Ensuring High Quality of Water Recycled from Wastewater to Augment Drinking Water Supplies

Megan H. Plumlee, Ph.D., P.E., Orange County Water District

Conventional water resources are not sufficient in many regions to meet the needs of growing populations. Thus, the *reuse* of wastewater for both drinking (potable) and non-drinking purposes is gaining acceptance around the world [1-3]. Wastewater is generated in domestic sewer collection systems as well as in industry and is now recognized as a valuable resource in water-stressed regions. Reuse is practiced in many parts of the United States, Japan [4], and other parts of the world, and has been engineered for over 100 years as a means of augmenting conventional drinking water supplies [1]. In the 1920s, the Los Angeles Department of Water and Power (United States) constructed a wastewater purification plant to accommodate increased water demand due to rapid development [5]. By the 1930s, spreading basins were being used in Southern California to recharge groundwater supplies with treated wastewater [2]; these large, man-made ponds are constructed to infiltrate water into the ground, such that local drinking water wells do not run dry. In 1968, the first direct reuse scheme for drinking water was constructed in Windhoek, Namibia; since then, numerous “indirect” potable reuse projects have been established globally [6], in which the treated (waste)water is first stored underground or in a reservoir where it comingles with other supplies before being withdrawn, treated, and distributed for drinking. In 1977, reverse osmosis (RO) membranes were first used to purify wastewater to make drinking water at Orange County Water District’s (OCWD) Water Factory 21, and since then have become a standard part of treatment facilities producing recycled water for drinking water supply augmentation [6].

Formed in 1933, OCWD in Southern California manages the local Orange County groundwater basin, which is the region’s major drinking water supply. As part of its mission, OCWD owns and operates the Groundwater Replenishment System (GWRS), which is the largest potable reuse facility in the world and was jointly developed with the Orange County Sanitation District. The facility purifies wastewater in a three-step advanced treatment process consisting of microfiltration, RO, and ultraviolet advanced oxidation. The raw wastewater comes from the local sewer system with minor industrial contributions, and is initially treated via conventional primary and secondary processes prior to the three-step advanced process. The advanced treated water is used in conjunction with other water sources (e.g., storm water), to recharge the groundwater basin via percolation and injection, referred to as “groundwater augmentation”. Committed to sharing information, OCWD has influenced the creation of water recycling projects around the globe and maintains an active Research & Development Department. Current research projects support the recycled water facility and the groundwater recharge operations at OCWD, many focusing on water quality.

Achieving and maintaining very good water quality is the primary objective of the purification process at OCWD and at other advanced treatment facilities around the world that produce recycled water. The objective of high water quality drives all aspects of facility operations from selecting treatment technologies, operating treatment units, calibrating sensors and designing monitoring programs. Water quality is measured regularly via both online monitors as well as from “grab” samples collected by staff for targeted lists of parameters and contaminants. The water meets all regulatory requirements for groundwater augmentation. In fact, due to the advanced purification, it is generally of a higher quality than more conventional water supplies when compared against nearly all drinking water standards. Nevertheless, engineers, scientists, and facility managers in the field of water recycling must remain ever vigilant with respect to ensuring water quality – in part because of the low quality of the source water (wastewater) and the continual emergence of new potential contaminants that could enter this valuable wastewater supply (e.g., new types of pharmaceuticals and industry chemicals entering commerce), and in part because of public perception-related challenges, i.e., the knowledge that the water was once wastewater.

There are millions of chemicals used in society for various applications, ranging from household products to specialty chemicals. Currently, over 135 million chemicals are registered with Chemical Abstract Services and about 15,000 more are added *every day*. Some portion of these chemicals will enter the wastewater supply used for recycling water, such as via use of the water in households and industry. Per a recent report, given the magnitude of this chemical “universe” and the huge variety of structures (single atoms to large biomolecules), “comprehensive chemical monitoring to identify each and every substance in the aqueous environment” (including wastewaters) is “vastly infeasible” [7]. Beyond just chemicals, new microorganisms are continually discovered in nature and human health research, which could also potentially enter the wastewater supply. Although advanced treatment using RO followed by ultraviolet advanced oxidation removes chemicals to non-detectable or low (safe) levels, and RO acts as a physical barrier to microorganisms (owing to filtration at pore sizes much smaller than viruses, bacteria, protozoa etc.) coupled with subsequent water disinfection via ultraviolet light, the recycled water community continues to identify ways to improve monitoring and source control, and to continue to optimize risk assessment and hazard control methods.

To this end, there are a number of exciting research developments in the water quality arena that are expected to be applicable relatively soon to real-world facilities recycling water. These include online real-time water quality sensors, "non-target" chemical analysis, bioanalytical techniques, and high-throughput DNA sequencing. Each of these is summarized briefly here and represents current research topics at OCWD. This research is typically conducted via collaboration between the water agency and university partners, which has been an effective model for advancing research in this industry.

Online, real-time monitoring of water quality has been a typical feature of recycled water treatment facilities for many years, for general parameters for which sensors are available. Common parameters include total organic carbon (TOC), salinity, turbidity, and others. Measuring real-time removal of these constituents via treatment demonstrates continuous facility performance; these data are largely used operationally and can also be interpreted as correlating with other water quality parameters like individual organic contaminants for which there are no sensors available. Current research seeks to optimize operational and regulatory use of this type of data and develop sensors for particular individual chemicals and microorganisms that may be of special concern, as well as sensors for parameters that could be good indicators/surrogates for more difficult-to-measure constituents. For example at OCWD, current research in collaboration with Kagoshima University (Japan) is demonstrating the utility of a newly developed method for measuring the notable carcinogen *N*-nitrosodimethylamine (NDMA) near-real time via an online prototype [8].

Traditional grab samples as well as online sensors are targeted methods designed to measure particular constituents. Given the number of potentially present chemicals in recycled water, non-target approaches are gaining more attention as a means to provide screening for a large number of compounds without *a priori* knowledge of the constituents possibly present in the sample. **Non-target analysis** (NTA) uses mass spectrometry to scan for a large number of compounds. Recently, an expert panel convened by the state of California on recycled water quality [7] stated that NTA holds promise as a powerful tool, but is still too complex and labor-intensive for regular use by facilities. In a recent OCWD research study, NTA was used to investigate possible chemical sources of disinfection byproducts (DBPs) found in recycled water.

Also aimed at screening for large numbers of chemicals without *a priori* knowledge, **bioanalytical tools** have recently been recommended as a more practical method than NTA. In these tests, an *in vitro* cell line or protein-system is exposed to the water sample and biologically responds if toxicity is present. This is in contrast to whole animal exposures (*in vivo* testing) which has significant cost and ethical concerns [9]. Again, more research and demonstration is needed – which, significantly, might be done at a large scale if the state of California soon requires bioanalytical monitoring at water reuse facilities in order for the state/industry to gain practical experience with these tools [7]. OCWD has volunteered samples from its recycled water facility for previous research studies, demonstrating no measurable toxicity in the finished water for a range of bioanalytical tests.

The above described emerging tools for measuring water quality focus on chemical constituents. Equally important, and representing the other major category of potentially present constituents in drinking and recycled waters, are microorganisms. Many types of microorganisms are of no concern; in fact, drinking and recycled waters are not sterile and never have been. Rather, it is particular disease-causing microbes (pathogens) that are of concern. For many decades, standardized microbial water quality requirements based on indicator monitoring have protected public health and ensured that recycled water does not contain pathogenic microorganisms. Looking to the future, the propagation of more advanced techniques will allow a more comprehensive assessment to screen for new pathogens and identify better microbial indicators. For example, recent advances in **high-throughput sequencing** have made sequencing the deoxyribonucleic acid (DNA) of a water sample feasible, i.e., sequencing the whole genomes of all of the organisms present in the sample (e.g., viruses, bacteria, protozoa, fungi, antibiotic resistant genes) in one test [10]. Future work may for the first time use this technique to characterize the microbial community of advanced treated water, further advancing the practice of potable reuse and providing fascinating insights not possible with previous methods.

Keywords: drinking water, recycled water, water quality, online monitoring, contaminant, toxicity

References

1. Kwan HEP: **State of the science review of membrane fouling: Organic, inorganic, and biological**. California Department of Water Resources; 2013: 250.

2. Sethi S, Xu P, Drewes J: **When Less is More**. *Civil Engineering Magazine Archive* 2007, **77**(9):72-75.

3. Giwa A, Akther N, Dufour V, Hasan SW: **A critical review on recent polymeric and nano-enhanced membranes for reverse osmosis**. *Royal Society of Chemistry Advances* 2016, **6**:8134-8163.

4. Asano T, Maeda M, Takaki M: **Wastewater reclamation and reuse in Japan: overview and implementation examples**. *Water Sci Technol* 1996, **34**(11):219-226.

5. NRC: **Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater**. Washington, D.C.: National Research Council of the National Academies, The National Academies Press; 2012.

6. Asano T, Burton FL, Leverenz HL, Tsuchihashi R, Tchobanoglous G: **Water Reuse: Issues, Technologies, and Applications**. New York, NY: Metcalf & Eddy, Inc., McGraw-Hill, Inc; 2007.

7. Drewes JE, Anderson P, Denslow N, Jakubowski W, Olivieri A, Schlenk D, Snyder S: **Final Report: Monitoring Strategies for Constituents of Emerging Concern (CECs) in Recycled Water - Recommendations of a Science Advisory Panel**. Convened by the California State Water Resources Control Board, SCCWRP Technical Report 1032; 2018.

8. Fujioka T, Tanisue T, Roback SL, Plumlee MH, Ishida KP, Kodamatani H: **Near real-time N-nitrosodimethylamine monitoring in potable water reuse via online high-performance liquid chromatography-photochemical reaction-chemiluminescence**. *Environmental Science: Water Research & Technology* 2017, **3**:1032-1036.

9. Leusch FD, Snyder SA: **Bioanalytical tools: half a century of application for potable reuse**. *Environmental Science: Water Research & Technology* 2015, **1**(5):606-621.

10. Leddy MB, Plumlee MH, Kantor RS, Nelson KL, Miller SE, Kennedy LC, Stamps BW, Spear JR, Hasan NA, Colwell RR: **High-Throughput DNA Sequencing to Profile Microbial Water Quality of Potable Reuse**. *Water Innovations* 2018 (wateronline.com), **January**: 33-37.