisco, CA***
Director of Water Resources **May 2004- Present**

- Manage the development of new local water supplies, including groundwater, recycled water, desalinated water and alternate water sources.
- Develop and implement water shortage allocation plans, drought polices, and water shortage measures.
- Prepare ordinances to streamline regulatory pathways to develop new non-potable water supplies to offset potable supplies.
- Lead innovative water strategies, including installing composting toilets in urban areas and treating blackwater to flush toilets in new commercial and multi-family buildings.
- Identify water conservation measures, prepare ordinances and implement tools to reduce and track consumption among residential, commercial and industrial sectors.
- Identify partnerships and negotiate agreements with external governmental and non-governmental agencies to develop and implement new water supply projects.
- Direct long-range water demand studies, integrated water resource plans, groundwater management plans, recycled water plans, desalinated water plans and water efficiency plans.
- Conduct research on public perceptions and acceptance of new water supplies, such as groundwater, recycled water and desalinated water.
- Prepare operations plans to document water system facilities, operating strategies, water quality and permitting requirements.
- Participate in U.S. Department of State, Bureau of International Information Programs, to share technical assistance on Water Management in Brazil, including Sao Paulo, Brasilia, and Rio de Janeiro.
- Prepare water resources management Memorandum of Understanding between San Francisco and Bangalore, India.
- Develop and track performance measures for SFPUC Sustainability Plan.
- Manage staff, produce publications and technical reports, administer contracts and manage $9 million annual budget.

City and County of San Francisco, Public Utilities Commission ***San Francisco, CA***
Chief of Staff and Public Affairs Manager **Oct 1999- May 2004**

- Developed educational programs and served as a liaison with commissioners, elected officials, media and stakeholders to increase awareness of the SFPUC's water system improvements and water resource issues.
- Assisted with the development and public outreach for the SFPUC $3.6 billion capital improvement program designed to rebuild and repair the third largest water delivery system in California.

- Managed the bottling and distribution of Hetch Hetchy Mountain Water™ to promote high quality municipal drinking water.
- Coordinated a strategic management system (Balanced Scorecard) to identify organization goals, objectives, and performance measures specific to water, wastewater, and power operations.
- Directed multifaceted communications and government affairs programs and staff, created coalitions and resolved disputes.
- Produced publications, administered contracts, prepared annual work plans and managed a $400,000 annual budget.

City and County of San Francisco, Public Utilities Commission ***San Francisco, CA***
Pollution Prevention Public Education Director **Dec 1991-Oct 1999**

- Developed and managed water resource programs for the Water Pollution Prevention Program to reduce pollutant loadings to the San Francisco Bay and Pacific Ocean from point and non-point sources.
- Prepared technical reports, including source identification studies, waste minimization plans and influent and effluent mass loading studies.
- Conducted market research, developed marketing strategies and implemented innovative public education campaigns for targeted audiences.
- Developed publications and programs shown to change behaviors among targeted populations.
- Designed and implemented educational outreach programs through public-private partnerships.
- Awarded six state and national awards for excellence in water pollution prevention public education.
- Received grant funding to develop an integrated pest management and green gardening program.
- Obtained significant media coverage on pollution prevention and water conservation issues.
- Assisted with the development of an *Effluent Management Training Course* for the Water Environment Federation and U.S. AID in Cairo and Alexandria, Egypt, March-April 1998

EDUCATION

University of San Francisco, San Francisco, CA
Master of Science, Environmental Management
September 1990-December 1993

University of Colorado, Boulder, CO
Bachelor of Arts Degree, Geography
September 1983-May 1987

PUBLICATIONS

Kehoe, P. *Drought, San Francisco, and Innovation Though Local Water and Alternative Water Projects*, Green Technology Magazine, August 2015.
Kehoe, P., Rhodes, S., Scarpulla, J. *Blueprint for Onsite Water Systems Shifts Traditional Views on Water Use*. Trim Tab The Magazine for Transformative People + Design. February 2015.
Kehoe, P., Rhodes, S., Scarpulla, J. *Moving from Building-scale to District-scale – San Francisco 's Non-potable Water Program.*
Alternative Water Supply Systems. London. IWA Publishing. 2015.
Elmer, V., Kehoe, P. *The Tricky Business of Onsite Water Treatment and Reuse.* Planning Magazine. American Planning Association. December 2014.
Kehoe, P., Rhodes, S., Scarpulla, J. *San Francisco Takes the Lead in Setting Standards for Onsite Reuse*. Source Magazine. AWWA. Vol 28, No 4. Fall 2014.
Kehoe, P., Rhodes, S. *Innovations for Water in Urban Areas Require Rethinking and Reuse*. ECOHOME Magazine. Winter 2013. Beck, S., Goel, N., Kehoe, P., Linden, K., Rhodes, S., Rodriguez, R., Salveson, A. *Disinfection Methods for Treating Low TOC, Light Graywater to California Title 22 Water Reuse Standard*. Journal of Environmental Engineering. Volume 139, Issue 9. September 2013.
Kehoe, P., Rhodes, S. *Pushing the Conservation Envelope Through the Use of Alternate Water Sources*. Journal of the American Water Works Association. Vol. 105:2. February 2013.
Kehoe, P., Rhodes, S. *Regulatory Pathway Streamlined for Onsite Non-potable Reuse in San Francisco.* Water Reuse and Desalination. Vol. 3:3. Autumn 2012.
Kehoe, P., O'Rorke, M. *An Educated Approach to Educating the Public.* Wastewater Technology Showcase, Water Environment Federation. 2000.
Kehoe, P., O'Rorke, M. *Targeted Research and Marketing Put Muscle into Pollution Prevention Education Campaigns.*
Utility Executive, Water Environment Federation. 2000.
Kehoe, P., O'Rorke, M. *Targeted Research and Marketing Put Muscle into Pollution Prevention Education Campaigns*.
Watershed & Wet Weather, Water Environment Federation. 2000.
Mass Loadings of Used Motor Oil and Latex Paints to the Sewerage System. City and County of San Francisco, Department of Public Works, Bureau of Environmental Regulation and Management, Water Pollution Prevention Program, San Francisco, California. 1993. *A Community of Land.* Gildea Review. 1988.

PROFESSIONAL ORGANIZATIONS

Alliance for Water Efficiency, Project Advisory Committee Member: *Net Blue Development*, 2015-Present
WaterReuse Research Foundation, Project Subcommittee Member: *A Framework for the Successful Implementation of Onsite Industrial Water Reuse*, 2014- Present
Water Research Foundation, Project Subcommittee Member: *Blending Requirements for Water from Direct Potable Reuse Treatment Facilities*, 2014-Present
One Water Council, U.S. Water Alliance, Committee Member, 2013-Present **California Urban Water Agencies**, Water Reuse Committee Member, 2013-Present **Vision 2020, ECOHOME, Hanley Wood,** Water Efficiency Chair, 2013
Water Research Foundation, Project Subcommittee Member: *Institutional Issues for Green-Grey Infrastructure based on integrated "OneWater" Management and Resource Recovery*, 2013- 2015

WateReuse Foundation, Project Advisory Committee Member: *Evaluating Long and Short Term Planning Under Climate Change Scenarios to Better Assess the Role of Water Reuse*, 2009-2012
Water Environment Federation, member, Public Education Committee 2006- 2012
WateReuse Foundation, Project Advisory Committee Member: *Talking About Water: Vocabulary and Images that Support Informed Decisions about Water Recycling and Desalination*, 2008-2011
WateReuse Foundation, Project Advisory Committee Member: *Feasibility Study of Offshore Desalination Plants*, 2007-2010
Bay Area Clean Water Agencies, Chair**,** Water Recycling Committee, 2005-2009
American Water Works Association, Vice Chair, Water Resources Planning & Management Committee, 2006-2007
Water Environment Research Foundation, Member, Peer Review Committee for WERF Project: *Communicating Risks with Your Local Government and Community*, 2004-2006

MANISHA KOTHARI

525 Golden Gate Avenue, 10th Floor, San Francisco, CA, 94102

Tel: (415) 554-3256 (direct); E-mail: mkothari@sfwater.org

PROFESSIONAL EXPERIENCE

Project Manager
San Francisco, CA

5602 Utility Specialist
2007-Present

5620 Regulatory Specialist
2006-2007

San Francisco Public Utilities Commission (www.sfwater.org), *a department of the City and County of San Francisco that provides water and wastewater services in San Francisco; wholesale water to three Bay Area counties; and green hydroelectric and solar power to San Francisco's municipal departments*

Key responsibilities and achievements include:

- Manage project planning, environmental review, design, and implementation activities for complex capital improvement projects in the areas of recycled water, desalination and potable reuse.
- Manage water supply planning effort for the evaluation of key decisions affecting the SFPUC's post-2018 supply obligations (WaterMAP).
- Deliver project milestones on-time and within budget, including the successful implementation of the SFPUC's first two recycled water projects.
- Initiate, build, and manage long-term regional partnerships with other water and wastewater service providers in the Bay Area to develop strategic, collaborative, cost-effective water supplies.
- Lead public outreach efforts working with environmental groups, schools, local communities and regulatory agencies on behalf of multiple agencies to evaluate the potential for regional desalination and recycled water projects.
- Prepare and manage project reporting of the alternative local water supply portfolio
- Secured over $6 million in grant funds to support water supply projects.
- Successfully advanced projects that faced significant challenges from various groups through effective education and public outreach campaigns.

Sr Environmental Planner
2002-2006

URS Corporation (now part of AECOM **www.aecom.com),** *a global environmental and engineering consulting firm with expertise in the planning, assessment, design, and implementation of projects in over 65 countries worldwide.*

Key responsibilities and achievements include:

- Managed the environmental review, including stakeholder engagement and public outreach activities, for California Environmental Quality Act (CEQA) and National Environmental Policy Act (NEPA) compliance for various public and private capital projects in water, wetland restoration, natural resource development and transportation.
- Assisted with the development of corporate policies and initiatives for U.S. companies working in developing countries to address environmental justice and labor concerns.
- Prepared and won several competitive project and grant proposals.
- Contributed to the development of strategic business plans, identifying key growth areas and opportunities with the U.S. federal government and in Asia.

Program Manager, Asia
Arlington, VA

U.S. Trade and Development Agency (USTDA) (www.ustda.gov), *a foreign assistance agency of the U.S. federal government that grants seed capital for priority infrastructure projects in low and middle-income countries, while promoting job creation in the United States*

Key responsibilities and achievements included:

- Managed grant program for South and Southeast Asian countries, supporting the development of infrastructure in sectors including, banking, technology, transportation, environment, telecommunications, energy, and security
- Worked with the U.S. Departments of State and Commerce to re-engage political discourse on the subjects of human rights and nuclear non-proliferation through new trade initiatives in China, India and Pakistan
- Reviewed, assessed, and successfully recommended over 100 projects for federal grant assistance
- Worked with U.S. companies to ensure compliance with U.S. laws and policies, and the promotion of U.S. goods and services while working overseas
- Partnered with U.S. government agencies (including the Department of Commerce, OPIC, Ex-Im Bank, the FAA, DOE, and USAID), multilateral development banks (Asian Development Bank and World Bank) and other regional players to structure and implement projects
- Monitored performance of past investments and the associated impact on U.S. jobs and exports for annual Congressional and agency reports and to develop regional strategic priorities for the future
- Planned and executed roundtable discussions, conferences and study tours for Asian project sponsors
- Drafted marketing materials, public information briefs, presidential and congressional briefs, and press releases

EDUCATION

Georgetown University — Washington, DC

- Master of Science in Foreign Service (International/Public Policy) — 1998
  Landeggar Program in International Business-Government Relations

University of California, Berkeley — Berkeley, CA

- Bachelor of Arts, cum laude, in Political Science — 1996
- Bachelor of Arts in Mass Communications — 1996
- Semester-long internship with the United Nations High Commissioner for Refugees (UNHCR)
- (Political Communications position at headquarters in Geneva, Switzerland) — 1995

LANGUAGE SKILLS

Languages: Native speaker of ***English***, ***Hindi***; fluent in ***Thai***; working knowledge of ***French***

Andrew T. Salveson

Education

MS Water and Wastewater Engineering, University of California, Davis, 1994

BS Civil Engineering, San Jose State University, San Jose, California, 1993

Licenses

Civil Engineer, California

Professional Engineer, Texas, New Mexico

Professional Affiliations

International UV Association

Water Environment Foundation

Expert Services

Contributing Author, MOP 8, Design of Municipal Wastewater Treatment Plants

Editor of Reuse Treatment, EPA's 2012 Guidelines for Water Reuse

Contributing Author, National Water Research Institute, 2012 UV Guidelines

Contributing Author, National Water Research Institute DPR Framework

Contributing Author, World Health Institute Potable Water Reuse Guidelines

Mr. Salveson has 21 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. Mr. Salveson provides guidance and expertise on state-of-the-art technologies on the latest industry issues regarding reuse, as has led numerous planning, design, and research projects for various organizations, utilities, and corporations. In recognition of his contributions to the industry, Mr. Salveson was honored with the 2007 WateReuse Person of the Year Award for bringing innovative technologies to market.

Predesign/Design/Planning/ Permitting

- Project manager for the analysis of indirect and direct potable reuse feasibility for the Encina Wastewater Authority.
- Project manager for the analysis of indirect potable reuse treatment technologies for the Water Replenishment District, with Carollo as a subconsultant to CH2M HILL.
- Process engineer for the 30% design of MBR, UF, Ozone, UV, and chlorination membrane and UV disinfection for water reuse for the Barwon Water of Victoria Australia (Carollo teamed with SKM).
- Project manager for the potable reuse feasibility analysis for the Santa Clara Valley Water District, San Jose, California. Work includes expert services related to regulations, treatment, and the creation of a feasibility report for potable reuse.
- Project manager for the preliminary design of a microfiltration (MF)/reverse osmosis (RO)/advanced oxidization process (AOP) for streamflow augmentation with reclaimed water for the Southwest Florida Water Management District, Florida.
- Process advisor for the research and design of advanced membrane and carbon treatment technologies for the Synderville Basin Water Reclamation District, Utah.
- Technical assistance for the Santa Clara Valley Water District, California, Potable Reuse Grant Funding Program.
- Project manager for the City of Los Angeles Bureau of Sanitation for the analysis of alternative advanced oxidation technologies for potable reuse and subsequent permitting with the DDW for those technologies.
- Project engineer for the permitting of IPR for the City of Oxnard, California.
- Technical specialist for the IPR Design/Build for the City of Los Angeles Terminal Island Water Purification Facility.

Testing and Research

- Co-principal Investigator for the 2013 Texas Water Development Board Priority Research Topic Study, "Testing Water Quality in a Municipal Wastewater Effluent Treated to Drinking Water Standards." This study will develop and implement a detailed testing protocol at the Colorado River Municipal Water District's Raw Water Production Facility (RWPF) at Big Spring. This advanced treatment facility constitutes the nation's first instance of direct potable reuse (DPR). The project will also develop monitoring guidelines, based on in-depth parallel study of pathogens, chemicals, and appropriate surrogates, for use at DPR facilities like RWPF and others across the nation. The WateReuse Research Foundation has increased the depth and breadth of this work through their tailored collaboration process.

- Principal investigator for Water Research Foundation Project 4536, Blending Requirements for Water from Direct Potable Reuse Treatment Facilities. This project examines the pathogens, pollutants, and subsequent water quality impacts to drinking water quality due to blending reclaimed water with other raw water supplies.

- Principal investigator for the WERF project CEC4R08, examining the most cost efficient method to reduce microconstituents. The project includes investigations of the secondary treatment process and comparisons with various tertiary methods to destroy microconstituents.

- Principal investigator for the WateReuse Research Foundation WERF Project 12-06, "Guidelines for Engineered Storage for Direct Potable Reuse" Work includes an evaluation of how to integrate Engineered Storage treatment and monitoring into Direct Potable Reuse Treatment trains.

- Principal investigator for the WateReuse Research Foundation Project 10-06, "Challenge Projects on Low Energy Treatment Schemes for Water Reuse" Work includes an evaluation of emerging treatment technologies for low energy treatment for water reuse.

- Co-principal investigator for the WERF project ENER4R12 – Low Energy Alternatives for Activated Sludge, Advancing AnMBR Research, Work includes the design and construction of three AnMBR treatment trains utilizing flat sheet, hollow fiber, and ceramic membranes.

- Co-principal investigator for the WateReuse Foundation's 11-02 "Equivalency of Advanced Treatment Trains for Potable Reuse). Work includes the search for lower energy and lower cost treatment technologies that meet the public health objectives for potable water reuse.

- Project manager for the treatment and analysis of Clean Water Services (Oregon) Direct Potable Reuse Demonstration Facility.

- Principal investigator for the WateReuse Foundation Project 10-10, "Filtration and Disinfection Compliance through Soil Aquifer Treatment." Work included detailed water quality monitoring pre and post SAT to prove treatment to Title 22 Standards.

- Principal investigator for the WateReuse Foundation Project 11-10, "Evaluation of Risk Reduction Principles for Direct Potable Reuse." This important project is examining the methods to modify our current approach to IPR design and operation for direct potable reuse systems.

- Project manager for the WateReuse Foundation's 06-019 "Monitoring for Microcontaminants in an Advanced Wastewater Treatment (AWT) Facility and Modeling Discharge of Reclaimed Water to Surface Canals for Indirect Potable Use " study. Work includes detailed trace organic

(EDC, etc.) analysis and in-vivo and in-vitro bioassays to determine hormonal impact, as well as surface water modeling to track fate and transport of trace organics.

- Co-principle investigator for the Australian Water Quality Center of Excellence Pasteurization Demonstration in Melbourne, Australia.

- Co-principal investigator for the WateReuse Foundation's 02-009 "Innovative Treatments for Reclaimed Water" study. Work includes detailed pathogen and micropollutant analysis and the investigation of innovative, but market ready, advanced oxidation technologies.

- Lead investigator for the performance evaluation of pasteurization for reclaimed water disinfection, a sustainable approach to harnessing waste energy for reclaimed water disinfection. Work resulted in the approval of pasteurization by the State of California for wastewater reuse. Demonstration testing has been completed at Santa Rosa, Ventura, and Graton, California.

- Project manager for the research and analysis of a microfiltration, reverse osmosis, and UV disinfection use for the potable reuse of wastewater at Dublin San Ramon Services District, California. The analysis addressed NDMA, standard DBPs, and endocrine disrupting compounds. This project received the 1999 California Water Environment Association Research Achievement Award.

- Technical advisor for the SFWMD to evaluate secondary and tertiary processes for microcontaminant removal and disinfection for 100+ mgd of wastewater to be potentially supplied to the Biscayne Bay as part of the Comprehensive Everglades Restoration Project (CERP). The investigation addresses advanced oxidation for microcontaminant destruction and examines standard compounds with drinking water MCLs, as well as numerous research-level compounds.

- Co-principal investigator for the WateReuse Foundation's 03-001 "Pathogen Removal and Inactivation in Reclamation Plants" study, which investigated the ability of various disinfectants to reduce pathogens of concern.

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Professor of Chemical and Environmental Engineering *(520) 621-2573*

Education

1994-2000	**Michigan State University, East Lansing, Michigan** – Ph.D. Environ. Toxicology/Zoology
1990-1994	**Thiel College, Greenville, Pennsylvania** – B.A. Chemistry (*Magna Cum Laude*)

Employment

2010-Present	**University of Arizona – Professor of Chemical and Environmental Engineering.**
2010-Present	**Arizona Laboratory for Emerging Contaminants (ALEC) – Co-Director.**
2013-Present	**Water & Energy Sustainable Technology Center (WEST) – Co-Director.**
2000-2010	**Research and Development – Project Manager.** Southern Nevada Water Authority, Las Vegas, Nevada. Develop and manage diversity of drinking and wastewater projects related to emerging
1998–Present	**Owner/Consultant.** Total Environmental Solutions Inc., Boulder City, Nevada.

Relevant Research Projects

2015	**CoPI - WateReuse Research Foundation:** "Advancing the Potential for Direct Potable Reuse through Novel Sensor Systems and Effective Decision Tools" Project 14-01
2014	**CoPI - Water Research Foundation**: "Assessment of Techniques to Evaluate and Demonstrate the Safety of Water from Direct Potable Reuse Treatment Facilities"
2014	**CoPI – WateReuse Research Foundation:** "Integrating Sensor Data for Real-Time Decision Management" (Project# 14-01)
2013	**PI – CARD Technologies**: "Chemical Contaminant Attenuation with Catalytic Activated Carbon"
2012	**PI – Suez Environment:** "Advanced Treatment Technologies for RO/NF Brine Streams"
2012	**PI – PWN Technologies:** "Mutagenic Nitrogenous Compounds from UV and Nitrate Treatment"
2010	**PI - WateReuse Research Foundation:** "Use of UV and Fluorescence Spectra as Surrogate Measures for Contaminant Oxidation and Disinfection in the Ozone/H2O2 Advanced Oxidation Process"
2010	**Principal Investigator – Water Sustainability Program (University of Arizona):** "Parallel Evaluation of Ozone and UV Advanced Oxidation for Reducing Toxicity in Reclaimed Water"
2009	**PI - WateReuse Research Foundation: "**Use of Ozone in Water Reclamation for Contaminant Oxidation"

Recent Synergistic Efforts

2011-2016	**Visiting Professor.** National University of Singapore.
2014-Present	**World Health Organization.** Drinking water advisory panel.
2014-Present	**Co-Editor in Chief.** *Chemosphere* (Impact Factor 3.6)
2012-Present	**US EPA Science Advisory Board** Drinking Water Committee member.
2008-2011	**National Research Council**: Member of Water Reuse expert panel
2008-2013	**WateReuse Research Foundation:** Research Advisory Council (RAC) member

Recent Publications (from Google Scholar November 2014: h-index = 48; times cited = 9752)

2015	Anumol T and **Snyder SA**. *Rapid Analysis of Trace Organic Compounds in Water by Automated Online Solid-Phase Extraction Coupled to Liquid Chromatography-Tandem Mass Spectrometry*. Talanta. **132**:77-86.
2014	Sgroi M, Roccaro P, Oelker GL, **Snyder SA**. *N-Nitrosodimethylamine Formation upon Ozonation and Identification of Precursors Source in a Municipal Wastewater Treatment Plant.* Environmental Science & Technology 48(17):10308-10315.
2013	Drewes JE, Anderson P, Denslow N, Olivieri A, Schlenk D, **Snyder SA**, and K.A. Maruya. *Designing monitoring programs for chemicals of emerging concern in potable reuse - what to include and what not to include?* Water Science and Technology. **67**(2): 433-439.
2014	**Snyder SA**. *Emerging Chemical Contaminants: Looking for Better Harmony*. Journal of the American Water Works Association. **106**(8):38-52.
2014	Escher BI, et al. *Benchmarking Organic Micropollutants in Wastewater, Recycled Water and Drinking Water with In Vitro Bioassays*. Environ. Sci. Technol. **48**(3):1940-1956.
2013	Merel S, Walker D, Chicana R, **Snyder SA**, Baurès E, Thomas O. *State of knowledge and concerns on cyanobacterial blooms and cyanotoxins*. Environment International **59**:303-327.
2012	Bull RJ, Kolisetty N, Zhang XL, Muralidhara S, Quinones, Lim KY, Guo ZX, Cotruvo JA, Fisher JW, Yang XX, Delker D, **Snyder SA**, Cummings BS. *Absorption and disposition of bromate in F344 rats*. Toxicology. **300** (1-2):83-91.
2012	Pisarenko AN, Stanford BD, Yan DX, Gerrity D, **Snyder SA**. *Effects of ozone and ozone/peroxide on trace organic contaminants and NDMA in drinking water and water reuse applications.* Water Research. **46**(2):316-326.
2012	Mawhinney DB, Vanderford BJ, **Snyder SA**. Transformation of 1H-Benzotriazole by Ozone in Aqueous Solution. Environmental Science & Technology. 46(13):7102-7111.

2012 Pisarenko AN, Stanford BD, Yan DX, Gerrity D, **Snyder SA**. Effects of ozone and ozone/peroxide on trace organic contaminants and NDMA in drinking water and water reuse applications. Water Research. 46(2):316-326.

2011 Stanford BD, Pisarenko AN, Holbrook RD, **Snyder SA**. Preozonation Effects on the Reduction of Reverse Osmosis Membrane Fouling in Water Reuse. Ozone: Science & Engineering. 33(5):379-388.

2011 Gerrity D and **Snyder SA**. Review of Ozone for Water Reuse Applications: Toxicity, Regulations, and Trace Organic Contaminant Oxidation. Ozone Science and Engineering. 33:253-266.

2011 Sarp S, Stanford B, **Snyder SA**, Cho J. Ozone oxidation of desalinated seawater, with respect to optimized control of boron and bromate. Desalination and Water Treatment. 27:308-312.

2011 Dickenson ERV, **Snyder SA**, Sedlak DL, Drewes JE. Indicator Compounds for Assessment of Wastewater Effluent Contributions to Flow and Water Quality. Water Research 45:1199-1212.

2009 Dickenson ERV, Drewes JE, Sedlak DL, Wert EC, **Snyder SA**. Applying Surrogates and Indicators to Assess Removal Efficiency of Trace Organic Chemicals during Chemical Oxidation of Wastewaters. Environmental Science & Technology 43(16):6242-6247.

2009 Wert EC, Rosario FL, **Snyder SA**. Effect of Ozone Exposure on the Oxidation of Trace Organic Contaminants in Water. Water Research. 43:1005-1014.

2009 Wert EC, Rosario FL, **Snyder SA**. Using UV Absorbance and Color to Assess Pharmaceutical Oxidation during Ozonation of Wastewater. Environmental Science & Technology. 43(13):4858-4863.

2008 Ikehata K, El-Din MG, **Snyder SA**. Ozonation and Advanced Oxidation Treatment of Emerging Organic Pollutants in Water and Wastewater. Ozone Science & Engineering. 30(1):21-26.

2008 Rosario-Ortiz FL, Mezyk SP, Doud DFR, Wert EC, **Snyder SA**. Effect of Ozone Oxidation on the Molecular and Kinetic Properties of Effluent Organic Matter. Journal of Applied Oxidation Technologies. 11(3):529-535

2007 Lei H and **Snyder SA**. 3D QSPR models for the removal of trace organic contaminants by ozone and free chlorine. Water Research 41:3271-3280

2007 Wert EC, Rosario-Ortiz FL, Drury DD**, Snyder SA**. Formation of Oxidation Byproducts from Ozonation of Wastewater. Water Research. 41:1481-1490

2006 **Snyder SA**, Wert EC, Rexing DJ, Zegers RE, Drury DD. Ozone Oxidation of Endocrine Disruptors and Pharmaceuticals in Surface Water and Wastewater. Ozone Science & Engineering. 28:445-460

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