WateReuse Research Foundation Report

The WateReuse Research Foundation (WateReuse) has funded several nearly complete and recently completed studies that explore the use of ozone-biologically active filtration (ozone-BAF) as an alternative treatment train that achieves comparable water quality to full advanced treatment. **Dr. Kati Bell**, (MWH), **Abigail Antolovich**, (Xylem), **Denise Funk**, (Gwinnett County Department of Water Resources), **Jennifer Hooper** (CDM Smith), **Julie Minton** (WateReuse Research Foundation), and **Larry Schimmoller** (CH2M) present key research findings that demonstrate its successful application in potable reuse.

Ozone-biologically active filtration –

an alternative treatment for potable reuse

As interest in sustainable water supply solutions continues to grow worldwide, advances in the science and engineering of water treatment are making broader applications of potable reuse practices possible. Utilities in the United States that are implementing potable reuse have historically relied on the full advanced treatment (FAT) train, modeled after the process used for planned indirect potable reuse (IPR) in California; however, alternative treatment trains that produce high quality water and address concerns in cost and concentrate disposal have also proven to be effective.

The FAT model incorporates microfiltration (MF), reverse osmosis (RO), ultraviolet (UV) light disinfection, and advanced oxidation (AOP) to form a multi-barrier treatment process for treating secondary wastewater effluent. This model has proven to be successful at California facilities such as the Groundwater Replenishment System in Orange County, Edward C. Little Plant in El Segundo (West Basin), Leo J. Vander Lans Water Treatment Facility (Water Replenishment System), and Cambria Emergency Water Supply. Other potable reuse projects using the FAT model include Big Spring, Texas, USA and three Western Corridor projects in Southeast Queensland, Australia.

As a modification of the FAT model, Singapore uses a similar treatment scheme with MF and RO but employs UV for virus reduction only, without the higher UV dose required for reduction of N-nitrosodimethylamine (NDMA) or the complimentary use of hydrogen peroxide or free chlorine to achieve advanced oxidation. The Singapore model, adopted by both the Beenyup Advanced Water Treatment Facility in Perth, Australia, and the Wichita Falls direct potable reuse (DPR) facility in Texas, relies on RO to reduce trace chemical constituents without a redundant method. California has adopted the requirement for advanced oxidation due to elevated levels of NDMA and 1,4-dioxane that were found in the Orange County groundwater monitoring wells before UV/AOP was implemented as well as to provide an additional barrier against unknown and future constituents of concern.

FAT and the modified forms used in Singapore, Texas, and Western Australia have become accepted as a standard treatment train based on past and ongoing success in California water reuse projects. While the process consistently provides exceptional quality product water that surpasses the quality of most conventional drinking water supplies, it can also be energy intensive and costly in terms of both capital and operations. Because of the toxic nature of the concentrate produced by the rejection of salts and other organic constituents from the RO process, facilities that cannot leverage ocean outfalls for brine disposal have limited or expensive options for concentrate disposal, some of which are extremely challenging to permit. The key benefits and drawbacks of FAT are summarized in Table 1.

An ozone generator installed at the Shoal Creek Filter Plant. Photo courtesy of Gwinnett County Department of Water Resources

Alternative treatment trains

Because of challenges posed by high treatment costs and concentrate disposal for FAT, many utilities considering potable reuse are evaluating alternative treatment trains capable of producing water quality that is equally protective of human health. Ozone-biologically active filtration (ozone-BAF) is one treatment train option that could be used because it addresses the destruction – not just the removal – of trace chemical constituents, and it does not produce a concentrate stream requiring disposal.

Table 1. Benefits and Drawbacks of FAT

Benefits	Drawbacks
Multiple instances of successful operation	High capital costs
Handles water quality from secondary treatment or tertiary treated effluent	High operating costs
Removes salt	High environmental costs
Methods of integrity monitoring provide high level of process assurance	Concentrate disposal or management is required
Consistency in product not dependent on optimized operations or operator attention	Trace chemical constituents remain in concentrate stream, potentially impacting receiving water body
Public acceptance for potable reuse	Finished water requires stabilization

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Left: Aerial view of the F. Wayne Hill Water Resources Center, which uses advanced wastewater treatment including ozone-BAF. Photo courtesy of Gwinnett County Department of Water Resources

Table 2

	Project Number	Project Title
Completed	4021	Occurrence, Impacts, and Removal of Manganese in Biofiltration Processes
	4155	Cost-Effective Regulatory Compliance with GAC Biofilters
	4129	Biological Drinking Water Perceptions and Actual Experiences in North America
	4215	Engineered Biofiltration for Enhanced Hydraulic and Water Treatment Performance
	4231	A Monitoring and Control Toolbox for Biological Filtration
	4312	An Operational Definition of Biological Stability
	4346	Optimizing Engineered Biofiltration
On-going	4429	Chemically Enhanced Biological Filtration to Enhance Water Quality and Minimize Costs
	4448	Optimizing Filter Influent Conditions for Improved Mn Control During Conversion to Biofiltration
	4459	Development of a Biofiltration Knowledge Base
	4525	Full-scale Demonstration of Engineered Biofiltraton and Development of a Biofiltration Tracking Tool
	4496	Converting Conventional Filters to Biofilters
	4555	Optimizing Biofiltration for Various Source Water Quality Conditions
	4559	Simultaneous Removal of Multiple Contaminants Using Biofiltration
	4574	Biological Oxidation Filtration for Ammonia Removal from Groundwater
	4620	Practical Monitoring Tools for the Biological Processes in Biofiltration

Water Research Foundation-Funded Biofiltration Studies: Current and Recently Completed

High rate biofiltration, both with and without ozone, has been used in the drinking water industry for decades. Prior to use of high-rate filtration, slow sand filters were used as biofilters since the early 1800s; when the industry changed to high-rate filtration in the early 1900s, pre-filter chlorine was applied, effectively eliminating biological activity in the filters. Thus, biofiltration is defined by the American Water Works Association's Biological Drinking Water Treatment Committee as the "operational practice of managing, maintaining, and promoting biological activity within a granular media filtration process to enhance the removal of organic and inorganic constituents before treated water is introduced into the distribution system."

Biofiltration can be implemented in any type of filter media that supports establishment of a biofilm; examples include slow sand filtration, rapid-rate filtration with or without pre-oxidation, granular activated carbon (GAC) filtration with or without pre-oxidation, riverbank filtration, aquifer filtration, and anoxic biological treatment. Indigenous microbial organisms populate the filtration media, and contaminants are biodegraded through direct substrate use or co-metabolism. Biofilters have been demonstrated to remove turbidity, natural organic matter (NOM), disinfection byproduct (DBP) precursors, taste and odor compounds, iron, manganese, ammonia, algal toxins, and trace chemical constituents including pharmaceuticals and personal care products. For these benefits, biofiltration has been the center of a great deal of water industry research, as exemplified by the partial list of recently completed and ongoing biofiltration studies funded by Water Research Foundation (WRF) for conventional drinking water applications. This research has shown that managing operational parameters such as pH, temperature, nutrients, pre-oxidation, and empty bed contact time can improve biofilter treatment performance; however, biofiltration does not remove salts that are measured as total dissolved solids (TDS). For potable reuse treatment trains that use biofiltration and that also require TDS management, other unit processes such as electrodialysis-reversal (EDR), chemical softening, nanofiltration (NF), or RO may be necessary for at least some portion of the process flow to achieve site-specific TDS targets. Biofiltration can be used to remove significant concentrations of ammonia or nitrate. However, it is important to consider how biofiltration is incorporated into potable reuse with respect to the level of nitrogen treatment that is provided at the wastewater treatment plant. This approach will ensure that total nitrogen requirements for drinking water are met, but it can also help prevent operational conditions that may result in the formation of undesirable products. For example, while NDMA can be removed by aerobic biofiltration, formation has been documented when biofilters are run in an anoxic mode.

Thus, when total dissolved solids reduction is not necessary from the source water, ozone-biologically active filtration (ozone-BAF) can provide a high quality source for drinking water supply when it follows advanced wastewater treatment that achieves nutrient removal. While recent WRF research has provided a fundamental mechanistic understanding of biofiltration in the drinking water industry, WateReuse is currently funding several studies on ozone-biofiltration for potable reuse that specifically focus on how this process can address wastewater-derived constituents that are not regulated

Table 3. WateReuse Biofiltration Research

Project Title (Number)	Principal Investigator	Relevant Objective	Status
Use of Ozone in Water Reclamation for Contaminant Oxidation (WRRF-08-05)	Shane Snyder, University of Arizona	Evaluate the synergism between ozone and biological filtration, including biological activated carbon (BAC)	Published
Equivalency of Advanced Treatment Trains for Potable Reuse (WRRF-11-02)	Rhodes Trussell, Trussell Technologies	Develop criteria for DPR and evaluate treatment options to meet criteria. Work included some pilot scale testing including ozone/BAC	3 deliverables available, Final report expected mid 2016
Minimizing Concentrate using Advanced Oxidation, Biofiltration, and Ion-Exchange Pretreatment for Electrodialysis Reversal (WRRF-12-10)	Charlie He, Carollo Engineers	Demonstrate whether the proposed pretreatment (ozonation and BAF) for the reduction of organic compounds in brine derived from RO treatment of reclaimed water can control organic fouling on EDR membranes necessary for brine volume reduction	Published
Critical Control Point Assessment to Quantify Robustness and Reliability of Multiple Treatment Barriers of a DPR Scheme (WRRF-13-03)	Troy Walker, Hazen and Sawyer	Conduct a hazard assessment of DPR treatment options (including ozone/BAC) to identify critical control points for operations and develop standard design approaches and response strategies to mitigate anomalies in system operations.	Final report expected mid 2016
Indirect Potable Reuse Investigation in Tucson, AZ (WRRF-13-09)	Larry Schimmoller, CH2MHill	Test the viability of the alternative potable reuse treatment scheme through water quality testing and treatment process performance monitoring. Included pilot scale testing with side-stream NF, ozone, BAF, and GAC	Final report expected mid 2016
Indirect Potable Reuse Investigation in Tucson, AZ (WRRF-13-09) Controlling Trace Organic Contaminants Using Alternative, Non-FAT Technology for Indirect Potable Water Reuse (WRRF-13-10)	Ben Stanford, Hazen and Sawyer	Investigate the advanced treatment of wastewater for indirect potable reuse (IPR) using ion exchange (IX), advanced oxidation processes (AOPs) and biofiltration as an alternative to FAT.	Final report expected late 2016
Development of Operation and Maintenance Plan and Training and Certification Framework for Direct Potable Reuse Systems (WRRF-13-13)	Troy Walker, Hazen and Sawyer	Develop a standard operations and maintenance plan and training and certification framework for various DPR treatment processes. This includes an ozone-BAC process.	Final report expected late 2016
Characterization and Treatability of TOC from DPR Processes Compared to Surface Water Supplies (WRRF-15-04)	TBD	Determine range of acceptable TOC concentrations and characteristics from alternative advanced water treatment approaches on potable water reuse projects; Characterize organic matter for drinking water source, potable water, secondary effluent, and non-RO based purified water treatment.	RFP
Optimization of Ozone-BAC Treatment Processes for Potable Reuse Applications (WRRF-15-10)	Zia Bukhari, American Water	Establish baseline relationships between ozone/BAC effluent TOC levels and DBPs and/or their formation potential. These relationships would be determined by examination of THM, HAA, nitrosamines, nitrosamine precursors, microbial ecology of BAC and organic constituents of BAC effluent.	Ongoing research
Demonstration of High Quality Drinking Water Production Using Multi-Stage Ozone-Biological Filtration (BAF): A Comparison of DPR with Existing IPR Practice (WRRF-15-11)	Denise Funk, Gwinnett County	Evaluate DPR with a two-stage ozone-BAF as a cost-effective method for providing drinking water (further described below)	Ongoing research

or are often not considered in *de facto* potable reuse scenarios.

WateReuse has supported several nearly complete or completed research studies that include ozone-BAF as an alternative treatment train to FAT, demonstrating the comparable water quality outcome. Additionally, several new projects focus on this treatment process for potable reuse, as summarized in Table 3.

Gwinnett County leverages ozone-BAF

To protect public health and provide safety in a potable reuse scenario, technologies for potable reuse should ultimately provide a product that is free of pathogens and toxic chemicals. As industry is looking for more cost-efficient means of implementing potable reuse, particularly where total dissolved solids do not require implementation of RO membranes, this combination of ozonation and BAF can achieve this objective when following wastewater treatment that provides nutrient removal.

The Gwinnett County Department of Water Resources (DWR), located in the US state of Georgia, currently implements planned IPR by use of advanced wastewater treatment including ozone-BAF at its F. Wayne Hill Water Resources Center (WRC); DWR also uses ozone-BAF at its drinking water plants as shown in Figure 1. As DWR is proactively evaluating options for meeting future water supply demands, DPR is being evaluated for feasibility as an option for their water supply portfolio. DWR is a “Utility Partner” for WRF Project No. 4508/WateReuse Project No. 13-14, which is a technical investigation of techniques to evaluate and demonstrate the safety of water from DPR facilities. The investigation involves examination of monitoring practices at full-scale IPR facilities. DWR is also participating in WRF Project No. 4555 *Optimizing Biofiltration for Various Source Water Quality Conditions*, which aims to optimize biofiltration at its existing water treatment plants.

Additionally, DWR was recently awarded a WateReuse Tailored Collaboration (WateReuse Project No. 15-11, *Demonstration of High Quality Drinking Water Production Using Multi-Stage Ozone-Biological Filtration: A Comparison of DPR with Existing IPR Practice)*. This project is pilot testing ozone-BAF as a treatment process for DPR, as shown by the grey dotted line in Figure 1. The objective of the DPR pilot will be to

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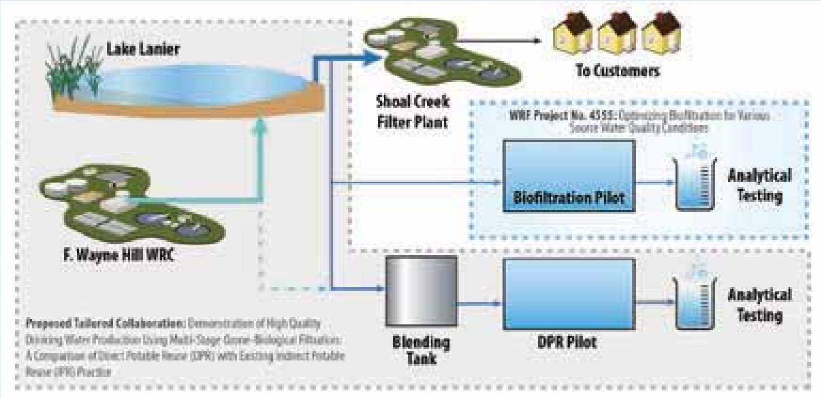

Top: Schematic of the existing indirect potable reuse system at the F. Wayne Hill water recycling facility in Gwinnett County, Georgia, USA. Courtesy of CDM Smith

> Ozone-biologically active filtration (ozone-BAF) is one treatment train option that could be used because it addresses the destruction – not just the removal – of trace chemical constituents, and it does not produce a concentrate stream requiring disposal.

evaluate the potential for using reclaimed water from the WRC in various blending ratios with Lake Lanier water, which is the sole water supply for nearly one million customers in Gwinnett County in metropolitan Atlanta, Georgia.

Performance data, including primary and secondary drinking water standards as well as unregulated microbial contaminants and chemical compounds, will be evaluated from the DPR pilot under various operating scenarios. The chemical compounds represented in this study will include: PPCPs, endocrine disrupting compounds (EDCs), disinfection by-products (DBPs), pesticides, and industrial chemicals. This data will be compared to drinking water quality produced under the current planned IPR scenario as well as with water quality that has been developed through other WateReuse-funded DPR pilots.

Call for water industry collaboration
More information on both regulations and costs of alternative treatment trains is needed, particularly given the increasing demand for potable reuse in the United States. The US Environment Protection Agency is developing a supplement to the *2012 Guidelines for Water Reuse*, anticipated for publication in 2016. This document will provide a technical overview of potable reuse, which will include discussion of existing regulatory frameworks that have been used for potable reuse. Additionally, some critically important work has already been conducted to evaluate the real cost of various treatment trains. One of the most relevant studies, by Schimmoller and Kealy (2014), compared the triple bottom line costs of full advanced treatment to a non-membrane based approach that included ozone oxidation, BAC filtration, GAC adsorption, and UV disinfection. Results showed that except for TDS, water of similar quality can be produced at significantly lower financial and social costs. For example, net present value costs for the full advanced treatment train ranged from 54 percent higher (without RO concentrate handling) to 300 percent higher (with RO concentrate handling) when compared to the non-membrane based train; greenhouse gas emissions, power consumption, and chemical use were also much higher for FAT.

US utilities have already implemented planned potable reuse, and many others are evaluating how this practice fits into a diversified water supply portfolio. While much of the technical information that is needed to support implementation of alternative treatment trains is already developed, challenges remain. One issue that remains is that much of the necessary information is not in a format that is readily accessible, or it has not been translated into a meaningful way for application to planned potable reuse. In response to this need, it is important for water industry groups to collaborate in order to compile this knowledge. Such a database could support cost-effective process selection and design for planned potable reuse that provides water quality that is protective of human health. Participation by regulatory authorities would help inform these efforts. Alternative treatment options that are less intensive in both capital and energy than the current model for implementation are critical to putting potable reuse within reach of utilities that are in great need of new water supplies.

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