Executive Summary

Integration of High-Frequency Performance Data for Microbial and Chemical Compound Control in Potable Reuse Systems (4954)

ES.1 Key Benefits

- Developed an event detection framework promoting proactive and rapid responses to direct potable reuse (DPR) process upsets and errors.
- An event detection system (EDS) based on this framework, implemented at a demonstration DPR facility, increased lead time prior to forced shutdowns and reduced response time.
- Identified 22 parameters that provide a basis for early detection of critical control point (CCP) failures.
- Classified CCP failures under one of three event types (monitoring point, process failure, or water quality), helping operators know which appropriate corrective action(s) should be taken.
- Demonstrated that statistical process control is a viable approach to configuring test bounds and thresholds specific to the site and unit process that accurately identify anomalous data at an acceptable sensitivity.

ES.2 Key Findings

- The four-step framework of data storage, data screening, data flagging, and event detection presented in Figure ES-1 can be implemented for real-time, continuous monitoring of DPR unit processes and provide early detection of possible process errors and upsets. The project team identified 22 out of 8,000 possible CCP monitoring parameters, implemented within the software via supervisory control and data acquisition (SCADA) tags. These SCADA tags enable a variety of parameters (e.g., chemical concentrations, percent removals, percent changes, etc.) to be transferred into a database, which can be read into an event-driven software. Events are categorized into three types: process failure, monitoring point, and water quality. Processes include ozone disinfection, membrane filtration, reverse osmosis (RO) filtration, and ultraviolet advanced oxidation (UV/AOP). The detection of events can be automated, provided the event happens in a predictable and systematic manner.

Figure ES.1. Event Detection Framework Steps.

- Event detection logic that provides longer lead times is desirable, but it may be more prone to false positive and nuisance alarms. However, if event detection logic is configured with limited sensitivity, there is a higher likelihood that the event will not be detected in a timely manner. An iterative, site-specific approach is necessary to optimize the event detection system (EDS) and achieve the appropriate level of sensitivity. This can be accomplished by challenge testing the event detection logic using historical data sets containing examples of known events and adjusting the test bounds and minimum consecutive failures based on the results.
- When used on a dataset with high-quality monitoring data, statistical modeling is effective for determining operating range bounds designed to provide early detection of possible unit process errors and upsets.
- A multidisciplinary team consisting of process engineers, operators, programmers, and systems integrators is needed to develop and deploy this type of tool and framework. Knowledge and operational experience with advanced water treatment processes are critical for formulating meaningful limits and logical tests for event detection.

ES.3 Background and Objectives

Protection of public health and a high degree of treatment reliability and performance are critical components of DPR projects. The implications of water quality excursions in the product water are magnified due to the absence of a significant environmental buffer that results in shorter retention time before reaching consumers. DPR projects must be able to demonstrate performance reliability to be protective of public health, and a key component to increasing reliability is responding to emerging performance excursions before they exceed regulatory thresholds. Reliability is centered on the ability of a potable reuse system to protect public health (Pecson et al. 2015a). This can be achieved through redundancy of treatment and monitoring to ensure that treatment objectives are reliably met or more reliably demonstrated. This project explored a software-based approach to enhance monitoring and ultimately increase reliability of potable reuse treatment trains.

Currently, potable reuse systems are controlled by programmable logic controllers (PLCs) and computerized control systems like distributed control system (DCS) and SCADA systems. Sensors are installed throughout the systems to monitor process performance, and alarms are set so that an alarm is issued at a value close to the regulatory threshold and at the regulatory threshold. While these alarm limits are set to provide lead time so that operators are alerted before the regulatory limit is breached, operators are responsible for assessing if readings are real (i.e., not a false positive), determining what caused the alarm limit to be breached, implementing corrective actions based on troubleshooting and evaluating if the issue has been resolved. Minimizing the response time to go through these steps is important to prevent escalation of the issue and potentially greater consequences. Proactive detection and diagnosis of potential issues within the DPR treatment train were the principal areas of focus when developing the EDS (Figure ES-2)

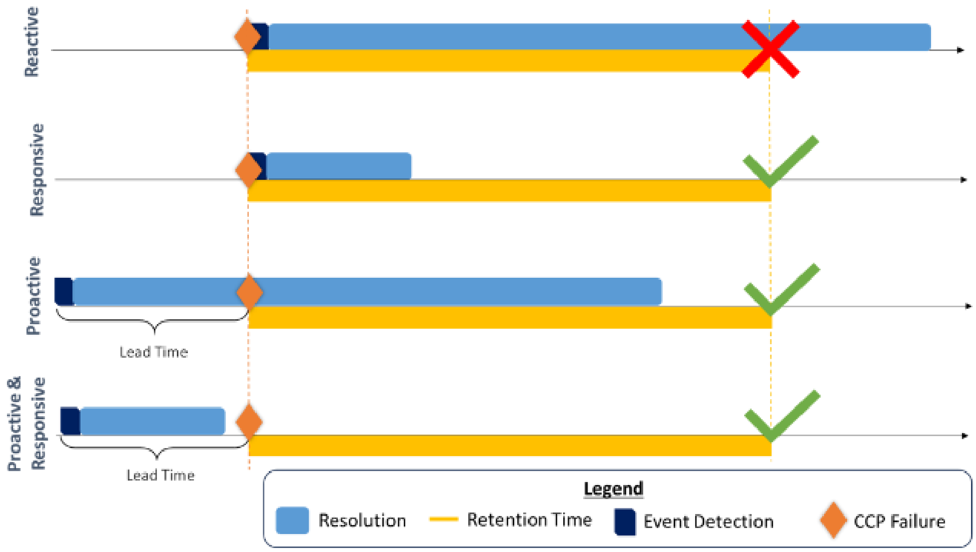

Figure ES.2. Response Time Scenario.

ES.4 Project Approach

The project objectives and major deliverables were achieved through four primary tasks: Literature Review and Utility Surveys/Case Studies (Chapter 2), Event Detection System Framework Development (Chapter 3), Event Detection System Implementation (Chapter 4), and Challenge Testing and Event Detection System Validation (Chapter 5). The project team considered numerous approaches for developing the automated EDS and included the following: open-source, artificial intelligence (AI), machine learning, and statistical modeling. A review of prior work on these topics evaluated existing open-source data analytic programs (e.g., CANARY and Pecos), Python packages for machine learning and statistical modeling, and timeseries analysis methods for configuring structured event detection logic. Interviews were conducted with Orange County Water District (OCWD), Veolia, and Hampton Roads Sanitation District (HRSD) to better understand how current monitoring and alarming systems are configured to reduce response time in indirect potable reuse (IPR) systems.

To develop event detection framework for DPR applications, the project team first identified the necessary software capabilities. Next, a curated list of CCP monitoring parameters was developed to focus only on data that would affect the pathogen removal capabilities of each unit process. Lastly, the operational experience and knowledge of the project team was leveraged to identify events that would impact the ability of the process to protect public health. These events consisted of one or more Pecos quality control tests configured with operating range bounds and minimum consecutive failure thresholds for the CCP monitoring parameters.

The EDS prototype was implemented at the City of San Diego's 1 million gallons per day (MGD) North City Pure Water Demonstration Facility (NCPWDF) to test the functionality of the scripts and evaluate the sensitivity of the event detection logic for providing advanced notice of potential issues. An iterative approach was employed when challenge testing the 12 implemented events with either simulated or naturally occurring process upsets. Pecos quality control test configurations within the EDS were adjusted as needed based on the challenge testing results.

ES.5 Results

The literature review and utility case studies confirmed that there is a need within the potable reuse industry for real-time data analytics that can provide advanced notice of potential process upsets and errors. Data-driven modeling (i.e., machine learning/AI) is most ideal for applications with extensive data, therefore it is not currently suitable for DPR facilities where data is limited because true CCP failures are rare. The EDS should be configured so that the results of its analysis are specific and actionable for operations staff. The project team found that this can be accomplished using statistical methods and existing open-source data analysis programs.

The four-step event detection framework developed by the project team can be used as a blueprint for other process engineers to design an EDS specific to their site. The four steps are (1) data storage, (2) data screening, (3) data flagging, and (4) event detection. Data storage involves receiving raw values from the control and monitoring system. Next, data generated while the DPR facility is not in production (i.e., product water is not being distributed) is screened out of the data set that will be analyzed. The tool then analyzed the screened data using Pecos quality control tests configured by the project team for each of the CCP monitoring parameters. The flagged data points represent potential events that warrant further evaluation. In the last step, the flagged data points are evaluated, and if the Pecos quality control test(s) correspond with the event detection logic for one of the three categories (process failure, monitoring point, water quality), then the EDS generates an alert for operations staff to review. For more complex events, multiple CCP monitoring parameters are used as event criteria and evaluated simultaneously so that the appropriate issue can be identified with greater certainty. The framework facilitates site specific configuration of event detection software while providing a well-defined workflow approach to the development of such a tool in DPR applications.

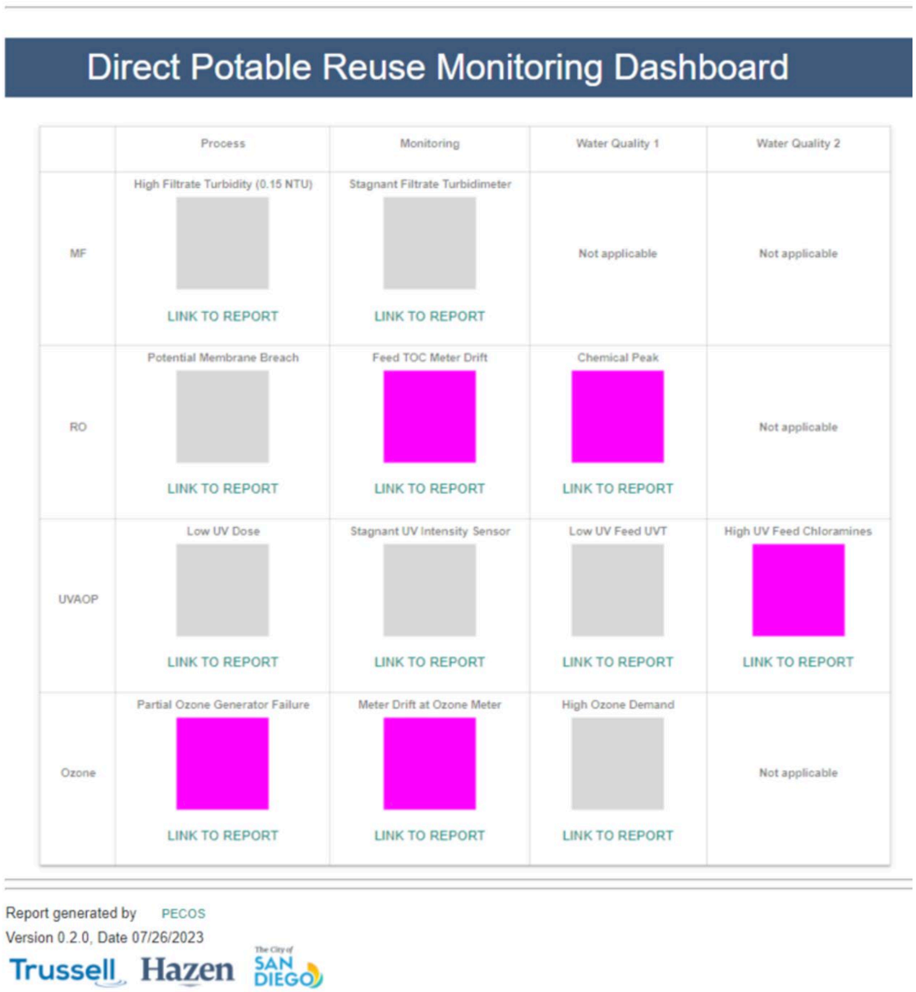

Figure ES.3. EDS Dashboard Output.

The project team successfully implemented a functional EDS prototype at the NCPWDF, and the associated files can be found in a publicly available Github repository, which can be accessed via the 4954 project page on the WRF website. Figure ES-3 displays the prototype's dashboard screen that was designed to communicate the status of the events configured for each unit process.

Figure ES-4 is an example report generated by the EDS during challenge testing when an ozone process failure event occurred in the timeframe that was being monitored.

Challenge testing using real and simulated process upsets validated the functionality of the EDS and enabled the project team to optimize the event detection logic so that events were accurately identified while nuisance/false alarms were avoided.

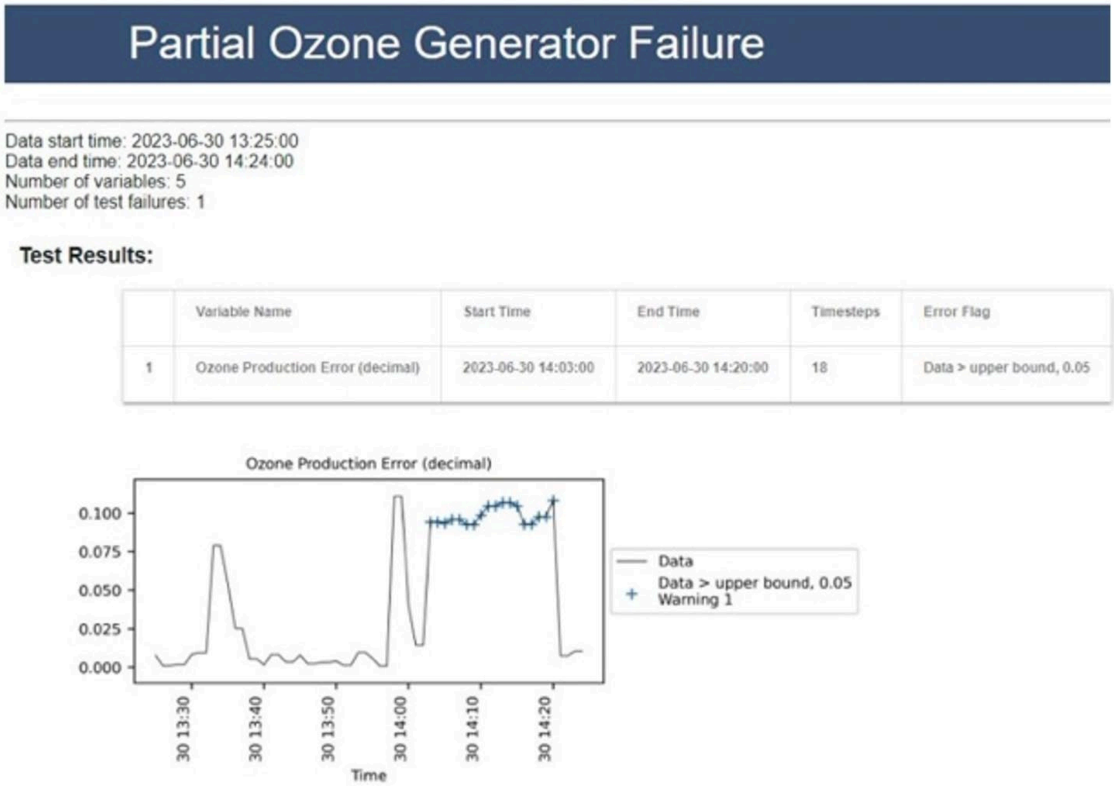

Figure ES.4. Partial Ozone Generator Failure Event Detection Report.

Related WRF Research	
Project Title	**Research Focus**
Monitoring for Reliability and Process Control of Potable Reuse Applications (1688)	This research evaluated whether real-time sensors could be used for process control of advanced treatment to ensure the safety of potable water for the community. Overall data from the pilot- and full-scale utility evaluations show that utilities in the United States and abroad have used online sensors successfully to monitor for the presence of chemical contaminants in real-time, but not microbial contaminants. Real-time monitoring gives potable reuse systems the ability to detect failures quickly and greatly reduce the response time needed to rectify upsets in a treatment system. The research indicates that at the same time, the need for engineered storage in direct potable reuse would be reduced due to the faster response time in monitoring. While online sensors have been demonstrated as highly useful for real-time water quality monitoring, this research identified several issues and gaps in sensor technology that should be addressed.
Critical Control Point Assessment to Quantify Robustness and Reliability of Multiple Treatment Barriers of DPR Scheme (1700)	The goal of this project was to apply the hazard analysis and critical control point (HACCP) methodology to identify critical control points (CCPs) and assess the reliability of those CCPs to manage acute and chronic health risks in direct potable reuse applications. The objective was to identify CCPs and then use full-scale operating data from facilities around the world to quantify the ability of those CCPs alone and in series to removal chemical and biological contaminants in

Related WRF Research	
Project Title	**Research Focus**
	potable reuse. An evaluation of process monitors and operational response was also included.
Integrated Management of Sensor Data for Real Time Decision Making (4759)	The objective of this research was to develop a framework for an overall decision support system (DSS) to aid operators and managers of direct potable reuse facilities make appropriate real-time actions based on anomalies and events at critical process control points and ensure regulatory compliance. The researchers developed an Excel-based decision support tool (DST) which can be configured based on specific facility characteristic and monitoring requirements. The DST, in conjunction with other decision support system components, can aid operators and managers of these facilities monitor process performance and identify and respond to process upsets or failures.
San Diego DPR (4765)	Performance data generated through this research project were used in a quantitative microbial risk assessment to demonstrate that a full-scale direct potable reuse (DPR) treatment train could reliably meet performance goals and produce a water that provides public health protection equivalent to, or greater than, conventional drinking water supplies. This report presents the results of the reliability analysis and challenge tests, and shows how a combination of redundancy, robustness, and resilience can ensure DPR safety.

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